Defense Manufacturing Management Guide for Program Managers

October 16, 2012

Chapter 1 - Overview of DOD Manufacturing Management

1.1 Objective

The Program Manager (PM) has the responsibility for and authority to accomplish program objectives for development, production, and sustainment to meet the user's operational needs. The PM shall be accountable for credible cost, schedule, and performance reporting to the Milestone Decision Authority (MDA). DOD program managers (PM) are responsible for acquiring quality products that:

- Satisfy the needs of the warfighter;
- Provide measurable improvements in functional capabilities; and
- Are affordable and arrive on schedule.

PMs accomplish this by exercising their judgment and thinking through the complex, enterprise-wide processes that they will have to use in order to identify and manage risk. A PM should be able to:

- Define the roles and goals of manufacturing management, and current issues;
- Identify manufacturing policy (DOD, Service, and/or Agency) that is applicable to their program;
- Describe the organizational structure for manufacturing management in OSD, and their Service or Agency;
- Outline organizational responsibilities for ensuring manufacturing considerations that are an integral part of their acquisition planning and execution;
- Describe the relationship between the Government and contractor PMs; and
- Describe how program office personnel are selected.

1.2 Background

In 1993 Defense Secretary Les Aspin held a dinner party for fifteen defense industry chief executives. After the dinner, Secretary Aspin provided a briefing that was so sobering that it became referred to as "the Last Supper." In the briefing, Secretary Aspin pointed out that:

- The DOD was supported by five contractors providing surface combatants, but could afford to sustain only two contractors;
- Five contractors supplied rocket motors, but needed only two;
- Three contractors provided bombers, but needed only one;
- Two contractors provided submarines, but needed only one; and so forth.

Secretary Aspin concluded the meeting by making it abundantly clear the Defense Department was not going to solve the industry's overcapacity problem - that would be up to those in the audience.

The rest is history. General Electric Aerospace merged with Martin Marietta, which combined with Lockheed. McDonnell Douglas joined Boeing. Grumman joined Northrop. When the dust had cleared, there were only a few firms left standing with the ability to provide the development and production capability needed by the warfighter in times of national emergency.

Almost two decades have passed since the so-called "Last Supper." Despite fighting two wars, budget constraints and affordability considerations the DOD may once again be forced to encourage a consolidation in the markets.

1.3 Introduction

Manufacturing is one of those enterprise-wide processes. Manufacturing is concerned with the conversion of raw materials into products based upon a detailed design. This conversion is accomplished through a series of manufacturing procedures and processes. It includes such major functions as manufacturing planning, cost estimating and scheduling; engineering; fabrication and assembly; installation and checkout; demonstration and testing; and product assurance. Manufacturing considerations begin as early as during the Analysis of Alternatives (AoA) in which the manufacturing manager and the PM must be able to understand the "manufacturing feasibility (risks)" are that are associated with each materiel solution.

1.3.1 The Role and Goal of Manufacturing

Manufacturing has several roles in the acquisition process. The first is to influence the design process so that the design is producible. That is, the design is efficient and can be manufactured using existing facilities, tools, equipment and people. The second role is to prepare for production or plan for production. The final role is to execute the manufacturing plan. Execute the plan in a way that reflects the design intent while ensuring repeatable processes and focusing on continuous improvement.

The role of manufacturing to influence the design is critical because of the impact design decisions have on life cycle costs (LCC). Studies have shown that by the time a Preliminary Design Review (PDR) is held around 80% of the program's life cycle cost are locked in even though only a small percentage of the programs cumulative costs have been expended. It is also the time when a program or contractor has the most opportunity to impact life cycle cost savings. By the time the Critical Design Review (CDR) is held the LCC commitment is around 90%. Manufacturing, logistics and other considerations must be taken seriously and taken seriously early or the program is doomed to becoming unaffordable.

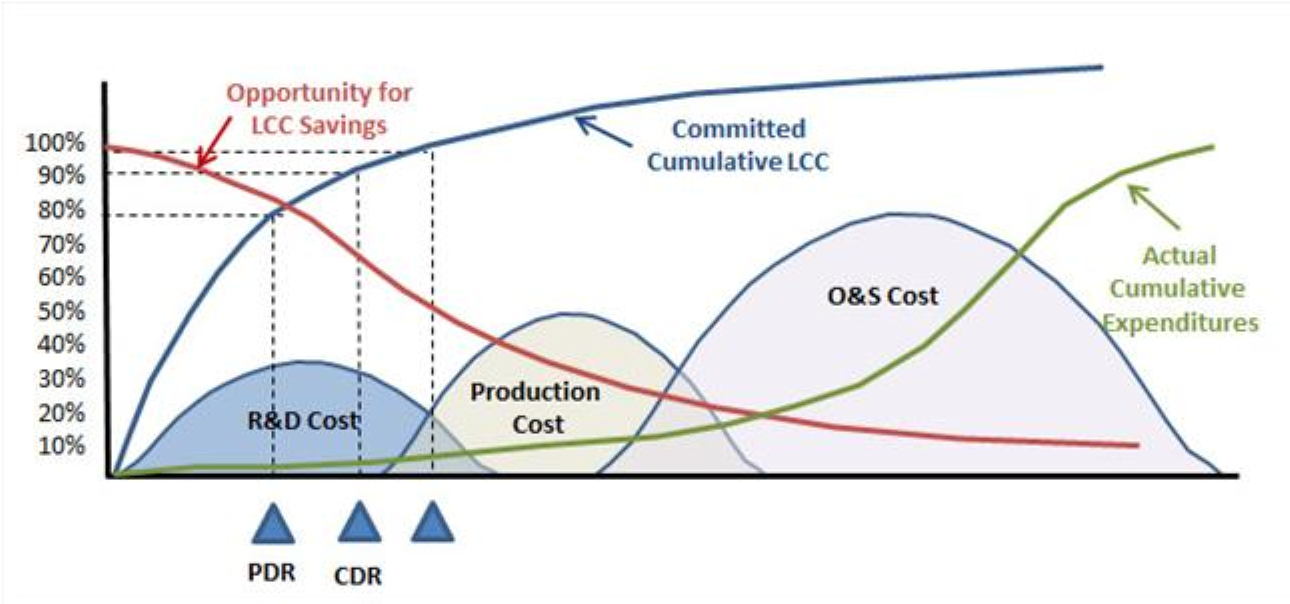

Figure 1-1 The Impact of Design Decisions on Life Cycle Cost

The goal of manufacturing is to deliver uniform, defect-free product, with consistent performance, that is affordable (see figure 1-1). There is a significant interrelationship between "uniform, defect-free product, consistent performance, and affordability" and there are significant benefits from these interrelationships, if they are optimized. One of those benefits is the reliability of the end item. If there is less variability, then the product works better and lasts longer, impacting the life cycle cost in a positive way. We will discuss these interrelationships in more detail in later chapters.

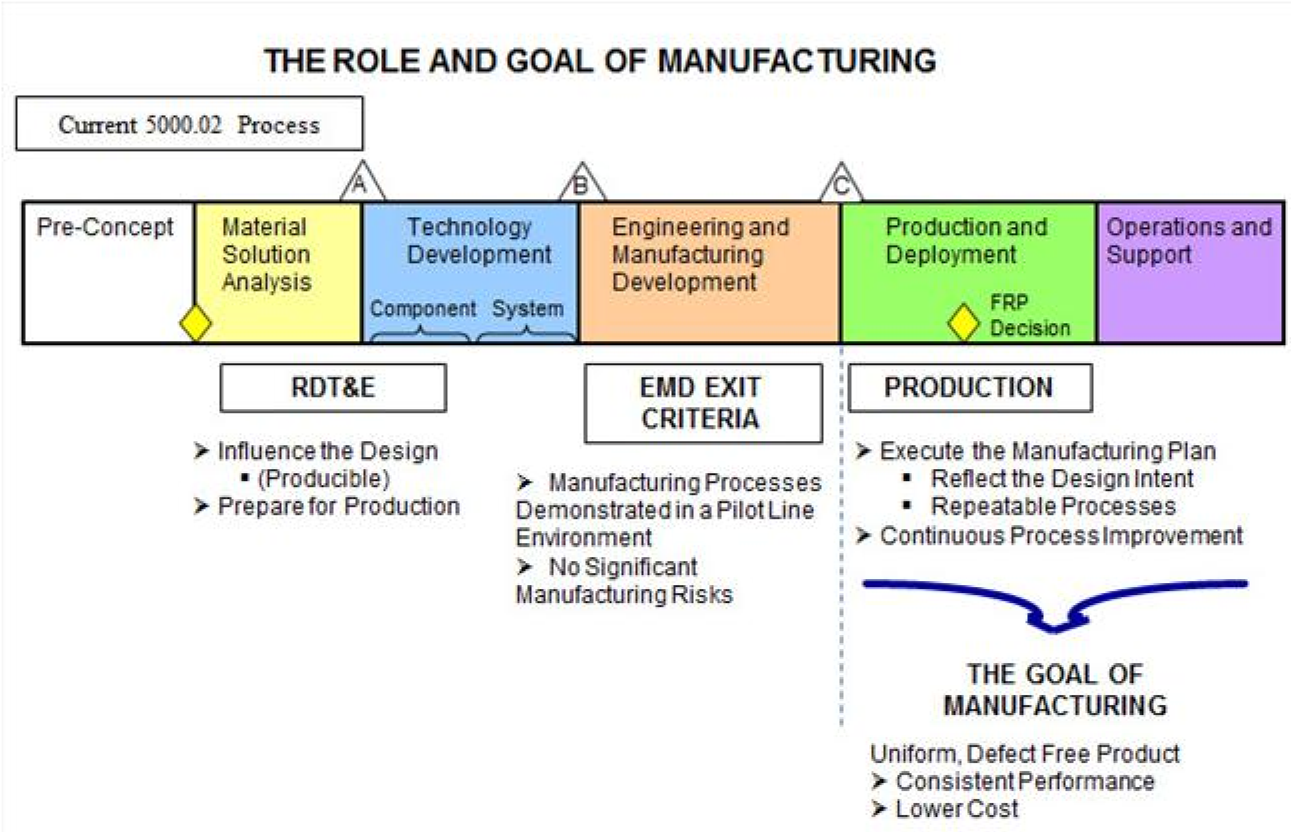

Figure 1-2 The Role and Goal of Manufacturing

1.3.2 Congressional Interest in Manufacturing

Congress recognized the need to identify manufacturing risk early in a program's life and added language to the FY 11 Defense Authorization Act, Section 812 Management of Manufacturing Risk in Major Defense Acquisition Programs, addressing this. Specifically, the SECDEF is required to develop guidance that will:

1. Require the use of MRLs as a basis for measuring, assessing, reporting, and communicating manufacturing readiness and risk on major defense acquisition programs throughout the Department of Defense;

2. Provide guidance on the definition of MRLs and how manufacturing readiness levels should be used to assess manufacturing risk and readiness in major defense acquisition programs;

3. Specify MRLs that should be achieved at key milestones and decision points for major defense acquisition programs;

4. Identify tools and models that may be used to assess, manage, and reduce risks that are identified in the course of manufacturing readiness assessments for major defense acquisition programs; and

5. Require appropriate consideration of the manufacturing readiness and manufacturing readiness processes of potential contractors and subcontractors as a part of the source selection process for major defense acquisition programs.

1.3.3 GAO Concerns

The U.S. Government Accountability Office (GAO) has published several reports on "Assessments of Selected Weapons Programs." Each report pointed out that cost overruns, poor performance and schedule delays were often caused by having insufficient knowledge about:

- Technology maturity,
- Design maturity, and
- Manufacturing maturity.

The 2010 GAO report (GAO-10-388SP), *Defense Acquisitions: Assessments of Selected Weapon Programs* , noted that "for 42 programs GAO assessed in depth, there has been continued improvement in the technology, design, and manufacturing knowledge programs had at key points in the acquisition process. However, most programs are still proceeding with less knowledge than best practices suggest, putting them at higher risk for cost growth and schedule delays."

A July 2002 GAO report (GAO-02-701), *Best Practices: Capturing Design and Manufacturing Knowledge Early Improves Acquisition Outcomes* , highlighted how capturing design and manufacturing knowledge early improves acquisition outcomes. Commercial companies understand the importance of capturing design and manufacturing knowledge early in product development, when costs to identify problems and make design changes to the product are significantly cheaper. In a knowledge-based process, the achievement of each successive knowledge point builds on the preceding one, giving PMs the knowledge they need to make decisions about whether to move forward with product development. Programs that follow a knowledge-based approach typically have a higher probability of successful cost and schedule outcomes.

1.3.4 Common Production Risks

Congress and the GAO are concerned about manufacturing as lack of attention to this function will increase risk and is a factor in cost overruns and schedule delays. The following items are common production risks that can greatly affect cost, schedule and performance if the program office is not proactive in managing them.

- Unstable requirements and too many engineering changes;
- Unstable production rates and quantities;
- Insufficient process proofing;

- Insufficient material characterization;
- Changes in **proven** materials, processes, subcontractors, vendors, and components;
- Lack of producibility consideration;
- Configuration management;
- Subcontractor management; and
- Special tooling and test equipment.

These risks can occur early in the program's life, not just during production.

The requirements process is the first and most important step in the acquisition process if the requirements are wrong then everything else will be wrong. Changes to requirements have strong ripple effects in cost, schedule and performance, and become magnified the farther along the system is. System requirements need to be as simple as possible, but no simpler, written in operational terms that all involved in the process understand. The farther a system proceeds toward production, the harder it should be to make requirements and Type I changes. The following gives an example of one reason NASA's Apollo Moon missions were successful: there was only ONE primary requirement:

"Send a man to the moon and return him safely within 10 years."

One easily understood requirement that set the stage for history's most complex successful engineered system. All other requirements were derived from just this one.

1.4 DOD Policy

The authority for DOD to conduct systems acquisition, and in-turn for manufacturing oversight, flows from:

- The law, and
- DOD Acquisition Policy Documents.

1.4.1 Law

There are many laws that are manufacturing related and impact the program office, for example:

- The National Environmental Policy Act (NEPA) requires Federal agencies to consider the environmental impacts of proposed actions, including actions within acquisition programs, before they are implemented.
- 10 US Code, Section 2440, Technology and the Industrial Base, requires the "Secretary of Defense to prescribe regulations requiring consideration of the national technology and industrial base in the development and implementation of acquisition plans for each major defense acquisition program."

There are other laws to be considered, and each will be addressed in it's appropriate chapter. The important learning point here is that "manufacturing needs to be a major consideration in all phases of acquisition" if the program is to be successful and meet the intent of the law.

1.4.2 Policy

DODD 5000.01, Defense Acquisition System, identifies the policies and principles that guide all defense acquisition programs to include the following manufacturing related policy excerpt:

- PMs shall provide knowledge about key aspects of a system at key points in the acquisition process. They shall reduce manufacturing risk and demonstrate producibility prior to full-rate production.

DODI 5000.02, Operation of Defense Acquisition Systems, establishes a simplified and flexible management system for translating joint capability needs and technological opportunities into stable, affordable, and well-managed acquisition programs. It applies to all defense technology projects and acquisition programs, although some requirements, where stated, apply only to Major Defense Acquisition Programs (MDAPs) and Major Automated Information Systems (MAISs).

DODI 5000.02 requires that PMs and their technical staff to:

- "Assess manufacturing feasibility" in the Materiel Solution Analysis Phase prior to Milestone A for the various material solutions identified in the Analysis of Alternatives (AoA);
- "Evaluate manufacturing processes" during the Technology Development Phase on prototype systems or appropriate component-level prior to Milestone B. The passing of a successful PDR will "identify remaining design, integration, and manufacturing risks. The program will exit the Technology Development Phase when "the technology and manufacturing processes for that program or increment have been assessed and demonstrated in a relevant environment and manufacturing risks have been identified;
- "Develop an affordable and executable manufacturing" process during the Engineering and Manufacturing Development (EMD) Phase. The Post-CDR assessment will include a demonstration that the "maturity of critical manufacturing processes has been accomplished. EMD shall end when "manufacturing processes have been effectively demonstrated in a pilot line environment" prior to Milestone C.

DOD has increased management focus on manufacturing and quality management during early program phases. There are significant costs associated with the manufacturing effort. These costs, to a great degree, are inherent in the design. As a design evolves, certain costs become essentially fixed. Given the objective of minimizing cost and the existence of projections that indicate limited dollars are available for future manufacturing effort, it is vital that PMs identify costs at the point when they are being fixed. Understanding the cause and effect relationships between these early decisions provides the justification for early assessments.

1.5 Organizational Structure

1.5.1 Undersecretary of Defense for Acquisition, Technology, and Logistics (AT&L)

The Undersecretary of Defense for Acquisition, Technology, and Logistics is the Principal Staff Assistant (PSA) to the Secretary and Deputy of Defense for all matters relating to the DOD Acquisition System; research and development; modeling and simulation; systems engineering; advanced technology; developmental test; production; systems integration; and logistics.

The Undersecretary of Defense for Acquisition, Technology, and Logistics has the direct responsibility for DOD manufacturing management policy and guidance in the acquisition of defense systems. The head of each DOD component (Military Departments and Defense Agencies), in turn, is responsible for developing and implementing procedures within the components. Figure 1-2 depicts the PMs reporting for defense system acquisition within the components.

DOD Directive 5000.01, the Defense Acquisition System, establishes the approval cycle and procedures for weapon system acquisition. The directive applies to the Office of the Secretary of Defense, the Military Departments, the Office of the Joint Chiefs of Staff, the Combatant Commands, the Office of the Inspector General of Defense, the Defense Agencies, the DOD Field Activities and Components.

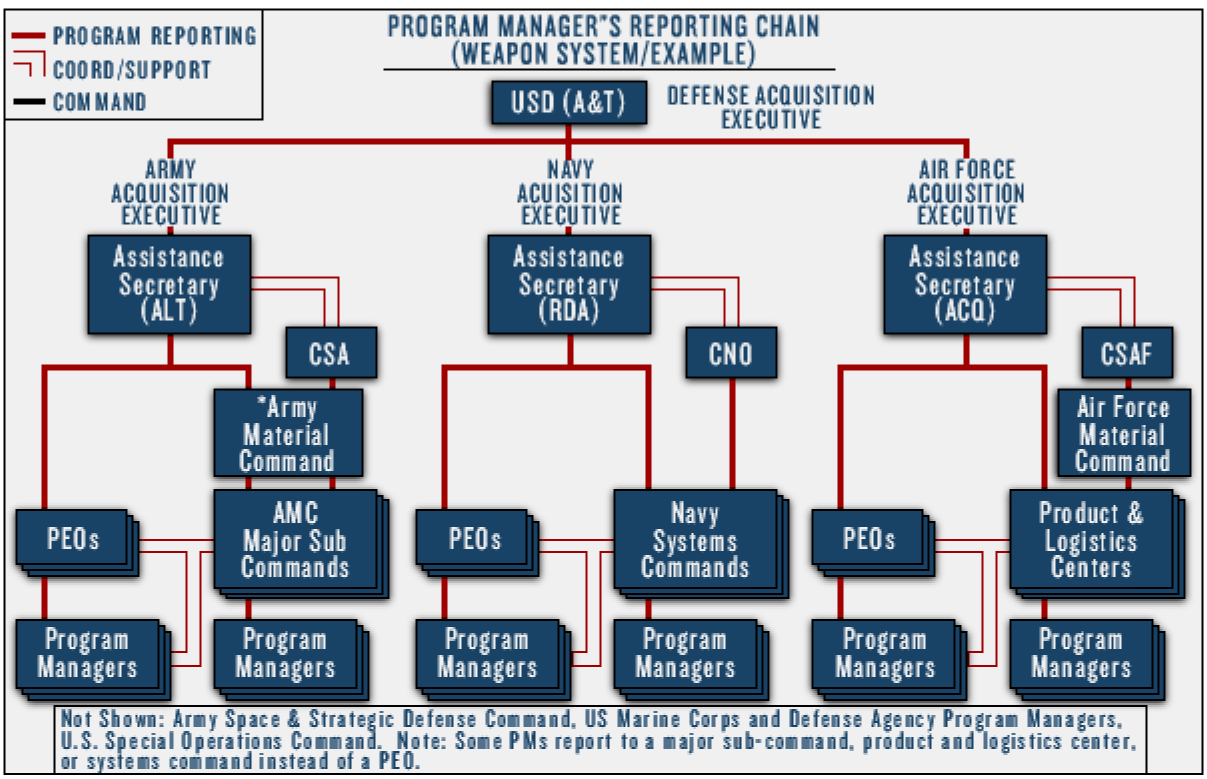

Figure 1-3 Program Manager's Reporting Chain (source ACQ 101)

The primary objective of Defense acquisition is to acquire quality products that satisfy user needs with measurable improvements to mission capability and operational support, in a timely manner, and at a fair and reasonable price. The Directive focuses on several major policy objectives to include:

- Promotion of Competition;
- Realistic Cost Projections;
- Affordability, the Reality of Fiscal Constraints;
- Knowledge-Based Acquisition to include the reduction of manufacturing risk and demonstration of producibility; and
- Application of a Systems Engineering Process, to name a few.

The directive establishes the Undersecretary of Defense for Acquisition, Technology, and Logistics as the Defense Acquisition Executive (DAE). In the exercise of this responsibility, the USD(AT&L) shall:

- Serve as the Defense Acquisition Executive with full responsibility for supervising the performance of the DOD Acquisition System; and
- Chair the Defense Acquisition Board (DAB).

The DAE is charged with assuring that the manufacture of each weapon system is performed so as to produce the most efficient, cost-effective, and highest quality end item possible. The DAE does this through their role as the Chairman of the Defense Acquisition Board (DAB). The DAB provides approval, policy guidance and issues resolution as the weapon system moves through the acquisition cycle from:

- Materiel Solution Analysis;
- Technology Development;
- Engineering and Manufacturing Development;
- Production and Deployment; and
- Operations and Support Review. (See Chapter 3 for a discussion of the acquisition process.)

A Component Acquisition Executive (CAE) is a single official within a DOD component that is responsible for all acquisition functions within that component. In the military departments, the officials delegated as CAEs (also called Service Acquisition Executives (SAEs)) are respectively, the Assistant Secretary of the Army (Acquisition, Logistics, and Technology) (ASA(AL&T)), the Assistant Secretary of the Navy (Research, Development and Acquisition) (ASN(RD&A)), and the Assistant Secretary of the Air Force (Acquisition) (ASAF(A)). The CAEs are responsible for all acquisition functions within their Components. This includes both the SAEs for the military departments and acquisition executives in other DOD Components, such as the U.S. Special Operations Command (USSOCOM) and Defense Logistics Agency (DLA), which also have acquisition management responsibilities.

The individual SAEs manage the established acquisition structure and process within their component, consistent with DOD guidance; report breaches to the program baselines; and establish policy for managing component programs.

Authority for acquisition management is assigned in a multi-tier management structure, depending on the programs acquisition category. Typically a PM reports to Program Executive Officers (PEOs), who report to the Component or Service Acquisition Executive (CAE/SAE), as shown in Figure 1-3. Each of the Services has structured their acquisition policy and program offices somewhat differently in responding to this reporting requirement.

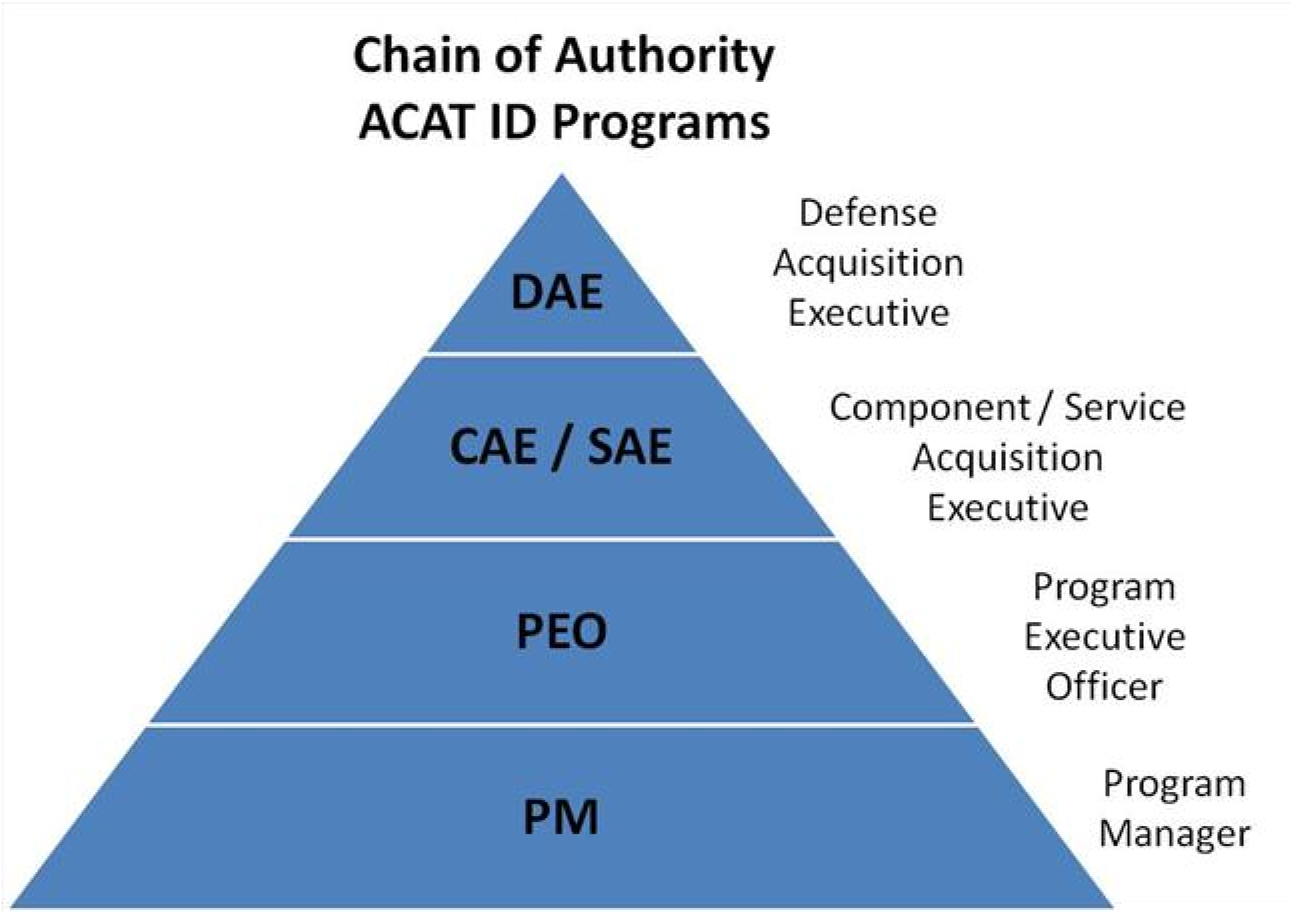

Figure 1-4 The ACAT ID Reporting Chain

1.5.2 Army

The Army's Acquisition Executive is the ASA (ALT) (Assistant Secretary of the Army for Acquisition, Logistics, and Technology) and is responsible for providing oversight for the life cycle management and sustainment of Army weapons systems and equipment from research and development; acquisition; test and evaluation; production; fielding; logistics; and disposition. The acquisition executive also oversees the Elimination of Chemical Weapons Program. In addition, he is responsible for appointing, managing, and evaluating program executive officers as well as managing the Army Acquisition Corps and the Army acquisition workforce to include manufacturing managers.

The ASA (ALT) provides manufacturing technology program guidance to the Army Materiel Command (AMC). The AMC Research, Development, and Engineering Command (RDECOM) manages the specific research, development, tests, and engineering support for each assigned weapon system within their respective technical areas. RDECOM also provides RDT&E support to organic (depot and arsenals) in coordination with the AMC G-4 and the life cycle management commands, to include Aviation and Missile Command, Communications and Electronics Command, and the Tank-Automotive Command.

1.5.3 Navy

The Navy's Acquisition Executive is the Assistant Secretary of the Navy (ASN) for Research, Development and Acquisition (RDA). ASN(RDA) has authority, responsibility and accountability for all acquisition functions and programs, and for enforcement of Under Secretary of Defense for Acquisition, Technology and Logistics procedures. The Assistant Secretary represents the Department of the Navy to USD(AT&L) and to Congress on all matters relating to acquisition policy and programs. ASN(RDA) establishes policies and procedures and manages the Navy's Research, Development and Acquisition activities in accordance with DOD 5000 Series Directives. The Assistant Secretary serves as Program (Milestone) Decision Authority on ACAT IC and II programs and recommends decisions on ACAT ID programs.

The ASN(RD&A) organization is responsible for the development and acquisition of Navy and Marine Corps platforms and weapon systems. The organization consists of an immediate staff to the Assistant Secretary, Program Executive Officers (PEOs), Direct Reporting Program Managers (DRPMs) and the Naval Systems Commands and their field activities. The PEOs and DRPMs are responsible for the development and acquisition of Naval systems. The Naval Systems Commands and their field activities are also responsible for systems acquisition and supporting those systems in the operating Fleet.

The Navy's principal subordinate Systems Commends (SYSCOMs), i.e., Naval Sea Systems, Naval Air Systems, Space and Naval Warfare, Naval Supply Systems. Naval Facilities Engineering, Marine Corps, and the Office of Naval Research are responsible for providing materiel support for the operating needs of the Navy and for certain Marine Corps needs. The SYSCOMs report directly to ASN (RDA). The program offices within the SYSCOMs are responsible for the manufacturing management functions for the defense systems under development. However, guidance on transitioning from development to production comes from the Assistant Secretary of the Navy for Shipbuilding and Logistics.

1.5.4 Air Force

The Air Force's Acquisition Executive is the Assistant Secretary of the Air Force for Acquisition (AQ) and is responsible for all Air Force research, development and non-space acquisition activities. SAF/AQ provides direction, guidance and supervision on all matters pertaining to the formulation, review, approval and execution of Air Force acquisition plans, policies and programs. The Air Force relies on its acquisition executives (the Air Force Acquisition Executive for Acquisition Category IC programs and Program Executive Officers in most cases for Acquisition Category II programs) to be program milestone decision authorities. Milestone decision authorities oversee the development and procurement of systems to meet Air Force mission requirements.

The Air Force has a single command, the Air Force Materiel Command (AFMC) that accomplishes all the research, development, acquisition and logistics support functions. The headquarters staff ensures the command successfully manages its research, development, acquisition, test and logistics services that keep Air Force weapon systems and warfighters ready for combat. AFMC consists of Product Centers (Aeronautical Systems Center, Air Armament Center, and Electronics Systems Center), the Air Force Research Laboratory, Test Centers, and Air Logistics Centers.

Responsibility for manufacturing policy within the Air Force is held by the Director of Science, Technology, and Engineering (AQR) within the Office for the Assistant Secretary of Acquisition. The Air Force Materiel Command is concerned with the defense systems acquisition process and the Directorate of Engineering and Technical Management is responsible for manufacturing.

1.6 DOD Responsibilities

1.6.1 DOD Directive 5000.01, the Defense Acquisition System

As stated previously, DOD Directive 5000.01, The Defense Acquisition System, gives the Undersecretary of Defense for Acquisition, Technology and Logistics as the DAE, the responsibility to establish acquisition policy to include manufacturing policy and direction.

1.6.2 DODI 5000.02, Operation of Defense Acquisition System

DODI 5000.02, Operation of Defense Acquisition Systems, emphasizes an evolutionary acquisition approach. Evolutionary acquisition requires collaboration among the user, tester, and developer. In this process, a needed operational capability is met over time by developing several increments, each dependent on available mature technology. Technology development preceding initiation of an increment shall continue until the required level of maturity is achieved, and prototypes of the system or key system elements are produced. Successive Technology Development Phases may be necessary to mature technology for multiple development increments (section 803 of Public Law (P.L.) 107-314.

Each increment is a militarily useful and supportable operational capability that can be developed, produced, deployed, and sustained. Each increment will have its own set of threshold and objective values set by the user. Block upgrades, pre-planned product improvement, and similar efforts that provide a significant increase in operational capability and meet an acquisition category threshold specified in this document shall be managed as separate increments under this instruction.

Long range planning and effective requirements allow for a smooth transition from development to production. The 5000.02 guidance provided for manufacturing assessments through the entire acquisition cycle and includes such areas as production planning, transition to production, concurrent engineering, quality management, continuous improvement, could cost, and manufacturing technology. The DAE passes this policy through the respective SAEs who are the senior acquisition executives within the DOD component having cognizance and management responsibility over defense systems. The manufacturing policy is assessed by the components' PEO and is provided to the program managers. The PEOs are the officials responsible for administering a defined number of acquisitions and reporting program status to the SAE. The concept behind this approach is that the acquisition system will be characterized by short, direct lines of communications; less staff interaction; and streamlined procedures. Overall the PM, who is the individual responsible for executing the program, will experience fewer layers of management oversight (no more than one management tier between the PM and the SAE), and will be able to receive the guidance he requires in a timely fashion.

1.6.3 DOD Directive 4245.6, Defense Production Management

DOD Directive 4245.6, Defense Production Management, issued 19 Jan, 1984, establishes policy and assigns responsibility for manufacturing management within the DOD components for the acquisition of major defense systems. The directive cites that a manufacturing strategy shall be developed as part of the program acquisition strategy. Manufacturing voids, deficiencies, and dependencies on critical foreign source materials shall be addressed. The producibility of each system design concept shall be evaluated to determine if the proposed system can be manufactured in compliance with the production cost and industrial base goals and thresholds. This direction, while cancelled under acquisition reform, is still practical for programs of all magnitudes and is supplemented with more detail by the respective DOD components.

Major programs in each service begin following the SECDEF or Deputy SECDEF acceptance of the mission need statement (MNS). The justification contains an analysis that has taken into consideration the existing technology base. Manufacturing management is considered at each decision point throughout the system life cycle.

- A manufacturing feasibility assessment is made by the responsible DOD component during the development of the component OSD decision leading to the concept demonstration/validation phase.
- The producibility of the design approach and production risks is reviewed prior to the full-scale development phase.
- Toward the end of the full-scale development phase, a final Production Readiness Review is performed to determine whether the program is ready to enter the production and deployment phase.

1.7 Government Program Manager Responsibilities

The government program manager (PM) needs to be concerned with manufacturing management early in the process of defense system acquisition. The design's stability and producibility, the development and demonstration of manufacturing processes, the tooling to be developed, and production testing and demonstration identified during preliminary design should be evaluated to determine the overall manufacturing risk, as well as cost and schedule impacts. Manufacturing risk is one of the important factors in making the decision to proceed within all phases of development and production. The following manufacturing considerations should be made during the appropriate acquisition phases:

Acquisition Phase	Manufacturing Consideration(s)
Materiel Solution Analysis	Assess Manufacturing Feasibility
Technology Development	Evaluate Manufacturing Processes Evaluate Producibility of the Design
Engineering and Manufacturing Development	Develop Affordable and Executable Manufacturing Processes

Table 1-1 Manufacturing Considerations by Phase

No later than the critical design review (CDR), a producibility analysis should be made to aid in the identification of risks, the development of preliminary cost and schedule estimates, and the identification of issues that must be resolved prior to the Milestone C decision. Preparation for Production Readiness Reviews should begin in the Engineering and Manufacturing Development phase. The Program Management Office (PMO) should establish and provide criteria to the contractor as early as possible. A successful Milestone C requires a plan for transitioning from development to production. The Milestone C decision requires verification of the product producibility and production schedule capabilities.

The PM should work closely with the contractor counterpart to ensure that all manufacturing objectives will be met. The PM should insist on aggressive producibility actions, comprehensive production planning and scheduling, and efficient manufacturing methods. Sufficient funds should be budgeted for use during all phases to accomplish these tasks. Producibility engineering and planning (PEP) and initial production facilities (IPF) definition efforts should start during product design to avoid incurring significant cost and delays in starting the manufacturing effort. Formal manufacturing maturity assessments should be conducted to support on-going risk assessments and trade studies.

The PM, through the manufacturing team in the PMO, should monitor progress against the manufacturing plan. The PMO team should have a good technical understanding of the product so that technical problems can be resolved and design modifications can be evaluated effectively. The PM, of course, must be aware of each contract and engineering change during the program, and the impact of that change on the overall program.

1.8 Relationship Between Government and Contractor Program Managers

Interaction between contractor manufacturing and quality assurance executives and the government PM is required during program planning when program schedules and budgets are being established. This relationship should continue throughout the life cycle of the program. Such interaction usually results in the development of better schedule and cost planning. Also, it increases the validity of information used by the contractor(s) for work force, technology and capital expenditure planning.

Interaction is required in the review of work in process and the contractor methods and procedures. This assists both government and contractor managers in their understanding of the manufacturing proposals and in the expeditious resolution of manufacturing problems. This interaction is an absolute necessity, and in some cases the PM will find that interaction between the government and contractor manufacturing personnel can serve as a forcing function for the top contractor design personnel to communicate and coordinate program decisions with their own manufacturing personnel. A management tool like Award Fee or Incentive Fee can increase visibility into the interaction aspects of the producibility program or other manufacturing and quality assurance considerations.

When budgeting for manufacturing, interaction will enable the government PMO to determine the significant cost impacts experienced by the contractor. Interaction increases the government PMO's understanding of the contractor's manufacturing operations and manufacturing pricing methodology, as well as the factors that can impact manufacturing operations.

1.9 Government Program Management Office Personnel Selection

Personnel selected to perform the manufacturing management task in a government PMO should be production-oriented and should understand fully the importance of continuing assessment of the manufacturing effort. Knowledge of the following is important for government personnel to have or to develop when they are assigned the manufacturing management responsibility:

- Manufacturing processes and their management;
- Conduct of manufacturing risk assessments;
- Technical Reviews and Audits;
- Systems Engineering, Producibility Engineering and other engineering functions/operations;
- Integrated Product and Process Teams;
- The technical performance requirements of the defense system/product (as specified in the contract);
- The DOD planning, programming, and budgeting cycle;
- Manufacturing planning and scheduling;
- Manufacturing Technology, SBIR and other technology development activities;
- The relationship of manufacturing management to acquisition strategy and source selection activities;
- Configuration management and its relationship to the manufacturing effort;
- Manufacturing controls to include work measurement, earned value management;

- Total quality management, continuous process improvement and Lean/Six Sigma;
- Industrial Base Assessments and Supply Chain Management operations;
- OSHA and Environmental Laws;
- Depot maintenance or repair facility operations;
- How to control/reduce costs; and
- Productivity improvement.

1.10 Summary

Bottom-line: Program managers need to balance risks with cost, schedule and performance. This balance can be significantly improved by involving manufacturing/QA staff personnel early in the acquisition process. In many cases, it is not just good practice, it is the law.

1.11 Related Links and Resources

Numerous reference documents impact the manufacturing management function throughout the acquisition process. These documents originate from many sources and range across academic disciplines, functional activities, and job specialties.

The following is a reference list of DOD Directives (D), Instructions (I), Manuals (M), Pamphlets (P) Military Standards (MS), and other documents. The documents listed contain DOD policy guidance applicable to the manufacturing management function. They are listed as sources of DOD manufacturing management information.

Note: Many of the documents listed are no longer required (due to acquisition reform), but still contain some very valuable information.

Number	Title
DODD 4245.6	*Defense Production Management*
DODD 5000.01	*Defense Acquisition System*
DODI 5000.02	*Operation of Defense Acquisition Systems*
GAO-10-388SP	*Defense Acquisitions: Assessments of Selected Weapon Programs*
GAO-02-701	*Best Practices: Capturing Design and Manufacturing Knowledge Early Improves Acquisition Outcomes*

2.1 Objective

The Program Manager (PM) has the responsibility for and authority to accomplish program objectives for development, production, and sustainment to meet the user's operational needs. These activities rely heavily on the capabilities and capacity of our defense industrial base. PMs need to specifically assess the capabilities of that industrial base in order to understand if the base can support their program.

The Defense Production Act of 1950 was enacted to ensure that an industrial capability was there to support our national objectives. Seven (7) titles were enacted as a part of the Defense Production Act. Three of these titles have been reauthorized and were active at the time of this update to the Guide. Those three are:

- Title I Priorities and Allocations (is the authority to demand priority for defense-related products);
- Title III Expansion of Productive Capacity and Supply (is the authority to provide incentives to develop, modernize, and expand defense productive capacity); and
- Title VII General Provisions (support a number of programs and activities).

The material which follows describes the structure and problems of the industrial base and the avenues available to the PM to achieve the necessary and available support from that base. At the end of this chapter you should be able to:

- Describe industrial base related laws, policies and guidance;
- Identify current industrial base concerns;
- Identify industrial base considerations within the acquisition framework;
- Describe the roles and responsibilities of the Industrial Analysis Center;
- Describe industrial base planning and investments activities; and
- Describe the role of the Defense Priorities System and Defense Materials System.

2.2 Background

The President's Budget for 2010 laid out a radically new approach for NASA that called for the investments in new technologies. In order to pay to develop these new technologies NASA was forced to cancel the Constellation program (Figure 2-1). The Constellation's boosters are solid rocket motors (SRMs). Each of these SRMs contains more than one million pounds of propellant. These SRMs, produced by Alliant Techsystems (ATK), require extensive investments in plant and equipment in order to safely mix and cast these boosters at their facility in Utah. The boosters for the Constellation program represents approximately 70% of the SRM business base for ATK. The cancellation left the SRM industrial base reeling. Thousands of people were laid off and tremendous strains were put on the entire supply chain as companies struggled to right-size. The impact was felt in the engineering (R&D) side of the house as well as on the shop floor. The impact to the industrial base (IB) was so significant that Congress directed the SECDEF " *to* *review and establish a plan to sustain the SRM Industrial Base, including the ability to maintain and sustain currently deployed strategic and missile defense systems and to maintain intellectual and engineering capacity to support next generation rocket motors as needed* ."

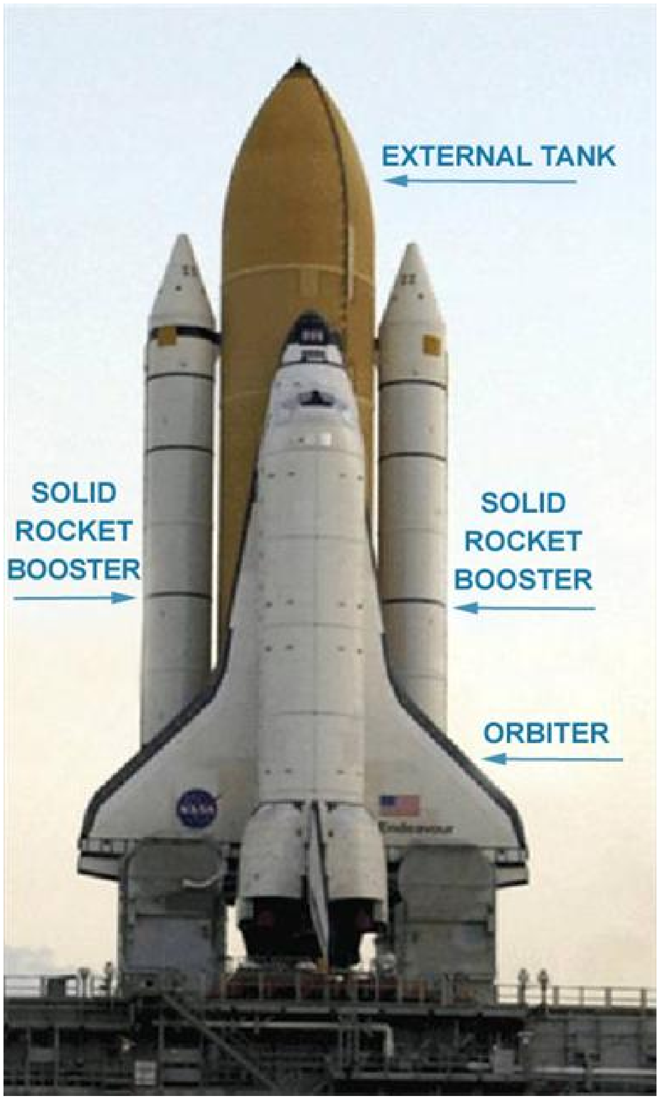

Figure 2-1 NASA Constellation Boosters

2.3 Introduction

The mission of the DOD is to provide the military forces needed to deter war and protect the security of our country. The heart of deterrence lies in our inventory of military equipment and human resources, and in the ability to develop and produce new systems in response to national emergencies.

2.3.1 Historical Context

History has shown that at times the industrial base was prepared to support these national emergencies and at other times we were not. In the 1930's the U.S. attempted to stay out of the growing war in Europe by passing the Neutrality Act of 1937. Then the Neutrality Act of 1939 allowed France and Great Britain to buy arms here in the states and ship them overseas on their carriers on a "cash and carry" basis. This kept us directly out of the war and allowed us to support those allied against the Germans. The rapid fall of France in 1940 shocked many Americans and caused President Roosevelt to sign the "Destroyers for Bases" deal in which we exchanged fifty (50) destroyers for 99 year leases on British bases in Europe. Congress later passed the "Lend-Lease Act" in 1941 which allowed the President to lend or lease war material in support of the allies. The Lend-Lease Act made the U.S. "the arsenal of democracy." Factories converted from civilian production to wartime production with amazing speed. Automobile factories converted to making tanks, typewriter companies began making machine guns, a factory that made silk ribbons began making parachutes. Thus when America did enter the war, we entered it with our industrial base on high alert.

The Peace Dividend at the end of WW II caused the demobilization of military forces (over 6 million in the Army alone), and the return to the production of commercial goods by factories that had turned to producing military materials. Under President Truman the U.S. ignored the need for modernizing its aging weapon systems in favor of a "nuclear shield" as the basis for our defense. The outbreak of war on the Korean peninsula found U.S. forces and our allies greatly outnumbered and facing better weapons. President Truman then understood that military preparedness and economic preparedness were inseparable and asked Congress to pass the Defense Production Act of 1950 giving him broad authority to allocate resources and material to the production of wartime goods and giving priority to defense production.

The lifeblood of this military capability is the United States' industrial base. The "industrial base" combines the manufacturing process with the managerial talent which establishes a strong economy and industrial sector to produce weapon systems required to provide for the defense of the country.

What is the industrial base (IB)? The term "domestic defense industrial base" is defined to mean *"domestic sources which are providing, or which would be reasonably expected to provide, materials or services to meet national defense requirements during peacetime, graduated mobilization, national emergency, or war* ." A domestic source is " *one performs in the United States or Canada substantially all of the research and development, engineering, manufacturing, and production activities required of such business concern under a contract with the United States relating to a critical component or a critical technology item* ." The industrial base is composed of prime contractors, together with tiers of subcontractors, with the plant and equipment, processes, material, and skilled workers necessary to develop and produce the hardware required to fulfill the nation's defense program. The industrial base includes government organizations and facilities such as labs, depots, shipyards and any other facility where production could occur.

2.3.2 Today's Environment

A number of problems have degraded the ability of the industrial base to respond to near-term readiness, surge and mobilization problems have resulted in a deterioration of the subcontractor and vendor base which has diminished the likelihood of competition and contributed to the emergence of production bottlenecks.

The decline in aircraft production for example has contributed to industry consolidation. Since 1990 the aircraft industry has seen significant consolidation (Figure 2-2), resulting in lower variety, which may adversely affect technological innovation. Innovation does not occur in isolation, and available knowledge that frames the definition and solution of problems constrains the behavior of firms. Thus, insufficient diversity results in a less resilient industry.

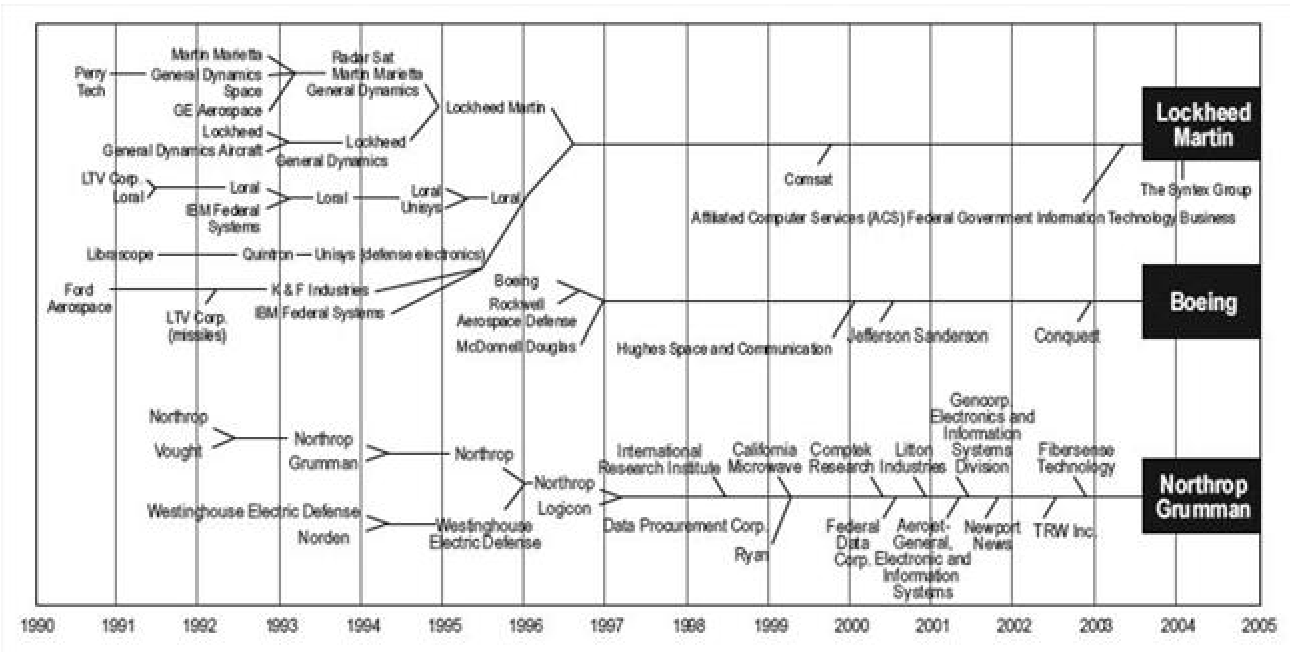

Figure 2-2 Consolidation of the Aircraft Industrial Base

To encourage industry's innovative response to the needs of our Service members, the 2011 National Defense Authorization Act (NDAA) has recommended a number of changes that will impact how the Department of Defense's (DOD) Office of Industrial Policy is organized and funded.

First, the NDAA establishes the position of Deputy Assistant Secretary of Defense for Manufacturing and Industrial Base Policy to reflect the expanded duties of the Industrial Policy office. The inclusion of "manufacturing" in the title ensures that the linkage between "industry" and "manufacturing" is firmly established and effectively coordinated.

Reporting to the Under Secretary of Defense for Acquisition, Technology, and Logistics, the Office of Manufacturing and Industrial Base Policy will expand its current mission to include managing a new Industrial Base Fund used to:

- Support the monitoring and assessment of the industrial base;
- Address critical issues in the industrial base related to urgent operational needs;
- Support efforts to expand the industrial base; and
- Address supply chain vulnerabilities.

The mission of the Office of Manufacturing and Industrial Base Policy is to sustain an environment that ensures the manufacturing and industrial base on which the Department of Defense (DOD) depends is reliable, cost-effective, and sufficient to meet DOD requirements. Manufacturing and Industrial Base Policy is responsible to ensure that DOD policies, procedures, and actions:

- Stimulate and support vigorous competition and innovation in the IB supporting defense; and
- Establish and sustain cost-effective industrial and technological capabilities that assure military readiness and superiority.

Manufacturing and Industrial Base Policy does so by:

- Monitoring industry readiness, competitiveness, ability to innovate, and financial stability as the Department moves to capabilities-based acquisitions in an era of increasingly sophisticated systems;
- Leveraging DOD research and development, acquisition, and logistics decisions to promote innovation, competition, military readiness, and national security;
- Leveraging statutory processes and promoting innovation, competition, military readiness, and national security; and
- Leading efforts for the Department to engage with industry to ensure openness and transparency with the goal of increasing effective public-private partnerships.

2.4 DOD Law/Policy

The requirement for Industrial Base assessments and other activities flows from the Law. This chapter will look at two specific laws and how they impact:

- PMs on acquisition programs, and
- Service and Agency acquisition offices.

2.4.1 Acquisition Related Industrial Base Laws, Policies and Guidance

2.4.1.1 Industrial Base Considerations In Acquisition Plans

10 USC Chapter 144, Section 2440 directs the Secretary of Defense to prescribe regulations requiring consideration of the national technology and industrial base (NTIB) in the development

and implementation of acquisition plans for each major defense acquisition program. A PM is responsible for knowing the capabilities of their industrial base and integrating those considerations in their risk assessments, acquisition planning and program implementation. Figure 2-3 shows the flow of requirements from law to policy to guidance for the assessment of the industrial base for acquisition programs.

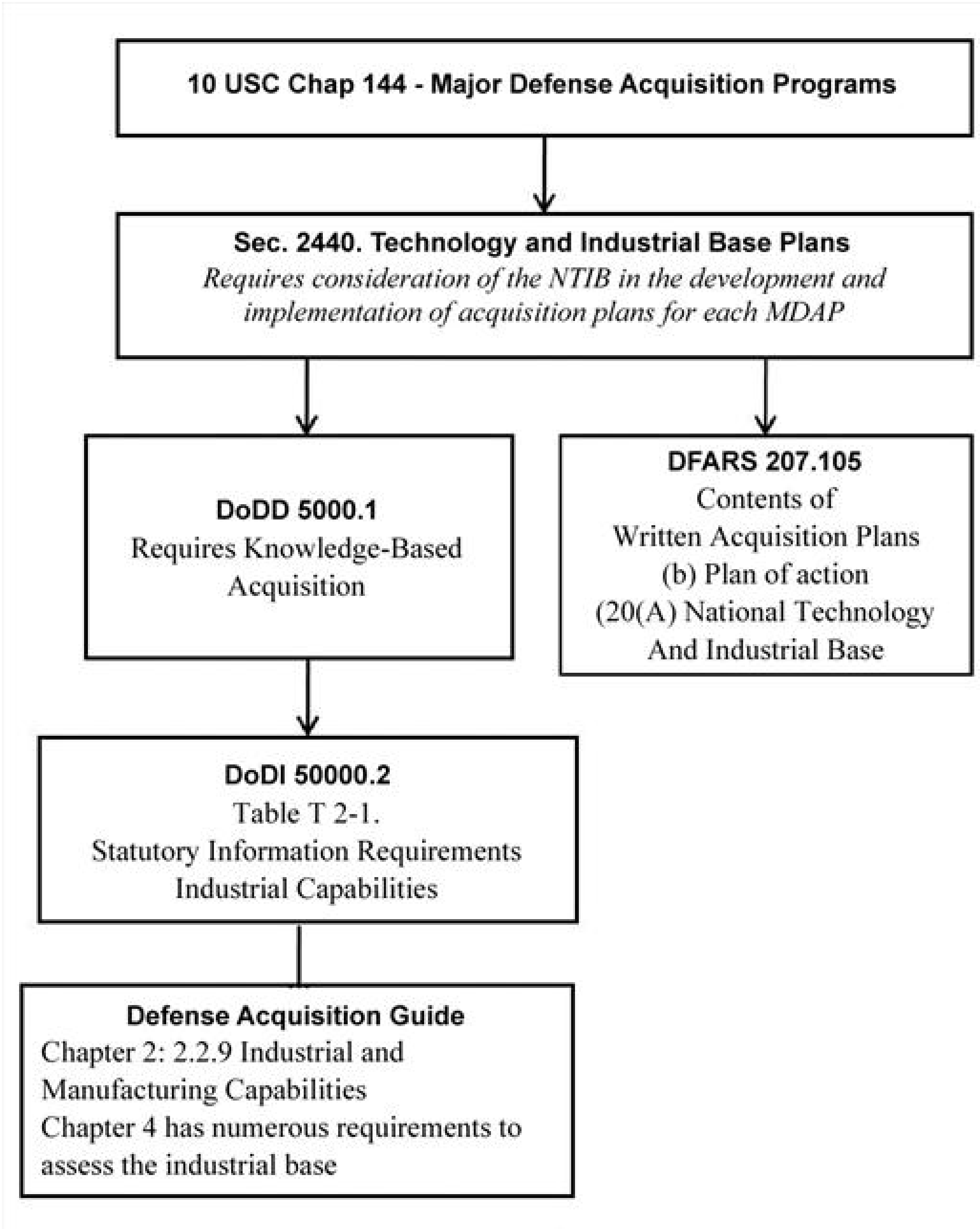

Figure 2-3 Industrial Base Requirements Flow

2.4.1.2 DODI 5000.1

It is DOD's policy to ensure that defense acquisition systems are responsive. That is these systems must ensure that advanced technologies are integrated into producible systems and deployed in the shortest time possible. In addition, the acquisition systems shall recognize the reality of fiscal constraints and to the greatest extent possible the PM must identify the major drivers of the total cost of ownership. Finally, the PM must provide knowledge about key aspects of a system at key points in the acquisition process. All of this requires an analysis and understanding of their industrial base's capabilities.

2.4.1.3 DODI 5000.02

Acquisition Strategies must consider Industrial Base capabilities at Milestones B and C. In addition, the Analysis of Alternatives (AoA) conducted in the Material Solution Analysis phase must include an assessment of manufacturing feasibility which will require an assessment of the industrial base capabilities. The Technology Development phase requires an evaluation of manufacturing processes, and this also requires an assessment of the industrial base.

2.4.1.4 Defense Acquisition Guide (DAG)

The Defense Acquisition Guide (DAG) has several sections that address the need to conduct industrial base assessments and these assessments are required early (pre-Milestone A) and throughout the life cycle of a program. A simple search of Chapters 2 and 4 of the DAG using a word search on "industrial base" will reveal all of these references.

2.4.1.4.1 Chapter 2

Chapter 2.2.9 Notes that the Technology Development Strategy (TDS) should identify and address how industrial capabilities, including manufacturing technologies and capabilities, will be considered and matured during the TD Phase. Industrial capabilities required to design, develop, manufacture, maintain, and manage DOD products.

Chapter 2.3.9 Notes that the development of Acquisition Strategy (AS) should include the results of an industrial base capability analysis to design, develop, produce, support, and if appropriate, restart an acquisition program.

2.4.1.4.2 Chapter 4

Chapter 4.3.2.1 Under the Purpose of Systems Engineering in Technology Development states that one of the SE requirements is to " *assess the industrial base to identify potential manufacturing sources* ." Similar requirements exists for each of the acquisition phases.

2.4.2 Other Related Industrial Base Laws, Policies and Guidance

Congress passed the following laws that impact the U.S. industrial base. U.S. Code; Title 10, Chapter 148 identifies five specific statutory requirements:

- Sets National Security Objectives for the Industrial Base;

- Establishes the Industrial Base Council headed by the Secretary of Defense;
- Establishes a program for the analysis of Technology and the Industrial Base;
- Requires an annual Industrial Base Report to be submitted to Congress; and
- Requires periodic assessments of the Industrial Base.

2.4.2.1 National Security Objectives For The Industrial Base

Section 2501 sets the national security objectives that the U.S. industrial base must be capable of:

- Supplying, equipping, and supporting the force structure of the armed forces;
- Sustaining production, maintenance, repair, logistics, and other activities in support of military operations of various durations and intensity;
- Maintaining advanced research and development activities to provide the armed forces with systems capable of ensuring technological superiority over potential adversaries;
- Reconstituting within a reasonable period the capability to develop, produce, and support supplies and equipment, including technologically advanced systems, in sufficient quantities to prepare fully for a war, national emergency, or mobilization of the armed forces before the commencement of that war, national emergency, or mobilization;
- Providing for the development, manufacture, and supply of items and technologies critical to the production and sustainment of advanced military weapon systems within the NTIB;
- Providing for the generation of services capabilities that are not core functions of the armed forces and that are critical to military operations within the NTIB;
- Providing for the development, production, and integration of information technology within the NTIB; and
- Maintaining critical design skills to ensure that the armed forces are provided with systems capable of ensuring technological superiority over potential adversaries.

2.4.2.2 National Defense Technology And Industrial Base Council

Section 2502 established the National Defense Technology and Industrial Base Council which is composed of the following:

- The Secretary of Defense,
- The Secretary of Energy,
- The Secretary of Commerce,
- The Secretary of Labor, and
- Such other officials as may be determined by the President.

The Council is responsible to ensure effective cooperation among departments and agencies of the Federal Government, and to provide advice and recommendations to the President, the Secretary of Defense, the Secretary of Energy, the Secretary of Commerce, and the Secretary of Labor, concerning:

- The capabilities of the NTIB to meet the national security objectives;

- Programs for achieving such national security objectives; and
- Changes in acquisition policy that strengthen the NTIB.

2.4.2.3 Analysis Of Technology And Industrial Base

Section 2503 makes the Secretary of Defense responsible for the establishment of a program for analysis of the NTIB with the following functions:

- The assembly of timely and authoritative information;
- Initiation of studies and analyses;
- Provision of technical support and assistance; and
- Dissemination, through the National Technical Information Service of the Department of Commerce, of unclassified information and assessments for further dissemination within the Federal Government and to the private sector.

2.4.2.4 Annual Report To Congress

Section 2504 requires the Secretary of Defense to provide Congress an annual report that includes the following information:

- A description of the departmental guidance;
- A description of the methods and analyses being undertaken by DOD and/or other Federal agencies, to identify and address concerns regarding capabilities of the NTIB;
- A description of the assessments prepared and other analyses used in developing the budget submission of the Department of Defense for the next fiscal year; and
- The identification of each program designed to sustain specific essential technological and industrial capabilities and processes of the NTIB.

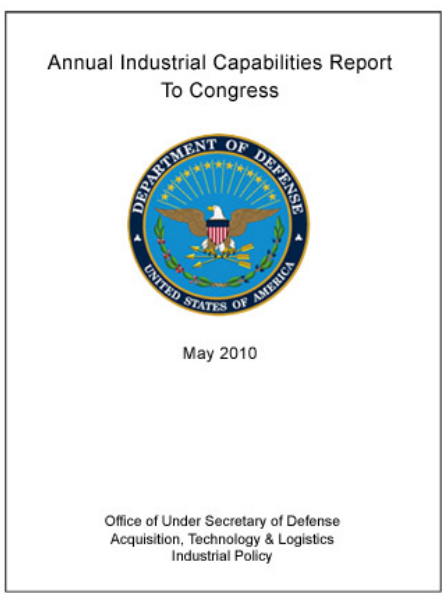

Figure 2.4 Annual Industrial Capabilities Report to Congress

2.4.2.5 Periodic Defense Capability Assessments

Section 2505 requires the Secretary of Defense to prepare selected assessments of the NTIB which should:

- Describe sectors or capabilities, their underlying infrastructure and processes;
- Analyze present and projected financial performance of industries supporting the sectors or capabilities in the assessment;
- Identify technological and industrial capabilities and processes for which there is potential for the NTIB not to be able to support the achievement of national security objectives; and
- Consider the effects of the termination of major defense acquisition programs in the previous fiscal year on the sectors and capabilities in the assessment.

The assessments need to include a discussion identifying the extent to which the NTIB is dependent on items which are produced outside of the United States and Canada and for which there is no immediately available source in the United States or Canada. The discussion on foreign dependency needs to:

- Identify cases that pose an unacceptable risk of foreign dependency, as determined by the Secretary; and
- Present actions being taken or proposed to be taken to remedy the risk posed by the cases identified, including efforts to develop a domestic source for the item in question.

2.4.2.6 DODI 5000.60 Industrial Base Capabilities Assessments

DODI 5000.60 provides policy and identifies responsibilities for assessing defense industrial capabilities. The purpose of the assessment is to ensure that the industrial capabilities needed to meet current and future national security requirements are available and affordable. The industrial base capability assessment will be used to use to determine:

- Whether a specific industrial capability is required to meet DOD needs, is truly unique, and is truly endangered; and, if so,
- What, if any, action the DOD should take to ensure the continued availability of the capability.

Government funds should not be used to preserve an industrial capability unless it is the most cost-effective and time-effective approach to meeting national security requirements. Enclosure 2 to DODI 5000.60 provides criteria for the assessment of endangered industrial capabilities and provides procedures for preserving (funding) the capabilities at the program level and below. The Defense Acquisition Executive (DAE) or the Component Acquisition Executive (CAE), under the authority of the DOD Component Head to which the program is assigned has the authority to approve the use of government funds to preserve a capability with an anticipated cost of less than $10 million annually. Any proposed investment should be accompanied by an industrial capability analysis summary report, with information copies to the Director, Industrial Policy.

For all non-ACAT programs, the Head of the Contracting Activity, under the authority of the DOD Component Head to which the item or program is assigned, shall approve decisions to use government funds of less than $10 million. In addition to Enclosure 2, DOD 5000.60-H is a DOD Handbook that details the process for conducting assessments of Defense Industrial Capabilities.

2.4.2.7 Defense Critical Infrastructure Program (DODD 3020.40)

2.4.2.7.1 What is Critical Infrastructure?

Systems and assets, whether physical or virtual, so vital to the United States that the incapacity or destruction of such systems and assets would have a debilitating impact on security, national economic security, national public health or safety, or any combination of those matters.

2.4.2.7.2 What is CIP?

Critical Infrastructure Protection (CIP) consists of actions taken to prevent, remediate, or mitigate the risks resulting from vulnerabilities of critical infrastructure assets. Depending on the risk, these actions could include changes in tactics, techniques, or procedures; adding redundancy; selection of another asset; isolation or hardening; guarding, etc.

DCIP is an integrated risk management program designed to support DOD Mission Assurance programs. When effectively applied, these programs form a comprehensive structure to secure critical assets, infrastructure, and key resources for our nation. The national defense and economic vitality is highly dependent upon the availability and reliability of both DOD and non-DOD owned critical infrastructure (such as: power, transportation, telecommunications, water supply, etc.). With limited resources to address risk to critical infrastructure, the DCIP relies on continuous analysis of changing vulnerabilities to all types of threats and hazards to effectively manage risk to the nation's most essential infrastructure. DOD established the Defense Critical Infrastructure Program (DCIP) for coordinating the management of risk to the critical infrastructure that DOD relies upon to execute its missions.

2.4.2.7.2.1 Federal Department

As a Federal department DOD's responsibilities include the identification, prioritization, assessment, remediation, and protection of defense critical infrastructure. Federal departments and agencies need to work together at a national level to "prevent, deter, and mitigate the effects of deliberate efforts to destroy, incapacitate, or exploit" critical infrastructure and key resources.

Federal departments are also directed to:

- Ensure homeland security programs do not diminish the overall economic security of the U.S.;
- Appropriately protect the information; and
- Implement the directive in a manner consistent with applicable provisions of law.

2.4.2.7.2.2 Sector-Specific Agency (SSA)

As the Sector-Specific Agency DOD has the responsibility to:

- Collaborate with all relevant federal departments and agencies, state and local governments, and the private sector, including key persons and entities in their infrastructure sector;
- Conduct or facilitate vulnerability assessments of the sector;
- Encourage risk-management strategies to protect against and mitigate the effects of attacks against critical infrastructure and key resources; and
- Support sector-coordinating mechanisms:
    - To identify, prioritize, and coordinate the protection of critical infrastructure and key resources; and
    - To facilitate sharing of information about physical and cyber threats, vulnerabilities, incidents, potential protective measures, and best practices.

The USD(AT&L) with the support of the USD(P), needs to:

- Integrate DCIP policies into acquisition, procurement, military construction, and installation guidance. Ensure DCIP-related guidance is developed and implemented that requires that, prior to system fielding or deployment, either commercial system developers remediate or senior-level DOD PM documents a risk management decision for all vulnerabilities identified.
- Develop policies, make recommendations, provide guidance, and approve science and technology efforts related to DCI. Synchronize these efforts with DHS science and technology efforts.
- Identify vulnerabilities in technologies relied upon by DCI that are developed, acquired, owned, or operated by the DOD, and develop effective risk response options to emerging vulnerabilities or threats to include cyber threats.
- Provide guidance to; monitor the activities of; and review, validate, and advocate funding for the Defense Infrastructure Sector Lead Agents for the DIB Logistics, Public Works, and Transportation Sectors. Coordinate such matters with the USD(P) and the Chairman of the Joint Chiefs of Staff, as appropriate.
- Identify, develop, update, and implement policy and processes into the DOD acquisition contracting process for improved protection of unclassified DOD information regarding controls on unclassified DIB systems and networks as part of DIB CA/IA activities.

2.4.2.8 DFARS 207.105 Contents Of Written Acquisition Plans

Acquisition plans must be correlated with the DOD Future Years Defense Program (FYDP), applicable budget submissions, and the decision coordinating paper/program memorandum, as appropriate. The acquisition planner needs to coordinate the plan with all those who have a responsibility for the development, management, or administration of the acquisition. The acquisition plan should be provided to the contract administration organization to facilitate resource allocation and planning for the evaluation, identification, and management of contractor performance risk.

Major defense acquisition programs need to address the following NTIB considerations in their acquisition plans:

- An analysis of the capabilities of the NTIB to develop, produce, maintain, and support such program, including consideration of the following factors related to foreign dependency;
  - The availability of essential raw materials, special alloys, composite materials, components, tooling, and production test equipment for the sustained production of systems fully capable of meeting the performance objectives established for those systems; the uninterrupted maintenance and repair of such systems; and the sustained operation of such systems.
  - The identification of items that are available only from sources outside the NTIB.
  - The availability of alternatives for obtaining such items from within the NTIB if such items become unavailable from sources outside the NTIB; and an analysis of any military vulnerability that could result from the lack of reasonable alternatives.
  - The effects on the NTIB that result from foreign acquisition of firms in the United States.
- Consideration of requirements for efficient manufacture during the design and production of the systems to be procured under the program.
- The use of advanced manufacturing technology, processes, and systems during the research and development phase and the production phase of the program.
- The use of contract solicitations that encourage competing offers to acquire modern technology, production equipment, and production systems that increase the productivity and reduce life-cycle costs.
- Methods to encourage investment by U.S. domestic sources in advanced manufacturing technology production equipment and processes.
- Expanded use of commercial manufacturing processes rather than processes specified by DOD.
- Elimination of barriers to, and facilitation of, the integrated manufacture of commercial items and items being produced under DOD contracts.
- Expanded use of commercial items, commercial items with modifications, or to the extent commercial items are not available, nondevelopmental items.
- Acquisition of major weapon systems as commercial items.

Major defense acquisition programs need to address the following Industrial Capability (IC) considerations in their acquisition plans:

- Provide the program's IC strategy that assesses the capability of the U.S. industrial base to achieve identified surge and mobilization goals. If no IC strategy has been developed, provide supporting rationale for this position.
- If, in the IC strategy, the development of a detailed IC plan was determined to be applicable, include the plan by text or by reference. If the development of the IC plan was determined not to be applicable, summarize the details of the analysis forming the basis of this decision.

- If the program involves peacetime and wartime hardware configurations that are supported by logistics support plans, identify their impact on the IC plan.

In addition, Major defense acquisition programs need to address several special considerations in their acquisition plans. See PGI 207-105(C) for additional information.

2.5 Industrial Base Concerns

During the 2010 Association of the United States Army (AUSA) Winter Symposium and Exposition Mike Cannon, Vice President for Ground Combat Systems at General Dynamics Land Systems, provided a bleak outlook for the Abrams tank industrial base. The major concern was that the program build is scheduled to be finished in the middle of 2013 with no follow-on production program planned or in place. Couple that with a lack of spares procurement and you have an industrial base capability that may be forced to go dormant. Once a production line goes cold it is very expensive to revive. This section will address several common industrial base concerns.

2.5.1 Capability, Capacity and Financial Stability

Critical to the success of any program is the ability of the acquisition team to understand the capacity to produce, the capability to produce, and the financial stability required to produce the items required by our warfighters.

Capability looks at the "ability to produce." It answers the question "does the contractor have the necessary manpower skills, machines, facilities, material and methods to produce at the item in question?"

Capacity looks at "rate and quantity." It answers the question "does the contractor have the ability to produce the item at the rates required by the warfighter, and can they meet surge requirements?"

Financial stability looks at the "viability of the firm" from an accounting and balance sheet perspective. It answers the question "does the company have the financial resources and financial stability to see to the program through completion?"

2.5.1.1 Industrial Capability

The program office should assess the impact of programmatic decisions on the national and international NTIB supporting U.S. defense to satisfy the requirements of 10 USC 2440 and DFAR Subpart 207.1. Overall Industrial Capabilities Assessments (ICAs) should address critical sub-tier, as well as prime contractor capabilities and should include:

- New and unique capabilities that must be developed or used to meet program needs;
- Identifying DOD investments needed to create new or enhance existing industrial capabilities. This includes any new capability (*e.g.* skills, facilities, equipment, etc.);

- Identifying new manufacturing processes or tooling required for new technology. Funding profiles must provide for up front development of manufacturing processes/tooling and verification that new components can be produced at production rates and target unit costs;
- Identifying exceptions to FAR Part 45, which requires contractors to provide all property (equipment, etc.) necessary to perform the contract;
- Program context in overall prime system and major subsystem level industry sector and market;
- Strategies to address any suppliers considered to be vulnerable;
- Risks of industry being unable to provide new program performance capabilities at planned cost and schedule;
- Alterations in program requirements or acquisition procedures that would allow increased use of non-developmental or commercial capabilities;
- Strategies to deal with product or component obsolescence, given DOD planned acquisition schedule and product life;
- Strategies to address reliability issues (*i.e.* , tampering, potential interrupted delivery from non-trusted sources, etc.) associated with commercial components for sensitive applications; and
- Strategies to utilize small business, including small disadvantaged business, women-owned small business, veteran-owned small business, service-disabled veteran-owned small business and small businesses located in Historically Underutilized Business Zones.

2.5.1.2 Elevating Industrial Capability Issues

Capacity is normally constrained by physical facilities, available productive equipment, tooling and/or test equipment. The portion of this capacity actually utilized is determined by the demand on the plant for current and known future workload. Firms engaged in the defense industry must be particularly aware of a need for excess capacity because its customer's (military) demands tend to be somewhat unstable over time.

While not specific to the Acquisition Strategy, program offices and the Military Services are encouraged to resolve identified industrial capability and capacity issues at the lowest level possible. However, there are cases when issues may impact more than a single program or Service. A program office should elevate an industrial capabilities matter via their Program Executive Officer to the Office of the Deputy Under Secretary of Defense (Industrial Policy) when an item produced by a single or sole source supplier meets one or more of the following criteria (even if the program office has ensured that its program requirements can and/or will be met):

- It is used by three or more programs;
- It represents an obsolete, enabling, or emerging technology;
- It requires 12 months or more to manufacture; and
- It has limited surge production capability.

2.5.2 Sources: Sole, Single and Foreign

Where and how you get your sources of material can be a vital concern for PMs. Having just one sole source, single source or foreign source in your supply chain could be a show stopper, especially if that item is a critical item that significantly impacts the capability of the system to perform its mission.

2.5.2.1 Sole Source

A sole source is one in which there is only one source for that item. There are no other alternatives. What happens if that sole source goes bankrupt or goes out of business for any reason? What happens if this situation happens overnight, like the plant burns down? What are you going to do to keep your program from being stopped in its tracks?

2.5.2.2 Single Source

A single source is one in which there is only one "qualified" source. This condition is slightly better than the sole source situation as there are other companies capable of making your item, they just have not been "qualified" as a source. Qualification can be an expensive and time consuming process. If you find yourself in a sole or single source situation you may want to consider an investment strategy to get a second source qualified, now do you not only have a backup source, you have competition.

2.5.2.3 Foreign Source

A foreign source is one that is outside of the U.S. industrial base. Remember that Canada is by law a part of the U.S. industrial base. Foreign sources carry with them many problems. The transfer of some intellectual information to companies outside of the U.S. can be restricted by International Traffic in Arms Regulations (ITAR) making it difficult to do business outside of the U.S. In addition, some countries restrict the types of items that their companies can sell to the U.S., for example items that go into nuclear programs are often restricted by countries with strong nuclear concerns. Sometimes politics can play a role and an item that is available this week may not be available next week due to political pressures. If you have a foreign sources item that is critical to your program, you might want to consider funding a second source, a U.S. source.

2.5.3 Lead Times/Long Lead Items

Lead times for defense materials and components can be long and volatile. There are various reasons for this situation, such as:

- Imbalances between capacity and demand;
- Competition from commercial suppliers;
- Poor quality and lack of process improvement;
- Production bottlenecks;
- Long testing cycles;

- Raw materials not available;
- Long contracting process;
- Lack of funding;
- Transportation; and
- Labor issues.

Lead times are severely impacted by capacity limitations. As orders increase beyond existing capacity, the contractor has the option to increase capacity or to add new orders to backlog. For a contractor with a reasonably steady demand and no capacity expansion, increasing backlog increases lead time. When these lead time increases are communicated to customers, their response to the lead time is to issue orders immediately to ensure material availability. With constant capacity, these new orders must also be added to backlog, which must then be reflected in increased lead time. As this self-fueling process, often called the lead time capacity syndrome, continues, a relatively small increase in demand can result in extremely large increases in lead times.

Some commodities, like electronics, have long lead times. In the case of electronics, especially space qualified electronics it is the testing that makes the items have a long lead issue. Steady-state life testing is performed to demonstrate the quality and reliability of devices by subjecting them to specified operational conditions over an extended period of time. The standard steady-state life test is 1,000 hours for many items. Corrosion testing can take up to 240 hours, and burn-in testing could be as long as 700 hours. Many space qualified electronic devices have a lead time measured in months, often due to testing requirements and lack of competition.

Natural disasters, such as the earthquake and tsunami that hit Japan in 2011 displaced nearly half a million people and severely disrupted production operations in Japan for many industries. The impact to production was so severe that automobile production for Toyota, Honda and Nissan were all slowed down, even at U.S. plants due to the lack of parts.

The area of component and material lead time is extremely critical to meeting program schedules and defining long lead and advanced buy requirements. The program office should maintain continuing visibility of the current status of and the forecast changes in lead times.

2.5.4 Surge and Mobilization

A factor that is unique to defense plant and equipment requirements is the excess capacity that must be established and maintained in order to provide for surge or mobilization capability. For example, during the wars in Iraq and Afghanistan the need for Mine Resistant Ambush Protected (MRAP) vehicles was tremendous. Lives depended on the ability of the defense industry to rapidly expand its manufacturing operations in support of on-going missions.

The following factors should be considered to improve planning for surge/mobilization:

- Planning should be highly selective. Products that would be required and could be supplied should be identified.

- Critical parts and essential manufacturing machinery, rather than just end items must be effectively planned. Planning must be done for the long lead items, the parts for which there are only a few suppliers, or the particular machinery that is already in use on three shifts.
- Critical labor categories must be examined since this could be a large potential problem. Planning must include other demands on this labor, including military reserve requirements.
- More research and development work needs to be sponsored to find substitutes for the many critical materials on which we are presently foreign dependent. Advances in manufacturing technology could aid in alleviating this problem.
- Purchases should be funded of all items which would significantly affect mobilization capability but would not significantly reduce peacetime defense production. An example would be buying long lead time parts one or two years in advance.

Most of the defense industry prime contractors have some excess plant capacity to gear up in the event of mobilization or surge, but the lower tiers, the parts suppliers and subcontractors, often represent the bottlenecks in mobilization capability. In developing these plans it is important to remember that different primes may depend on the same subs for "surge." The industrial base assessment needs to look at the entire supply chain in order to identify all risks. Below are some of the risks associated with surge capabilities:

1. Surge production capacity may be available at the prime level at a reasonable cost subject to these conditions:

    a. A number of second and third tier suppliers could become choke points;

    b. Continued reliance on offshore capability for low cost labor processing, some unique products and coproduction could lead to major disruptions; and

    c. Critical materials, if not stockpiled and supplied as required, could become production stoppers.

2. The major output drivers are the basic availability of production capacity (production and test equipment, manpower, material, energy, etc.) at the prime and subtier level. Waivers and deviations can contribute to accelerated production and, in specific instances, perpetuate major bottlenecks if not granted.

3. Early funding may be a real need to build subcontractor capability and to support increased demand for subcontractor and prime working capital.

Mobilization involves preparing for war or other emergencies through assembling and organizing national resources; and the process by which the military services, or part of them, are brought to a state of readiness for war or other national emergency. This includes activating all or part of the Reserve components, as well as assembling and organizing personnel, supplies, and material.

2.5.5 Diminishing Manufacturing Sources and Material Shortages (DMSMS)

Diminishing Manufacturing Sources and Material Shortages (DMSMS), the loss of sources of items or material, surfaces when a source announces the actual or impending discontinuation of a product, or when procurements fail because of product unavailability. DMSMS may endanger the life-cycle support and viability of the weapon system or equipment.

Compared with the commercial electronics sector, the Department of Defense (DOD) is a minor consumer of electrical and electronic devices. While the electronic device industry abandons low-demand, older technology products, the DOD seeks to prolong the life of weapon systems. These conflicting trends cause DMSMS problems as repair parts and/or materials disappear before the end of the weapon system life cycle. Although electronics are most likely to be discontinued, obsolescence of non-electronic and commercial off-the-shelf (COTS) items also poses a significant problem to weapon systems. In short, DMSMS is a threat to system supportability.

Solving DMSMS is complex, data intensive, and expensive. There are two approaches to solving DMSMS in a system: reactive (you address DMSMS problems after they surface) and proactive (you identify and take steps to mitigate impending DMSMS problems). DOD policy prescribes the proactive approach.

An effective proactive DMSMS program does the following:

- Ensures that all parts and material to produce or repair the system or equipment are available;
- Reduces, or controls, total ownership cost (TOC);
- Minimizes total life-cycle systems management (TLCSM) cost;
- Eliminates, or at least minimizes, reactive DMSMS actions;
- Evaluates design alternatives;
- Provides for risk mitigation as it applies to DMSMS;
- Evaluates more than one approach to resolve DMSMS issues; and
- Collects metrics to monitor program effectiveness.

DMSMS discontinuance notices alert PMs that production is concluding for a specific part (i.e., the part is about to become unavailable). The notices usually contain part numbers, last order and shipment dates, minimum order quantities, and sometimes national stock numbers. To receive a problem notification, the program office must first know their parts and be working with the various organizations that can provide discontinuance notifications. Notifications of a DMSMS problem typically come from any or all of the following sources, depending on program phase:

- Government Industry Data Exchange Program (GIDEP);
- Defense Supply Center Columbus (DSCC);
- Government repair activities;
- Part manufacturers; and
- Original equipment manufacturers (OEMs).

Because of the numerous sources for notices, the potential exists for inaccurate, duplicate, or late arrival of notices to the cognizant program office. A notice may arrive at a program office as early as when a manufacturer begins to plan the discontinuance of a device or as late as years after a device has been discontinued.

2.5.5.1 Government Information Data Exchange Program

GIDEP has been designated as the central repository within the DOD for all discontinuance notices. GIDEP receives documented notices from parts manufacturers or GIDEP participants about parts or production lines that will be discontinued. After receipt of a notice, GIDEP prepares and distributes alerts through subscriber activities within the DOD and to member organizations in private industry. GIDEP alerts usually contain part numbers, last order and shipment dates, minimum order quantities, and national stock numbers. To become a GIDEP subscriber, program offices contact the GIDEP Operations Center in Corona, California. Their internet home page is http://www.gidep.org .

2.5.5.2 Defense Supply Center Columbus

DSCC is a procurement and supply activity for the Federal Government and is an inventory control point for material managed by the Defense Logistics Agency (DLA) in Ft. Belvoir, Virginia. DSCC provides discontinuance notices to program offices for electronic components and assists in identifying resolutions for DMSMS electronic devices. For life of type (LOT) buy purposes, DSCC assists calculating demand and reviewing alternatives. Program offices work with DSCC when programs are in the sustainment phase.

2.5.5.3 Government Repair Activities

Government repair activities may issue internal government alerts following "no bid" or "not available" responses to equipment or part procurement efforts during repair of systems during sustainment. In these cases, a technical referral is usually generated on a DLA Form 339, *Request for Engineering Support* and forwarded to an inventory control point (ICP), which may pass the information to an in-service engineering agent (ISEA) for further review and analysis. Contact with ICP and ISEA technical referral personnel may be necessary to obtain specific alert information from these organizations.

2.5.5.4 Part Manufacturers

Part manufacturers ***may*** notify the OEMs and the program offices via letter or phone if they are a known customer. They also notify GIDEP, DSCC, and commercial database subscription services that their parts are, or will soon be, discontinued. Many part manufacturers have web pages that provide details and suggestions for possible replacements on parts that they discontinue. Program offices access these sites periodically to obtain information about parts availability.

2.5.5.5 Original Equipment Manufacturers

OEMs send discontinuance notices when part manufacturers or government agencies are not direct purchasers of a part. For example, alerts may be originated by OEMs when a component manufacturing contract cannot be filled because a supplier has provided them a discontinuance notice on a part needed for a contracted component. Some OEMs also provide discontinuance notices on their web pages, which can be accessed periodically. To ensure receipt of OEM notifications, program offices usually insert appropriate requirements and clauses in system sustainment support and production contracts.

2.5.5.6 Risk Mitigation

The key to DMSMS risk mitigation is prevention, and a successful DMSMS program will involve several elements:

- Senior Management Support;
- Establishment of a DMSMS Management Team;
- Use of Predictive Tools;
- Accurate Bills of Materials (BOMs); and
- Financial Resources.

2.5.5.6.1 Senior Management Support

Management buy-in (commitment) is crucial to the DMSMS program. The interest of senior leaders ensures that the acquisition disciplines (engineering, logistics, management, contracting) will support the DMSMS program. One method for securing cooperation from managers of both the customer (program office) and the supplier is to conduct periodic DMSMS management reviews.

2.5.5.6.2 DMSMS Management Team (DMT)

DMSMS is collaborative and multidisciplined; therefore, a DMT is fundamentally important. The DMT composition could include any combination of disciplines-managers, engineers, technicians, logisticians, and other skill types-and organizations, including support contractors, original equipment manufacturers (OEMs), prime contractors, and other government organizations such as the Defense Logistics AgencyLand and Marine (DLA-L&M) or Defense MicroElectronics Activity (DMEA). The DMT needs a plan to guide the DMSMS program. The team will need adequate resources to ensure success.

2.5.5.6.3 Predictive Tools

Use of a predictive tool is integral to finding DMSMS in electronic components in the configuration. All predictive tools monitor the status of electronic components in the BOM and forecast their obsolescence. Each tool has different loading criteria and output and report formats. The DMT should carefully select the tool that is right for its program based on needs and cost.

2.5.5.6.4 Accurate BOM

A BOM is a list of the subordinate parts (electronic, electrical, mechanical) in an assembly (e.g., an SRU/SRA or a subsystem assembly). Without it, forecasting, impact analysis, component analysis, and other DMSMS-related activities are not possible. An indentured BOM depicts the top-down breakout relationship of parts to the next higher assembly components (from system to box to board). A flat-file BOM lists parts without indenturing relationships. An initial task of the DMT is to (1) obtain the BOMs (from the integrating OEM), (2) develop them from available data, or (3) negotiate for access to contractor-owned technical data packages (TDPs), technical manuals (illustrated parts breakdowns), and engineering change proposals (ECPs).

2.5.5.6.5 Financial Resources

Ideally, funding for DMSMS would be available early in the development of a program-when the design is most cost-effective to influence-to ensure that the DMSMS management program is properly resourced. The cost of implementing resolutions is generally not part of the DMT funding. It typically comes from research and development funds or operation and support funds. DMSMS corrective action projects must be prioritized with all other program needs. To be competitive, the case for spending money to fix DMSMS must be compelling.

2.5.6 Strategic and Critical Materials Stockpiling

The Strategic and Critical Materials Stock Piling Act (50 U.S.C. 98) requires that a stockpile of strategic and critical materials be acquired to decrease and preclude dependence upon foreign sources of supply in times of national emergency. Authority for management of the operational aspects of the National Defense Stockpile has been delegated to the Defense Logistics Agency, Defense National Stockpile Center (DNSC). Policy oversight remains with the Under Secretary of Defense (Acquisition, Technology & Logistics).

During World War II and the Korean conflict, the concept of a stockpile was to provide a secure source of industrial raw materials for suppliers to process, so fabricators and subcontractors could provide parts and components needed to manufacture weapon systems and to maintain basic essential industries. Although his concept is still important, the United States is moving away from a basic materials intensive society. Whereas the stockpile was an insurance foundation of fundamental raw materials upon which the industrial base could rely, today's need is increasingly focused on selective applications throughout the various tiers of manufacturing to make up for lost capacities in order to support surge of the weapon and equipment production lines which will exist at the time of national emergency.

Beginning with the early 1990s, the Department of Defense determined that over 99% of the inventory on-hand was excess to the Department's needs and Congress authorized its disposal. From then until the end of Fiscal Year 2009, DNSC had $6.493 billion in sales, over $4.360 billion of which was transferred to various military programs or the General Fund of the Treasury. Reductions in the number and quantity of stockpiled materials have led to a corresponding reduction in the DNSC infrastructure. DNSC has reduced the number of its operating depots, is closing out leased storage sites, and is reducing its workforce.

While DNSC has been drawing down its inventory, questions have arisen as to the need for a stockpile. As a result of concerns over the availability and access to various raw materials, Congress directed that DOD review its current stockpile disposal policy and determine whether the National Defense Stockpile is properly configured to assure future availability of materials for defense needs in light of current world market conditions. In January 2008, the USD(AT&L) established a working group to review the findings of the previous studies and the issues raised by Congress. The conclusions of the working group included that the current DOD policy for disposal of stockpiled materials needed to be revised to reflect today's global marketplace, and that the NDS should be reconfigured into the Strategic Material Security Program (SMSP) to encompass the full range of responsibilities required to develop an integrated, comprehensive approach to strategic materials management.

In conjunction with the formation of the working group, sales of certain commodities were suspended or curtailed. Each of the materials selected has no viable substitute, is a material with respect to which the U.S. is wholly or substantially import dependent or is a commodity that faces significant risk of supply disruption. Pending the outcome of the current policy review, sales of the following commodities were suspended to retain remaining quantities in the NDS inventory: Niobium/Columbium, Tantalum Carbide, Platinum, Iridium, Tin and Zinc. Sales of the following commodities were curtailed to hold a goal quantity (the equivalent of one year's Annual Materials Plan (AMP): Beryllium, Cobalt, Ferromanganese, Ferrochromium High and Low Carbon, Tungsten Metal Powder and Ores and Concentrates, and Germanium. Competitive sales offerings will continue for these materials until the goal quantity is reached. The suspension or curtailment of sales of these commodities is contingent upon meeting the previously mandated statutory financial requirements from the sales of these commodities.

Program management offices should perform a study early in the program to identify critical material problems due to uncertain availability or foreign dependency. Contractors should be encouraged to establish material management programs that cover availability, conservation, reclamation, substitution, and the minimal use of critical materials. Increased emphasis should be placed on efforts to improve existing manufacturing processes and introduce new manufacturing technologies that would make more efficient use of critical materials. Defense systems designs that economize on critical materials should be encouraged with incentive awards to contractors.

2.6 Industrial and Manufacturing Capability Assessments in the Acquisition Lifecycle

The analysis of industrial capability provides the basis for estimating the ability of the production base to meet specified production requirements as well as the facility's maximum capabilities to provide a certain item or items. They also suggest what types of actions could be taken to enhance a firm's ability to respond to demand for needed products. These actions are called Industrial Preparedness Measures (IPMs). These IPMs may include such actions as:

- Modernizing or expanding facilities
- Developing improved production techniques
- Awarding "pilot line" contracts
- Establishing or maintaining stand-by production lines

- Maintaining a warm production base
- Acquiring and maintaining plant equipment packages with all the necessary special tools, dies, fixtures and special test equipment
- Establishing and maintaining multiple production sources
- Conducting special studies
- Pre-stocking raw materials, semi-finished materials, components and assemblies
- Multiyear contracting
- Establishing programs to increase the retention of personnel with key technical skills
- Exercising guarantee authority of the FAR and Defense Production Act
- Recommending design changes or waivers
- Underwriting the establishment/ maintenance of U.S. production sources for critical defense material when no current U.S. source exists

According to DODI 5000.02 Acquisition Strategies must consider Industrial Base capabilities at Milestones B and C. In addition, the Analysis of Alternatives (AoA) conducted in the Material Solution Analysis phase must include an assessment of manufacturing feasibility which will require an assessment of the industrial base capabilities. In addition, 10 USC 2440 requires that "the Secretary of Defense shall prescribe regulations requiring consideration of the national technology and industrial base in the development and implementation of acquisition plans for each major defense acquisition program."

2.6.1 Material Solution Analysis Phase

During the Materiel Solution Analysis Phase, the industrial and manufacturing capability should have been assessed for each competing alternative in the AoA. The results of the assessment should be used to develop the Technology Development Strategy (TDS) by illustrating the differences between alternative approaches based on industrial and manufacturing resources needed.

The AoA should have identified new or high risk manufacturing capability or capacity risks if they exist. The TDS should highlight how these risks areas are going to be addressed and minimized in the Technology Development (TD) Phase, on the path to full manufacturing capability in the Production and Deployment Phase. Specifically, where new or high risk manufacturing capability is forecasted the TDS should specify how this new capability will be demonstrated in a manufacturing environment relevant for the TD Phase.

2.6.2 Technology Development Phase

The Technology Development Strategy (TDS) should identify and address how industrial capabilities, including manufacturing technologies and capabilities, will be considered and matured during the Technology Development (TD) Phase. Industrial capabilities encompass public and private capabilities to design, develop, manufacture, maintain, and manage DOD products.

A discussion of these considerations is needed to ensure the manufacturing capability will be assessed adequately, and reliable, cost-effective, and sufficient industrial capabilities will exist to support the program's overall cost, schedule, and performance goals for the total research and development program.

During the TD Phase the program office should conduct an industrial capabilities assessment. The resulting Industrial Base considerations will be summarized in the TDS in support of Milestone B. The industrial capabilities assessment will address implications of the TDS for (1) a competitive marketplace; (2) the viability of any associated essential industrial/technological capabilities; and (3) the potential viability of non-selected firms as enduring competitors for defense products. In addressing these factors, consider:

- Span of time between current and potential future contract awards that make selection critical to supplier business decisions;
- Other businesses of the same type or emerging capabilities that could serve as a replacement solution;
- Decisions that will impact a supplier's future viability (jeopardize future competitiveness or does not provide a sufficient business case to keep the capabilities/unit around for the future); and
- Decisions that will establish new industrial capabilities (new facilities, demonstrate and "productionize" new technologies, preserve health of the industrial base).

Technology Development Strategy (TDS) should summarize plans for how the industrial and manufacturing readiness will be addressed in the Technology Development (TD) Phase to ensure that manufacturing maturity is appropriate to enter Engineering and Manufacturing Development, particularly for new or high risk manufacturing endeavors.

During the TD Phase, the industrial and manufacturing capability should be assessed in light of each prototype and/or competing design under consideration. The purpose of this assessment is to baseline needed industrial capability and to identify remaining required investments. While it is not expected that contractors would have a complete factory and supply chain established this early in a program, key knowledge must be obtained on critical manufacturing processes, production scale-up efforts, and potential supply chain issues. TD Phase considerations should include:

- Manufacturing processes and techniques not currently available;
- Design producibility risks;
- Probability of meeting delivery dates;
- Potential impact of critical and long-lead time material;
- Production equipment availability;
- Production unit cost goal realism;
- Cost and production schedule estimates to support management reviews;
- Manufacturing feasibility and cost and schedule impact analyses to support trade-offs among alternatives;
- Recommendations for anticipated production testing and demonstration efforts; and
- Methods for conserving critical and strategic materials and mitigating supply disruption risks and program impacts associated with those materials.

2.6.3 Engineering and Manufacturing Development Phase

For Major Defense Acquisition Programs and major systems with production components, the Acquisition Strategy should highlight the strategy for assessing industrial and manufacturing readiness. During the Engineering and Manufacturing Development (EMD) and Production and Deployment (P&D)/Low-Rate Initial Production (LRIP) Phases, the industrial and manufacturing readiness should be assessed to identify remaining risks prior to a full-rate production go-ahead decision.

The EMD Acquisition Strategy should define how the program management office will assess that the industrial capabilities are capable to support program requirements through the P&D and Operations and Support (O&S) phases. The P&D Acquisition Strategy for approval at Milestone C should update the assessment process, including relevant findings thus far, and highlight any risks that may have been identified.

The EMD Acquisition Strategy should also highlight the strategy for assessing the manufacturing processes to ensure they have been effectively demonstrated in an appropriate environment, such as a pilot line environment, prior to Milestone C. The manufacturing environment should incorporate key elements (equipment, personnel skill levels, materials, components, work instructions, tooling, etc.) required to produce production configuration items, subsystems or systems that meet design requirements in low rate production. To the maximum extent practical, the environment should utilize rate production processes using production processes forecasted to be used in LRIP. The Acquisition Strategy should strategically describe the EMD phase planning to assess and demonstrate that the manufacturing processes/capabilities, required for production will have been matured to a level of high confidence for building production configuration products in the P&D phase.

2.6.4 Production and Deployment Phase

For Milestone C, key manufacturing readiness considerations include:

- Industrial base viability,
- Design stability,
- Process maturity,
- Supply chain management,
- Quality management,
- Facilities, and
- Manufacturing skills availability.

Sources of data to inform industrial and manufacturing readiness could include: technical reviews and audits, Program Status Reviews, pre-award surveys, Production Readiness Reviews, Industrial Capabilities Assessments, trade-off studies, tooling plans, make-or-buy plans, manufacturing plans, and bills of material. An important output includes actions to reduce or address any remaining risks.

The Milestone C review should provide the status of assessments of manufacturing processes and highlight the steps needed to progress from an EMD manufacturing environment to an LRIP environment.

For the Full Rate Production Decision Review Acquisition Strategy update, the Program should identify remaining risks prior to a production go-ahead decision. Key considerations should include industrial base viability, design stability, process maturity, supply chain management, quality management, and facilities and manufacturing skills availability. Sources of data could include technical reviews and audits, Program Status Reviews, pre-award surveys, Production Readiness Reviews, Industrial Capabilities Assessments, trade-off studies, tooling plans, make-or-buy plans, manufacturing plans, and bills of material. Important outputs include actions to reduce or handle remaining risks.

2.6.5 Operations and Support Phase

In many cases, commercial demand now sustains the national and international industrial base. The following considerations will improve public and private capabilities to respond to DOD needs:

- Defense acquisition programs should minimize the need for new defense-unique industrial capabilities.
- Foreign sources and international cooperative development should be used where advantageous and within limitations of the law (DFARS Part 225).
- The Acquisition Strategy should promote sufficient program stability to encourage industry to invest, plan, and bear their share of the risk. However, the strategy should not compel the contractor to use independent research and development contracts, except in unusual situations where there is a reasonable expectation of a potential commercial application.
- Prior to completing or terminating production, the DOD Components should ensure an adequate industrial capability and capacity to meet post-production operational needs.
- Where feasible, Acquisition Strategies should consider industrial surge requirements and capability for operationally-expendable items such as munitions, spares, and troop support items. These are likely surge candidates and should receive close attention and specific planning, to include use of contract options. The program office should identify production bottlenecks at both the prime and sub-tier supplier levels for high use/high volume programs in an asymmetric warfare construct. Surge capability can be included in evaluation criteria for contract award.
- When there is an indication that industrial capabilities needed by DOD are endangered, an additional analysis is required as the basis for determining what if any DOD action is required to preserve an industrial capability (see DODD 5000.60 and DOD 5000.60-H). Considerations for the analysis include:
    - DOD investments needed to create or enhance certain industrial capabilities;
    - The risk of industry being unable to provide program design or manufacturing capabilities at planned cost and schedule;
    - If the analysis indicates an issue beyond the scope of the program, the PM should notify the MDA and PEO;

- When the analysis indicates that industrial capabilities needed by the DOD are in danger of being lost, the DOD Components should determine whether government action is required to preserve the industrial capability; and
- The analysis should also address product technology obsolescence, replacement of limited-life items, regeneration options for unique manufacturing processes, and conversion to performance specifications at the subsystems, component, and spares levels.

2.6.6 Industrial Capability and the Acquisition Strategy

The development of the Acquisition Strategy should include results of industrial base capability (public and private) analysis to design, develop, produce, support, and, if appropriate, restart an acquisition program. This includes assessing manufacturing readiness and effective integration of industrial capability considerations into the acquisition process and acquisition programs. For applicable products, the Acquisition Strategy should also address the approach to making production rate and quantity changes in response to contingency needs. Consider these items in developing the strategy:

- Technology and Industrial Base, including small business,
- Design,
- Cost and Funding,
- Materials,
- Process Capability and Control,
- Quality Management,
- Manufacturing Personnel,
- Facilities, and
- Manufacturing Management.

2.7 Industrial Analysis Center (IAC)

The mission of the Industrial Analysis Center is to continually analyze risks and identify risk mitigation measures needed to sustain a reliable, technologically superior, affordable and resilient defense industrial base. The IAC provides mission critical information and analysis to senior decision makers in OSD, the Joint Staff, Combatant Commanders, military services, defense agencies and other government organizations. The IAC accomplishes its mission by accomplishing the following:

- Providing mission critical information and analyses on essential and unique industrial capabilities;
- Providing assessments of industrial capability risks for an industry sector, sub-sector, commodity or specific industrial site to meet current and future weapon systems acquisition requirements; and
- Executes responsibilities for the Defense Industrial Base (DIB) Sector within the Defense Critical Infrastructure Program (DCIP) as the DCMA Lead Agent.

The IAC conducts Industrial Base Assessments using a standardized questionnaire which they send out to companies of interest and they complete the survey. After the survey has been completed a small team visits the company to follow-up on the questions and to get a tour of the facilities. The questionnaire addresses some of the following IB considerations:

- Suppliers name, location, etc.
- Company Ownership (public or private)
- Facility Size and other facility information
- Sales and sales backlog
- Distribution or Sales Mix (% government vs commercial)
- DOD Programs Supported
- Significance of Current Program to overall sales
- Maturity of product technology
- Production Status
- Industry Status (consolidations, rising or falling market, etc.)
- Unique or Critical Manufacturing Processes
- Technology Issues (Obsolescence, etc.)
- Vendor or Supply Chain issues
- Industrial Base Risks
- Production Rate

The IAC accomplishes sector assessments in the following areas:

- Aircraft
- Ammunition
- Electronics
- Information Technology
- Land Vehicles
- Missiles
- Shipbuilding
- Space
- Troop Support
- Weapons

In addition, the IAC performs the following:

- Sector analysis by performing an integrated and comprehensive analysis of the industrial and technological capabilities, capacities and financial viability of that sector;
- Systems analysis by providing technology readiness, financial and economic assessments on emerging technologies and associated industrial base capabilities;
- Industry surge analysis by providing industrial base analysis of products or sectors to assess prime and sub-tier contractor on their production capabilities, production rates, lead times, critical contractors, limiting factors, production readiness and DMSMS program; and
- Homeland Defense analysis by providing Defense Critical Infrastructure Program (DCIP) analysis of critical assets.

The IAC has a leadership role in the Joint Industrial Base Working Group (JIBWG). The mission of the JIBWG is to develop and implement techniques to exchange information and collaborate on tasks relative to issues associated with the defense industrial base. The IAC provides functional support to:

- Defense Critical Infrastructure Program,
- Industrial Surge Analysis,
- Technology Assessments, and
- Industrial Assessments.

The information and analysis conducted by the IAC is used to provide decision support for:

- Acquisition Decisions
- Congressional Inquiries
- Technology Readiness Reviews
- Deliberate Planning
- Contingency Planning
- Comport Support Operations
- Mission Assurance
- Operational Readiness
- Consequence Management

2.8 Industrial Base Planning

Industrial base planning helps to ensure that a viable industrial base exists that can respond to wartime demands. Post-War industrial preparedness planning began in 1947 when cold-war tensions increased. It was part of an effort involving many government agencies that sought to prepare the United States for a defense emergency. The government did not pay industrial firms directly for such planning, and they participated on a voluntary basis. These practices generally persist today. Early planning emphasized the conversion of civilian industry to defense production, resembling what occurred at the beginning of World War II. Planners also sought to determine production capacity and allocate it among the competing demands of the armed services.

After the Korean War started, the President created the Office of Defense Mobilization at the cabinet level to coordinate the mobilization activities of the executive branch. That elevation gave emergency planning high visibility and influence, but the effect was not lasting. Government attention to planning probably reached its low point when President Nixon abolished the Office of Emergency Preparedness in 1972 and distributed its functions to other government agencies. Congress created the Federal Emergency Management Agency in 1978 as an attempt to recentralize and increase the effectiveness of the dispersed functions. Today, acquisition managers accomplish Industrial Preparedness Production Planning under DFAR requirements.

2.8.1 DFAR Subpart 208.72: Industrial Preparedness Production Planning

2.8.1.1 Definitions

"Industrial base" means that part of the total privately-owned and Government-owned industrial production and maintenance capacity of the United States and Canada, which will be available during national emergencies to manufacture and repair items required by the departments.

"Industrial preparedness production planning" means planning designed to maintain an adequate industrial base to support DOD requirements for selected essential military items in a national emergency.

"National emergency" means a condition declared by the President or the Congress which authorizes certain emergency actions in the national interest, including partial or total mobilization of national resources.

"Planned item" means any item selected for industrial preparedness planning under the criteria of DODI 4005.3, Industrial Preparedness Planning.

"Planned producer" means an industrial firm which has agreed by either non-binding memorandum of understanding or binding contract/contract clause to provide production capacity data, to maintain existing capacity for a negotiated period of time, and to accept contracts for planned items upon the request of the Government.

2.8.1.2 Industrial Preparedness Production Planning (IPPP) Program

Under the Industrial Preparedness Production Planning (IPPP) program, DOD components and the industry work together to ensure essential military items are available during an emergency. Departments and agencies select weapon systems and items for planning in accordance with DODI 4005.3, Industrial Preparedness Planning. Planning is conducted only with U.S. or Canadian sources. The use of privately-owned facilities is preferred to minimize the need for Government investment. Departments and agencies will include Government-owned production facilities in the industrial base only when private industry is unable to provide the facilities necessary to support DOD requirements; or the facilities are necessary for reasons of national security; or to ensure a quick response capability to meet fluctuating demands.

The authority under current contracting procedures to accomplish industrial planning actions includes:

- Leasing of Government-owned property to planned emergency producers under the authority of the Military Leasing Act of 1947, 10 U.S.C. 2667;
- Acquisitions in the interest of national defense under FAR 6.202(a)(2), or in case of a national emergency or to achieve industrial mobilization under FAR 6.302-3;
- Acquisition of items restricted under 225.7005 and Subpart 225.71;
- Use of multiyear contracting (FAR Subpart 17.1);
- Providing Government production and research property to contractors; and

- Use of direct payment for idle facilities or idle capacities reserved for defense mobilization production.

2.8.1.3 Industrial Preparedness Production Planning Procedures

The contracting officer may contract for industrial planning efforts for selected essential military items. These efforts may include, but are not limited to, the maintenance of Government-owned industrial facilities (real and personal property) or production data packages. These planning efforts may be acquired through an individual service contract or as a line item on a contract for a planned item.

2.9 Industrial Base Investments

There are many industrial base investment programs such as the DOD ManTech Program. Chapter 8 of this guide will discuss ManTech and other investment strategies and programs in detail. This section will address Title III to the Defense Production Act.

2.9.1 Defense Production Act - Title III

The Defense Production Act (DPA) of 1950 was created at the outset of the Korean War to ensure the availability of the nation's industrial resources to meet the national defense needs of the United States by granting the President powers to ensure the supply and timely delivery of products, materials, and services to military and civilian agencies.

2.9.1.1 Expansion of Productive Capacity and Supply

The DPA Title III program is designed to develop, maintain, modernize, and expand the productive capacities of domestic sources for critical components, critical technology items, and industrial resources essential for the execution of the national security strategy of the United States. Title III authorizes the Federal Government to provide incentives to modernize and expand our productive capabilities.

The Air Force is the Executive Agent and has established a DPA Title III program office with overall responsibility for all DPA Title III functions, under broad guidance from OSD. This program office is the advocate and action point for all Department of Defense-requested DPA Title III projects.

The direct and indirect benefits to defense programs resulting from Title III initiatives are substantial. By stimulating private investment in key production resources, Title III helps to:

- Increase the supply, improve the quality, and reduce the cost of advanced materials and technologies needed for national defense;
- Reduce U.S. dependency on foreign sources of supply for critical materials and technologies; and
- Strengthen the economic and technological competitiveness of the U.S. defense industrial base.

Title III activities serve to lower defense acquisition and life-cycle costs and to increase defense system readiness and performance through the use of higher quality, lower cost, technologically superior materials and technologies. In FY2008 Congress funded DPA title III purchases for $94.2 million for. This funding was used for numerous projects to include:

- Beryllium Production,
- Lithium Ion Battery Production,
- Space Grade Traveling Wave Tubes,
- Radiation Hardened Microelectronics, and
- Others.

2.9.1.2 Title III Success Stories

Radiation Hardened (RadHard) Microelectronics: The challenge is that electrical circuitry in space is highly susceptible to degradation from natural and nuclear weapon-induced radiation. In addition, most RadHard devices are produced overseas, limiting competition, forcing us to accept a foreign dependency and the need to face technology export restrictions. The two remaining U.S. suppliers needed to improve their productive capabilities and efficiencies by at least two generations of technology and establish more efficient production capabilities in order to meet future DOD needs. Through Title III investments the two U.S. sources invested well over $200M in state-of-the-are microelectronics production tools and facilities that met the needs of both the companies and the DOD. The Title III program was successful in establishing two production capabilities, giving our contractors U.S. sources and competition.

Thermal Batteries: Thermal batteries are used today in many of our modern weapon systems because of their long shelf life (can be stored up to 20 years) and high-power output (relative to battery weight). The most common thermal battery configuration is for lithium based systems. For a long time Eagle Picher in Joplin, Missouri was the only viable domestic producer of thermal batteries. However, several industrial base concerns caused DOD managers to consider Title III investments to develop additional domestic production facilities. These concerns included a fire at the Joplin, MO plant and Eagle Picher's filing for bankruptcy in 2005. As a result of Title III investments, there are now additional producers of thermal batteries giving the DOD increased production capability and competition.

2.10 Defense Priorities System and Defense Materials System

The purpose of DPAS is to:

- Assure the timely availability of industrial resources to meet current national defense and emergency preparedness program requirements; and
- Provide an operating system to support rapid industrial response in a national emergency. In pursuing these goals we attempt to minimize disruptions to normal commercial activities.

2.10.1 Defense Priorities System Rated Orders

The Defense Priorities and Allocations System (DPAS) Program is a means to assure timely availability of industrial resources to meet national defense requirements and a way to provide a framework for rapidly expanding industrial resources in a national emergency, specifically as needed to support DOD Weapon Systems. It guarantees on-time delivery of items and services, contains a mechanism for resolving DPAS disputes between the DOD and industry, and provides a process for optimizing delivery of urgently needed material during wartime or contingency operations.

The Defense Materials System (DMS) and the Defense Priorities System (DPS) were designed to help ensure that national programs are maintained on schedule by providing priority treatment for the purchase of products and materials by government agencies, contractors, subcontractors and their suppliers. This is accomplished by directing the flow of materials and products to the nation's military, atomic energy, space, and domestic energy production or construction programs.

The DMS and the DPS provide the means for exercising the priority and allocation authorities of the President for the purpose of promoting the national defense. They also provide a system which can be promptly expanded to direct the industrial economy of the country to meet the exigencies of war, or other programs designated by law and a Presidential finding as being essential to national security and to maximize domestic energy supplies.

2.10.1.1 Defense Production Act and Associated Executive Orders

Under Title 1 of the Defense Production Act of 1950 the President is authorized to establish priorities in the performance of contracts or orders for the purpose of assuring contract performance. He is also authorized to allocate materials and facilities for the purpose of promoting the national defense. The term "national defense" is defined in the Defense Production Act as "Programs for military and atomic energy production or construction, military assistance to any foreign nation, stockpiling, space, and directly related activity."

Executive Order 11912 delegates to the administrator of General Services authority to use the priorities and allocations authority of the DPA to maximize domestic energy supplies.

Executive Order 12148 delegates to the Federal Emergency Management Agency, General Services Administration (FEMA/GSA) overall authority for the supervision and coordination of the emergency planning activities of the Federal Departments and Agencies. It also makes FEMA responsible for assessments of the nation's industrial capability to support military and essential civilian emergency requirements.

Implementation of functions under Title 1 of the DPA has been assigned by the Secretary of Commerce to the Domestic and International Business Administration (DIBA). The administration of these powers with respect to industrial production and allocations of designated materials is accomplished through a series of regulations and orders called the Defense Priorities System and the Defense Materials System.

The rules for rated orders under DPS relating to the status, placement, acceptance, and treatment of priority rated contracts and orders are contained in Defense Priorities System Reg. 1. There are two types of priority ratings: DO ratings and DX ratings. A complete priority rating consists of either one or the other of these ratings symbols and the appropriate program identification symbol (e.g., DO-A 1 or DX-A3).

All DO ratings have equal preferential status and take priority over all unrated orders. The program identification symbol which is part of the rating does not affect the preferential status of the rating, that is, the rating DO-A 1 has the same preferential status as the rating DO-E2. All DX rated orders have equal preferential status and take priority over all DO rated orders and unrated orders.

Between rated orders of equal preferential status, priority is given to the order which was received on the earlier date. If there is a conflict between orders of equal preferential status received on the same date, preference must be given to the order which has the earliest required delivery date.

2.10.1.2 Assignment of Priorities to Rated Contracts

The DMS and the DPS require that any contractor or supplier who receives a DO or OX rated contract or order must use the assigned priority rating in obtaining products, materials, or services needed to complete production, construction and research and development projects for such programs. Properly identified rated orders are called "mandatory acceptance orders" because they must be accepted and given preferential delivery over nonrated orders.

Priorities are assigned to prime contracts by Claimant Agencies. The Department of Defense initiates the use of ratings by assigning them to prime contracts or purchase orders for defense related items. The prime contractors to whom the priority ratings are assigned must place these rating symbols on the subcontracts and purchase orders which they place to complete their rated contracts. Subcontractors and suppliers who accept priority rated orders from their customers must use the ratings they receive to obtain products, components, and materials to fill such rated orders.

2.10.2 Assignment of Priorities

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2.10.3 Request for Special Assistance

The DPAS is designed to be largely self-executing. However, from time-to-time production or delivery problems will arise. In this event, special priorities assistance is available from Commerce and from the Delegate Agencies.

Special priorities assistance is available for any reason consistent with this regulation. Generally, special priorities assistance is provided to expedite deliveries, resolve delivery conflicts, place rated orders, locate suppliers, or to verify information supplied by customers and vendors. Special priorities assistance may also be used to request rating authority for items not automatically ratable.

When a contractor finds that the delivery promised by a supplier will not support the contract delivery schedule, or if he is unable to obtain acceptance of orders for products or materials required to perform the contract, he shall request assistance from the appropriate Claimant Agency, generally through the procuring organization, often through the program office.

Request for assistance must establish that:

- There is an urgent need for the products, materials or services covered by the mandatory acceptance order;
- The contractor has exercised reasonable effort to resolve the problem through employment of his own resources;
- The request for assistance is timely; and
- The request is not seeking to: (a) Force the solution of purely technical problems, (b) Press for price advantage, (c) Force the resolution of contractual problems, (d) Force unnecessary acceleration of delivery dates, (e) Secure performance beyond the reasonable capability of the supplier, and/or (f) Force acceptance of superior terms and conditions of sale.

Each level of the contractual chain is expected to employ its full resources in attempting to resolve the problem before passing the assistance request to the next higher level. If the Claimant Agency to whom the request may be sent is unable to overcome the difficulty, the request is forwarded to the Office 01 Industrial Mobilization (OIM) in the Department of Commerce for appropriate action.

OIM officials will attempt to expedite the deliveries, correct any bottleneck, or have the order accepted, by negotiating directly with the supplier or perhaps by locating other sources of supply. OIM provides special assistance in such cases using either formal or informal administrative methods.

A directive Issued by OIM takes precedence over all mandatory acceptance orders depending on the terms of the directive. For this reason it is a particularly useful formal tool in eliminating bottlenecks and expediting orders. A contractor must accept and comply with each directive issued. Directives usually require a contractor to take some specific action as defined in the directive itself. Directives take precedence over all rated orders both (DO and OX) as well as over unrated orders. Directives, unlike priority ratings, are not extendible to the lower tiers in the production chain.

2.11 Summary

Industrial base assessments are required by law. These assessments make sense and can be used to understand and manage supply chains and risks associated with industrial capabilities.

2.12 Related Links and Resources

Numerous reference documents impact the manufacturing management function throughout the acquisition process. These documents originate from many sources and range across academic disciplines, functional activities, and job specialties.

The following is a reference list of DOD Directives (D), Instructions (I) Manuals (M), Pamphlets (P) Military Standards (MS), and other documents. The documents listed contain DOD policy guidance applicable to the manufacturing management function. They are listed as sources of DOD manufacturing management information.

Note: Many of the documents listed are no longer required (due to acquisition reform), but still contain some very valuable information.

Number	Title
DoD 5000.60-H	*A DoD Handbook: Assessing Defense Industrial Capabilities*
DODI 5000.60	*Defense Industrial Capabilities Assessments*
DoD Directive 4400.1-M	*Defense Priorities and Allocations Manual*
US Code Title 10: Chapter 148	*National Defense Technology and Industrial Base, Defense Reinvestment, and Defense Conversion*
SD-22	*DMSMS: A Guidebook of Best Practices*

3.1 Objective

Chapter 3 establishes a Life Cycle Acquisition Framework (Figure 3-1) model of the process by which products are developed and produced. Program managers (PMs) along with their integrated product teams (IPTs) use the systems engineering (SE) process to turn requirements into hardware and software solutions for the warfighter. The overarching outcome of early and continuous technical planning is the design, development, and fielding of systems that meet the contractual and performance requirements of the warfighter at an affordable cost. The SE process serves as a basis for integrating manufacturing management into systems engineering activities.

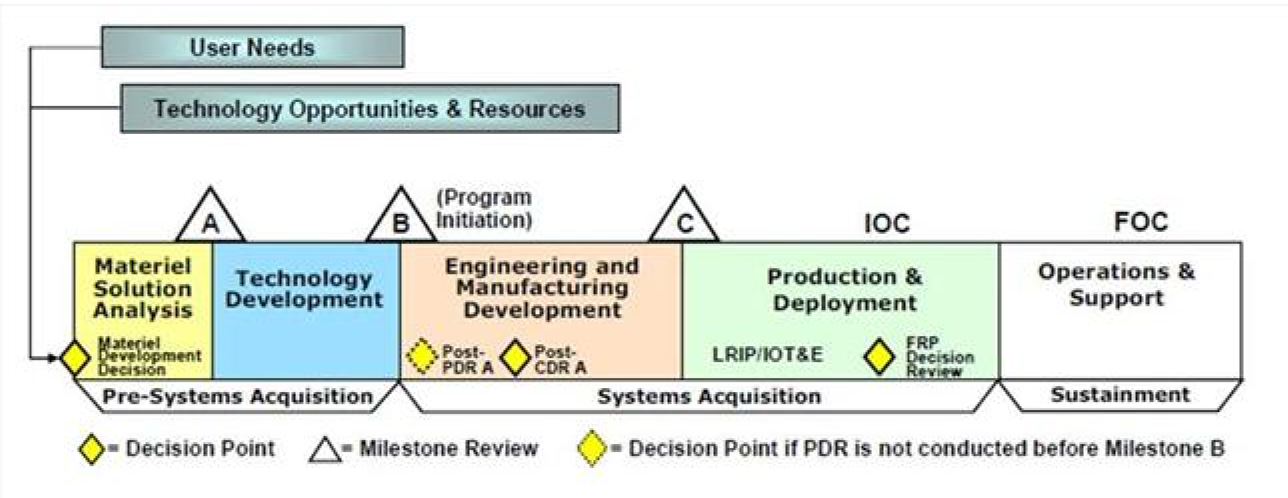

Figure 3-1 Life Cycle Framework View

A program manager should be able to:

- Define the development process for acquisition programs;
- Identify the roles and activities of manufacturing during the various phases of an acquisition program;
- Identify the various inputs and output documents that should contain the appropriate manufacturing considerations for that phase of the program; and
- Identify the opportunities and investments requirement in order to mitigate acquisition risk early.

3.2 Background

In any new product development program there are three critical points that require the capture of specific knowledge to achieve successful outcomes.

- **Knowledge Point 1** : is achieved when the customer's requirements are clearly defined and resources exist to satisfy them. Commercial companies insist that technology be mature at the outset of a product development program and, therefore, separate technology development from product development.
- **Knowledge Point 2** : is achieved when the product's design is determined to be capable of meeting product requirements-the design is stable and ready to begin initial manufacturing of prototypes.
- **Knowledge Point 3** : is achieved when a reliable product can be produced repeatedly within established cost, schedule, and quality targets.

DODI 5000.02 emphasizes the need for knowledge in this paragraph, "Following the Materiel Development Decision, the MDA may authorize entry into the acquisition management system at any point consistent with phase-specific entrance criteria and statutory requirements. Progress through the acquisition management system depends on obtaining ***sufficient knowledge*** to continue to the next phase of development."

In a recent GAO review, the GAO noted that successful DOD programs, like the AIM-9X and the FA-18-E/F programs, had achieved similar knowledge as the commercial companies, resulting in good cost and schedule outcomes. However, DOD programs, which had unstable designs and immature manufacturing processes, experienced poor cost and schedule outcomes.

Source : GAO Study: GAO-020701: "Capturing Design and Manufacturing Knowledge Early Improves Acquisition Outcomes"

3.3 Introduction

3.3.1 The Systems Engineering Process

The PM has the critical role of establishing and implementing a systems engineering approach that includes all stakeholders and leads all participants to translate operational needs and capabilities into technically feasible, affordable, and operationally effective and suitable increments of a system. The systems engineering approach should be exercised over all the phases of acquisition from the Material Solution Analysis phase through to the Operations and Support phase and when executed properly should give you the sufficient knowledge to proceed into the next phase of acquisition.

Program managers exercise leadership, decision-making, and oversight throughout the system life cycle. Implementing a systems engineering approach adds discipline to the process and provides the program manager with the information necessary to make valid trade-off decisions to balance cost, schedule, and performance throughout a program's life cycle.

The Systems Engineering Process provides an integrated technical framework for systems engineering activities throughout the acquisition phases of a system's life cycle, highlighting the particular systems engineering inputs, activities, products, technical reviews, and outputs of each acquisition phase. These activities are typically implemented using a multidisciplinary team of subject matter experts (SMEs) that are often charted as an Integrated Product Team (IPT) (Figure

3-2). The formation of the IPT is a critical task for the program manager. Also, according to a 25 Aug 2010 AT&L Memo, the program lead for Production, Quality and Manufacturing is a "Key Leadership Position (KLP)" for all Major Defense Acquisition Program (MDAP) and Major Automated Information System (MAIS).

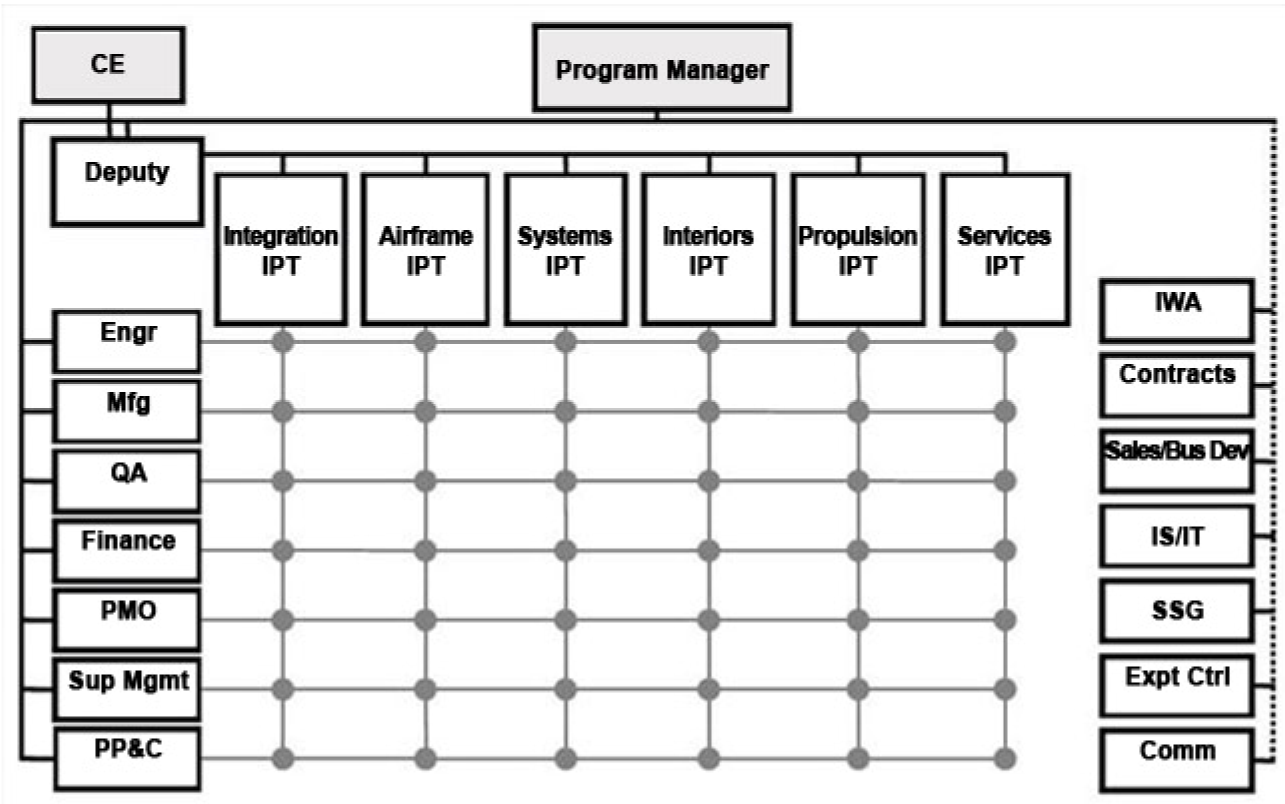

Figure 3-2 Notional Integrated Product Team Structure

The "new model for DOD Systems Engineering" introduces 8 Technical Management Processes and 8 Technical Processes. A model of the interrelationships among those 16 processes is depicted in Figure 3-3. This depiction provides a contemporary-and more comprehensive-model of the systems engineering process.

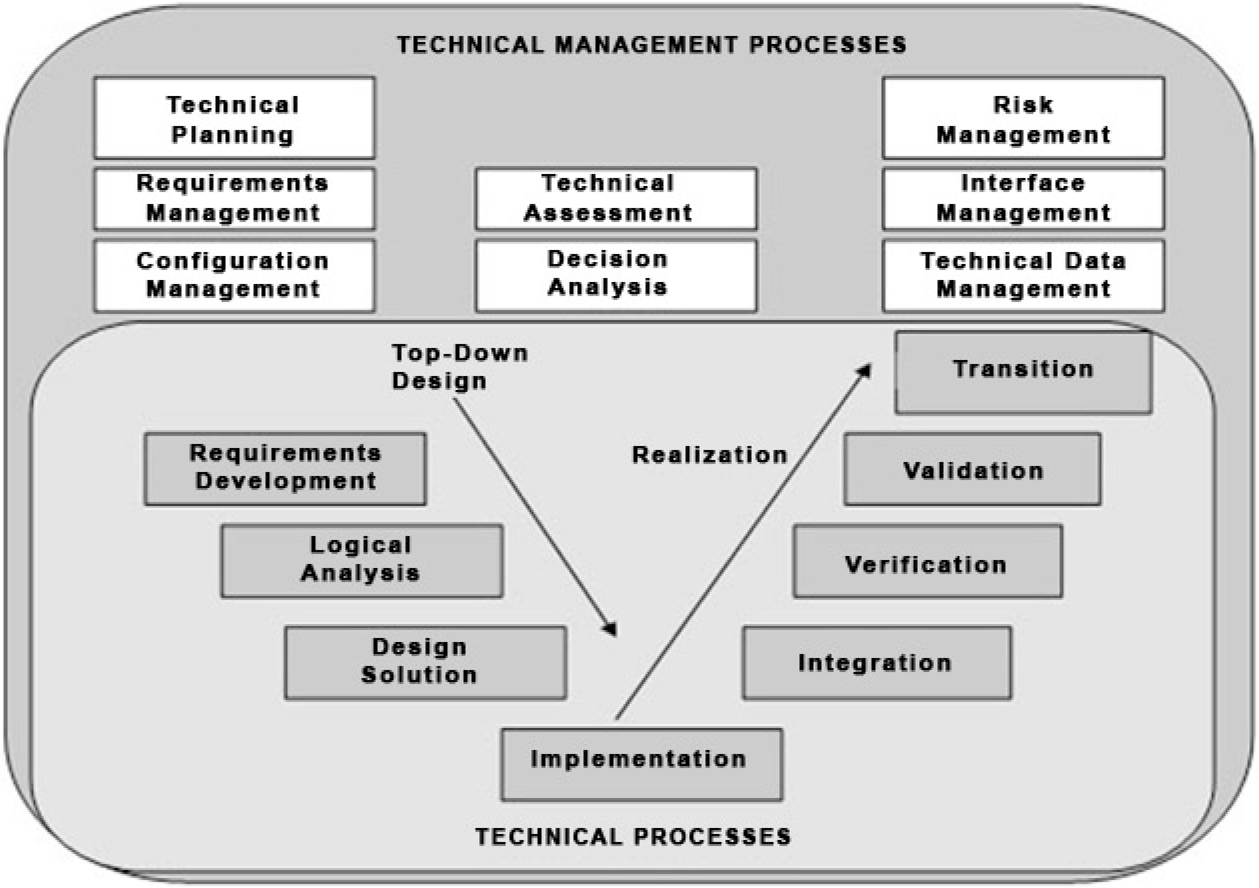

Figure 3-3 Systems Engineering Process Model (New)

The Technical Management Processes form the executive-or control logic-that steers system development to meet project or phase objectives..

The Technical Processes are depicted in a V-shaped pattern often referred to as a "Vee Diagram." This pattern portrays the ***top-down design*** that occurs as requirements are progressively allocated from the system level down to lower-level elements. The ***bottom-up realization*** (build/test) progresses from the lowest level components to higher assemblies to achieve the complete system. The Technical Processes are applied iteratively across the life cycle and at different levels in the system hierarchy to elaborate and mature the system.

The Defense Acquisition Guide (DAG) Chapter 4.3, *Systems Engineering in the System Life Cycle* , depicts each of these technical processes and contains descriptions of key systems engineering activities during each phase. Each of these SE technical processes is comprised of:

- Inputs,
- Top-Down Design Process,
- Bottom-Up Realization Process, and
- Outputs.

Outputs are documents that require development at the end of each phase and may become input documents for the next phase. Manufacturing/QA managers should be actively engaged in each of these technical processes. For example, during the top-down design activities, producibility engineering should be a major consideration, especially in the Technology Development and Engineering and Manufacturing Development phases. Implementation is the beginning of the bottom-up realization process and includes the fabrication and assembly of components and subsystems to be used for testing and validation. Implementation (fabrication and assembly) is clearly a task which requires manufacturing/QA planning and execution.

3.3.2 The Systems Engineering Plan (SEP)

Program managers shall prepare a Systems Engineering Plan (SEP) for each milestone review, beginning with Milestone A. The SEP is a detailed formulation of actions that should guide all technical aspects of an acquisition program. Program managers should establish the SEP early in program formulation and update it at each subsequent milestone. It is intended to be a living document, tailored to the program, and a roadmap that defines comprehensive SE activities, addressing both government and contractor technical activities and responsibilities.

Programs develop and update a SEP for Milestone Decision Authority (MDA) approval in conjunction with each milestone review and integrated with the program acquisition strategy. Technical reviews form the backbone of an effective Systems Engineering Plan (SEP). The SEP is established early in the program definition stages and updated periodically as the program matures.

The SEP describes the program's overall technical approach, including processes, resources, and metrics, and applicable performance incentives. It describes the systems engineering processes to be applied, the approach to be used to manage the system technical baseline, and how systems engineering will be integrated across the Integrated Product Team (IPT) structure. Additionally, the SEP describes the timing, conduct, entrance criteria, and success/exit criteria of technical reviews.

A well-managed, periodically updated Systems Engineering Plan, that documents a sound technical planning approach, should lead to successful Developmental (DT) and Operational Testing (OT) where the system meets all of the required technical and programmatic specifications. The successful implementation of proven SE processes results in a system solution that is:

- Robust to technical, production, and operating environments;
- Adaptive to the needs of the user; and
- Balanced among multiple requirements, design considerations, and budget constraints.

3.4 Manufacturing Management for Major DOD Acquisition Programs

The acquisition framework describes the business and technical activities that need to take place over the life cycle of an acquisition program. These activities and considerations must be tempered with the realities of the acquisition program (cost, schedule and performance) and the end objectives of that program.

Manufacturing management is a subset of program management planning. Consequently, the plan for accomplishment of the manufacturing activities should be embedded in the program management planning documents and the systems engineering process. The manufacturing management approach should be defined relatively early for all phases of acquisition. This early definition is necessary since activities appropriate for later phases often need to appear as planning guidance in the program documentation or contracts developed in earlier phases. In addition, funding for these activities must be captured and allocated in a timely manner in order to reduce risk and mature the program. It is therefore suggested that the entire framework be reviewed when developing plans or contractual requirements for a specific phase. This will allow the manufacturing manager to consider the potential impact of future activities and establish a base line for the types of activities which should have been accomplished in earlier phases.

Manufacturing management focuses on the responsibilities of the personnel involved within the program management office for achieving a capability to successfully enter and complete the production phase. This requires a design that is producible and a factory floor that is capable and has the capacity for the planned rates of production. The maturing of these capabilities begins early and requires an analysis of the following areas:

- Emerging Technologies,
- The Industrial Base,
- Design/Producibility,
- Cost Drivers and Cost Estimating,
- Funding for Maturing the Manufacturing Processes,
- Materials Availability and Environmental Impacts,
- Supply Chain Management,
- Process Capability and Control,
- Quality Management/Supplier Quality Management,
- Manufacturing Management and Workforce,
- Facilities Availability, and
- Special Tooling and Test Equipment.

3.5 Material Solution Analysis (MSA) Phase

3.5.1 Manufacturing Task: Evaluate Manufacturing Feasibility

One of the major accomplishments of the Material Solution Analysis (MSA) Phase is to evaluate manufacturing feasibility or to answer the question "can you build it?" The MSA Phase presents the first real opportunity to influence systems design and begin planning for production by balancing technology opportunities and current practices against cost, schedule and performance. User capabilities need to be expressed in terms of key performance parameters (KPPs) and other quantifiable parameters to include:

- System performance requirements to meet mission requirements; and

- The full range of sustainment requirements (materiel availability, production capability, reliability, maintainability, logistics footprint, supportability criteria, etc.) needed to meet system sustainability and affordably over the life cycle.

The MSA Phase is a trade study to identify materiel solutions to address gaps in capability based on an Analysis of Alternatives (AoA). The AoA is done independently from the program management office and forms the basis for selecting the recommended approaches for material solutions. At the close of the AoA, the program office takes ownership of the approach and conducts additional engineering analysis to support the development of the Technical Development Strategy (TDS) and the Systems Engineering Plans (SEP). Manufacturing considerations should be a component of the AoA guidance, addressed in the AoA study plan and included in the TDS and SEP.

Systems engineering analysis provides the PM with the technical basis for Technology Development phase execution, including the identification of critical technology elements (CTEs) and manufacturing process areas requiring risk-reduction efforts. In particular, during Material Solution Analysis the Integrated Product Team (IPT) performs the following activities:

- Develop initial view of system requirements and system design concepts: The team begins its engineering analysis, conducts trade studies, and formulates possible system solutions. The analysis effort develops preliminary system functional and performance requirements.
- Identify critical technology elements (CTEs) and conducts a technology maturity assessment of the hardware and software options with a focus on the CTEs.
- Conduct an assessment of ***manufacturing feasibility*** .

The program manager should ensure that a manufacturing feasibility assessment is accomplished as a part of the AoA. The feasibility estimate determines the likelihood that a proposed material solution can be produced using existing manufacturing capabilities while meeting quality, production rate and cost requirements.

The feasibility analysis involves the evaluation of:

- Producibility of the potential design concepts;
- Critical manufacturing processes and special tooling development which will be required;
- Test and demonstration required for new materials;
- Alternate design approaches within the individual concepts; and.
- Anticipated manufacturing risks and potential cost and schedule impacts.

The feasibility assessment identifies the manufacturing risks incurred in selecting a particular design. The assessment forms, in part, the basis for moving into the Technology Demonstration phase. Without this assessment, the program manager may find that the program cannot be accomplished within the defined cost and schedule thresholds as a result of incompatibilities between the system design and the manufacturing technology available to execute it. Milestone phase objectives and manufacturing considerations are outlined in Figure 3.4.

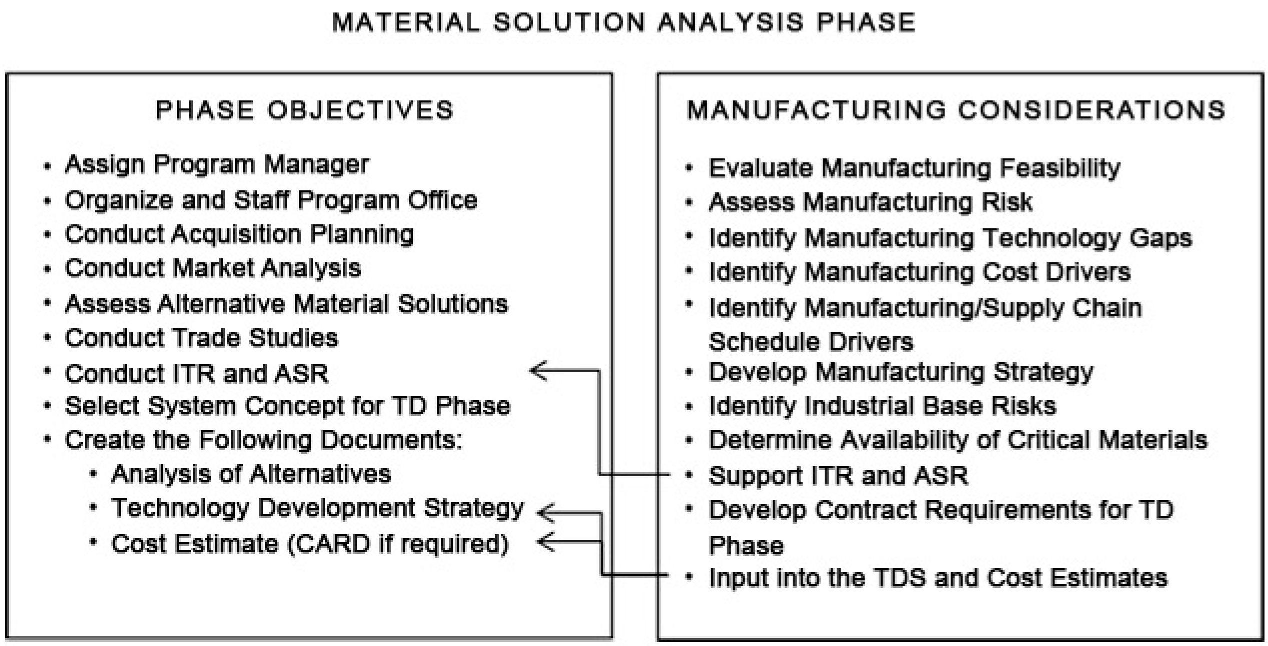

Figure 3-4 Manufacturing Considerations during the MSA Phase

Appropriate documentation for manufacturing considerations should be incorporated into the Technology Development Strategy (TDS) and Systems Engineering Plan (SEP).

3.5.2 Inputs

The following information sources provide important inputs to the MSA phase systems engineering process and should contain manufacturing considerations:

- Analysis of Alternatives (AoA) Plan; and
- Alternative Maintenance and Sustainment Concept of Operations. Many maintenance and sustainment considerations are impacted by manufacturing/production capabilities.

3.5.3 Key Activities

Key activities during the MSA phase include the following:

Top-Down Design:

- Interpret User Needs;
- Analyze Operational Capabilities and Environmental Constraints;
- Develop Concept Performance (and Constraints) Definition and Verification Objectives;
- Decompose Concept Performance into Functional Definition and Verification Objectives; and
- Decompose Concept Functional Definition into Concept Components and Assessment Objectives.

Bottom-up Realization:

- Develop Component Concepts (manufacture and assemble), Enabling/Critical Technologies, Constraints, and Cost/Risk Drivers;
- Analyze and Assess Enabling/Critical Components Versus Capabilities;
- Analyze and Assess System Concept Versus Functional Capabilities;
- Analyze and Assess Concept and Verify System Concept's Performance; and
- Analyze and Assess Concepts Versus Defined User Needs and Specified Environmental Constraints.

There are many opportunities during this process for manufacturing/QA managers to make a difference. For example, translating requirements into design solutions can be improved by using a tool called "Quality Function Deployment." Trade Studies are a normal part of both the Top-Down Design and Bottom-up Realization process during these trade studies it would be helpful if you used Design of Experiments to identify the key or critical factors that drive performance and affordability. The implementation is the development of components (CTEs) and the identification of constraints and cost drivers. Manufacturing/QA considerations should be a major part of implementation and include an assessment of current production capabilities and future requirements. Any gaps in manufacturing capabilities needs to be identified as a risk, and time and resources set aside to mature these critical manufacturing processes. Testing needs to include an assessment of the impact manufacturing variation on key characteristics has on performance, reliability, and affordability.

3.5.4 Technical Reviews

Technical reviews are a major part of the systems engineering process and are conducted by members of the Integrated Product Team (IPT). These reviews serve to confirm:

- Major technical efforts within a specific acquisition phases have been conducted;
- Outputs of that acquisition phases have been achieved; and
- The program is ready to progress toward the next acquisition phase.

Technical reviews are an important tool for subject matter experts, like manufacturing managers, to assess, identify and mitigate risk early. Each of these reviews will be discussed in greater detail in Chapter 12.

3.5.4.1 Initial Technical Review (ITR)

The ITR assesses the capability needs and materiel solution approach of a proposed program and verifies that the requisite research, development, test and evaluation, engineering, ***manufacturing*** , logistics, and programmatic bases for the program reflect the complete spectrum of technical challenges and risks. The success of the ITR depends, in part, on independent SME review of each of the identified cost drivers (engineering, ***manufacturing*** , logistics, test, etc.).

3.5.4.2 Alternative Systems Review (ASR)

The ASR assesses the proposed materiel solutions to ensure that the one or more materiel solution(s) have the potential to be affordable, operationally effective and suitable, and can be developed to provide a timely solution to a need at an acceptable level of risk. The intent is to reduce technical risk, validate designs, validate cost estimates, ***evaluate manufacturing processes*** , and refine requirements. The ASR helps ensure that sufficient effort has been given to conducting trade studies that consider and incorporate alternative system designs and other technical considerations.

3.5.5 Outputs

The following information sources provide important outputs to the systems engineering process supporting the MSA phase that should contain manufacturing considerations:

- System Safety Analyses (ensure a Preliminary Hazard List is completed for each system concept including hazardous materials used in production);
- Systems Engineering Plan (to include competitive prototype planning);
- Support and Maintenance Concepts and Technologies;
- Inputs to Technology Development Strategy, to include competitive prototype planning;
- Inputs to Analysis of Alternatives (AoA); and
- Inputs to Cost and Manpower Estimate.

3.5.6 Other Considerations

3.5.6.1 Develop the Technology Development Strategy (TDS)

The TDS must be approved for entry into the Technology Development Phase and guide efforts within established goals. The TDS should include proposed exit criteria for the TD Phase and plans to support entry to the ensuing phase. TDS elements that should contain manufacturing considerations are summarized below:

TDS Element	Description
Risk and Risk Management	Summary of risk management process; include related "risk cube" per Risk Management Guide for DOD.
Technology Maturation	Identification of critical technology element (CTEs) and strategy for attaining TRL 6 for each.
Industrial and Manufacturing Capabilities	Industrial Capability Analysis: assesses the ability of the industrial base to design, develop, produce, and support the program.
Business Strategy	Multiple competitive procurements to investigate alternative technologies; careful consideration to draft CDD.
Resource Management	• Program office staffing and support contractors organization • Cost and funding status • Cost control • Earned Value Management

• Cost and Software Data Reporting

Table 3-1 Manufacturing Inputs to the Technology Development Strategy

3.5.6.2 Develop Manufacturing Strategy

The manufacturing strategy is a subset of the overall acquisition strategy and can include considerations such as competition. Competition is a major contributor to reducing weapon system cost. If the program will be dual sourced, the early planning must take into account the strategy required to assure availability of capability and data and data rights for dual sourcing. New manufacturing technologies, if required by the system concept, will require specific plans for development, proofing and transition of the technology to the eventual producer. This effort will necessitate close coordination with the service manufacturing technology organization to assure compatibility of the technology development schedule with the system development schedule. Production rates and quantities also play a major role in driving manufacturing cost as they will drive decisions on what production processes to use, types of tooling required, make-buy decisions, etc. The best strategy is one that has a gradual build to rate production and then hold production at a steady state for a period of time without fluctuating.

3.5.6.3 Estimate Manufacturing Cost

Detailed manufacturing cost estimates cannot be developed during the MSA phase, but cost drivers can be identified based on proposed materials and process selections that may be inherent in the proposed material solutions. In addition, producibility cost can be assessed and investments in manufacturing technologies can be estimated. These estimates can be used to help develop the Cost Analysis Requirements Document (CARD) when required, or for other cost estimates when a CARD is not required.

Cost estimates will be used to evaluate affordability and in establishing initial program thresholds. In most cases, the estimates will be developed through the use of statistically based cost estimating relationships or by comparison of the proposed systems with similar systems whose costs are known. The cost estimates will be used for evaluating and selecting system concepts for entry into the Technology Development phase.

3.5.6.4 Manufacturing Technology (ManTech) Investments

The objective of the ManTech program is to improve performance while reducing acquisition cost by developing, maturing and transitioning advanced manufacturing technologies. The manufacturing feasibility assessment should identify high risk manufacturing process areas that may require investments in ManTech or other programs. These investments must be identified early so that these manufacturing capabilities will be matured on time to support rate production.

3.6 Technology Demonstration (TD) Phase

3.6.1 Manufacturing Task: Evaluate Manufacturing Processes and Risks

The Technology Development Phase develops and demonstrates prototype designs to reduce technical risk, validate designs and cost estimates, ***evaluate manufacturing processes*** , and refine requirements. It is focused to mature, prototype, and demonstrate technologies in a relevant environment and results in a preferred system concept that achieves a level suitable for low risk entry into Engineering and Manufacturing Development.

If a platform or system depends on specific technologies to meet system operational threshold requirements in development, production, operation, and sustainment, and if the technology or its application is either new or novel, then that technology is considered a critical or enabling technology. These critical technology elements (CTEs) are evaluated to assess technology maturity.

Additionally, the Technology Development Phase efforts ensure the level of expertise required to operate and maintain the product is consistent with the force structure. Technology development is an iterative process of maturing technologies and refining user performance parameters to accommodate those technologies that do not sufficiently mature (requirements trades).

Competitive prototyping and effective employment of systems engineering, applied through the Systems Engineering Plan (SEP), and monitored with meaningful technical reviews, will reduce program risk, identify potential management issues in a timely manner and support key program decisions. Manufacturing managers should be making significant inputs into these documents and activities. Milestone phase objectives and manufacturing considerations are outlined in Figure 3.5.

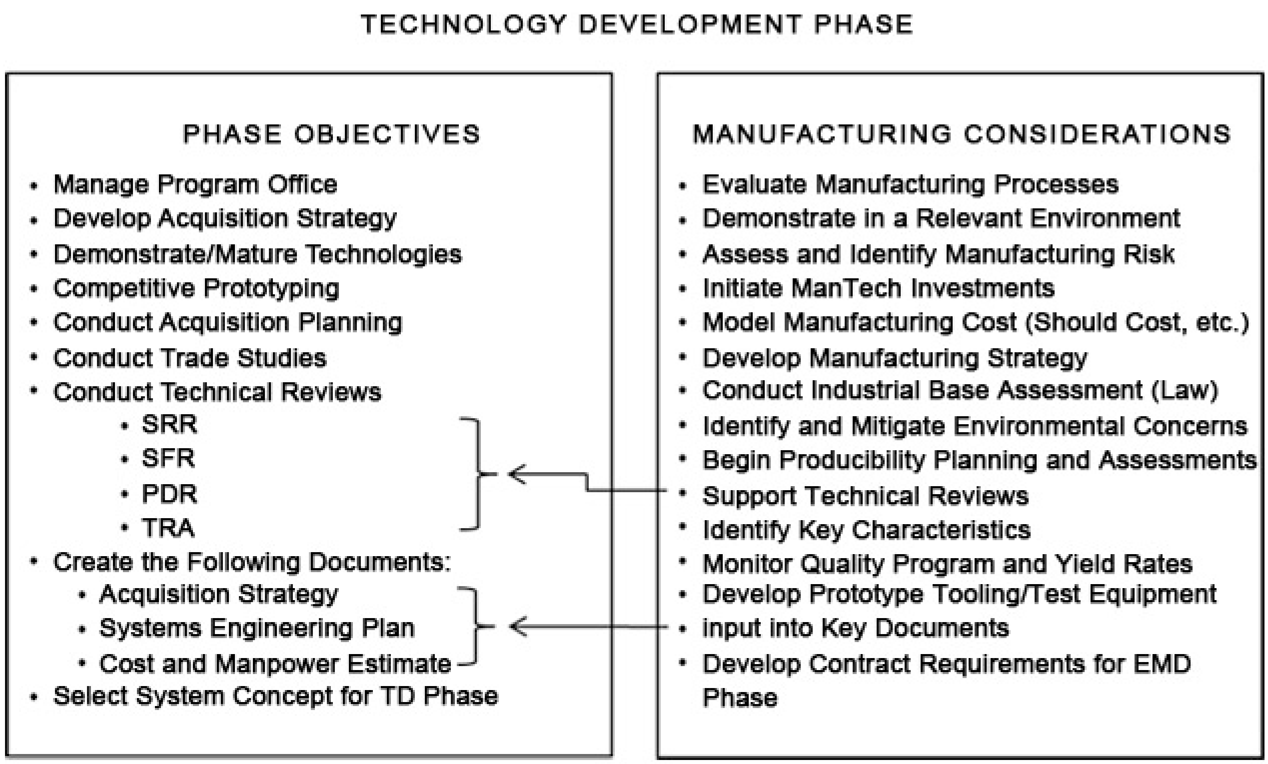

Figure 3-5 Manufacturing Considerations for the TD Phase

3.6.2 Inputs

The following information sources provide important inputs to the TD phase systems engineering process and should contain manufacturing considerations:

- System Safety Analysis,
- Support and Maintenance Concepts and Technologies,
- Analysis of Alternatives (AoA),
- Systems Engineering Plan, and
- Technology Development Strategy.

3.6.3 Key Activities

Key activities during the TD phase include the following:

Top-Down Design:

- Interpret User Needs;
- Analyze Operational Capability and Environmental Constraints;
- Develop System Performance Specifications and Enabling/Critical Technologies and Prototypes Verification Plan;

- Develop Functional Definitions for Enabling/Critical Technologies/Prototypes and Associated Verification Plan; and
- Decompose Functional Definitions into Critical Component Definition and Technology Verification Plan.

Bottom-up Rationalization:

- Design/Develop System Concepts (manufacture and assemble prototypes), *i.e* ., Enabling/Critical Technologies;
- Update Constraints and Cost/Risk Drivers;
- Demonstrate Enabling/Critical Technology Components Versus Plan;
- Demonstrate System and Prototype Functionality Versus Plan;
- Demonstrate/Model the Integrated System Versus the Performance Specification;
- Demonstrate and Validate the System Concepts and Technology Maturity Versus Defined User Needs;
- Transition to Integrated System Design;
- Interpret User Needs, Refine System Performance Specifications and Environmental Constraints;
- Develop System Functional Specifications and Verification Plan to Evolve System Functional Baseline; and
- Evolve Functional Performance Specifications into System Allocated Baseline.

Trade Studies are a normal part of both the Top-Down Design and Bottom-up Realization process. Manufacturing considerations should be a part of Trade Studies.

3.6.4 Technical Reviews

3.6.4.1 System Requirements Review (SRR)

The SRR is conducted to evaluate the systems requirements to determine if they are fully defined and consistent with the mature technology solution, and to trace the systems requirements to the Initial Capabilities Document (ICD) or draft Capability Development Document (CDD). The IPT's makes a determination that the system requirements, approved materiel solution, ***available product/process technology*** , and program resources form a satisfactory basis for proceeding into the EMD phase. The SRR should be tailored to the technical scope and risk of the system, and be addressed in the SEP.

3.6.4.2 System Functional Review (SFR)

The SFR determines whether the system's lower-level performance requirements are fully defined and consistent with the mature system concept, and whether lower-level systems requirements trace to top-level system performance and the Capability Development Document. A successful SFR is predicated upon the IPT's determination that the system performance requirements, lower level performance requirements, and plans for design and development form a satisfactory basis for proceeding into preliminary design. The SFR should be addressed in the SEP.

3.6.4.3 Preliminary Design Review (PDR)

The PDR is a technical assessment establishing the physically allocated baseline to ensure that the system under review has a reasonable expectation of being judged operationally effective and suitable and has a reasonable expectation of satisfying the requirements within the currently allocated budget and schedule. A successful PDR should include an assessment of the "producibility of the design and an assessment of manufacturing costs and risks.

3.6.4.4 Technology Readiness Assessment (TRA)

The TRA is a regulatory information requirement per DODI 5000.02. The TRA is a systematic metrics-based process that assesses the maturity of Critical Technology Elements (CTEs) and is a requirement for all acquisition programs.

The TRA should be considered not as a risk assessment, but as a tool for assessing program risk and the adequacy of technology maturation planning. The TRA scores the current readiness level of selected system elements, using defined Technology Readiness Levels (TRLs). The TRA highlights critical technologies (***including critical manufacturing-related technologies***) and other potential technology risk areas that require program manager attention.

3.6.5 Outputs

The following information sources provide important outputs to the systems engineering process supporting the TD phase that should contain manufacturing considerations:

- Risk Assessment;
- Systems Engineering Plan;
- Programmatic Environment, Safety, and Occupational Health Evaluation (PESHE);
- National Environmental Policy Act (NEPA) Compliance Schedule;
- Technology Readiness Assessment;
- Inputs to Integrated Baseline Review;
- Inputs to Acquisition Strategy;
- Inputs to Affordability Assessment; and
- Cost and Manpower Estimate.

3.6.6 Other Considerations

3.6.6.1 Develop Acquisition Strategy

An acquisition strategy is a high-level business and technical management approach designed to achieve program objectives within specified resource constraints. It is the framework for planning, organizing, staffing, controlling, and leading a program. It provides a master schedule for research, development, test, production, fielding and other activities essential for program success, and for formulating functional strategies and plans.

The production portion of the strategy is concerned with ensuring that the contractor's design is producible and that timely industrial capability will exist to provide the hardware (and associated software) within stated goals. Manufacturing considerations for inclusion in the strategy can include: establishing feasibility, assessing risks, identifying capable manufacturers and manufacturing technology maturation, capabilities of the industrial base, availability of critical materials, and the transition from development to production. Further considerations may include: the production processes, quality assurance procedures, personnel, and facilities. Strategy alternatives may include phased procurement, low-rate initial production, component breakout, productivity enhancement, industrial modernization, and dual sourcing.

3.6.6.2 Develop the Systems Engineering Plan (SEP)

The purpose of the Systems Engineering Plan (SEP) is to help programs develop their systems engineering (SE) approach, providing a firm and well-documented technical foundation for the program. The SEP is a living document in which periodic updates capture the program's current status and evolving SE implementation and its relationship with the overall program management effort. The SEP should be organized into five critical focus areas:

- Program Requirements;
- Technical Staffing and Organization Planning (Manufacturing Planning);
- Technical Baseline Management;
- Technical Review Planning; and
- Integration with Overall Management of the Program.

As the program matures its critical technologies, it is important to mature the requisite manufacturing processes needed to build your prototype and production items. This includes a requirement to conduct a preliminary producibility analysis, and consider the life cycle costs of proposed manufacturing, assembly and test processes.

3.6.6.3 Develop Initial Manufacturing Plan

The purpose of the manufacturing plan is to describe the method of achieving production goals employing the resources (manpower, machines, materials, methods and measurements) of the contractor and subcontractors. It should reflect all the time phased actions which are required to produce, test and deliver acceptable systems on schedule and at an affordable cost, and should reflect the degree of system definition attained during the TD Phase. The plan should identify the following:

- Producibility planning and implementation;
- Initial cost estimates to include estimated learning curves;
- Fabrication methods planned within the facilities;
- Technology development;
- Planned use of competition;
- Long lead procurement or limited production requirements;
- Manufacturing risk assessments; and
- Contract requirements for EMD.

3.6.6.4 Producibility Planning and Implementation

Producibility is an engineering function directed toward generating a design which is compatible with the manufacturing capability of the proposed factory floor. It is often considered the most important determinant of product cost, due to the effect on both production and sustainment costs. The Technology Development contract should require that the contractor develop a Producibility Plan and producibility criteria to guide the design effort. The plan should describe specifically what activities will be accomplished in each phase, the responsible organization, and the management controls that will be established to ensure successful accomplishment. The program management office (PMO) should review the plan with a focus on the realism, completeness and clarity of the planning accomplished by the contractor. Formal submission of the plan may be required by the contract or may be reviewed at the contractor facility.

Producibility criteria should reflect a blending of general criteria (such as minimum parts count) and specific criteria applicable to the type of equipment being developed. The producibility program will be effective if the design engineers understand and apply the producibility design criteria. Each competing design needs to be evaluated from a producibility standpoint. Producibility evaluations will serve as a basis for estimating the likely manufacturing cost and assessing the level of manufacturing risk of the system. Results of these assessments will support the development of specific contractual provisions for the EMD phase. Ignoring producibility can lock the acquisition program into design solutions which can only be accomplished at unnecessarily high levels of production cost or design changes which can entail substantial technical, cost and schedule risk.

3.6.6.5 Develop Initial Manufacturing Cost Estimate

During the TD phase, as the design matures, the contractor and the PMO should be able to create estimates based upon specific design characteristics and knowledge of the manufacturing system which will be used to fabricate the end items. For example, it should be possible to utilize a higher order estimating standard, such as hours per circuit board (by type), or cost of casting base upon number of castings and total weight. If a design-to-production unit cost requirement is included in the contract, the reasonableness and attainability of the contractor's production cost goal should be assessed to prevent the program from being based on unattainable goals which will later cause unavoidable cost growth. Manufacturing cost models should include:

- The ability to be used in design trades to assess the cost impacts of specific design changes, alternative production processes or process improvements;
- The ability to incorporate the current, actual manufacturing costs into the production cost estimate; and
- The ability to support Finance and Contracting processes (such as independent program estimates, proposal preparation, fact-finding & negotiations, budgeting, and what-ifs.)

3.6.6.6 Fabrication of Prototypes

When the design is defined, prototypes are fabricated. There are two primary purposes for prototype fabrication. They are:

1. Demonstrate through test that the product has the features and capabilities required; and
2. Validate that the product can be built within the cost and schedule give known production techniques.

Prototype fabrication includes building the prototypes in a ***production relevant environment*** and recording the time and cost required to build the end item. You are probably using low volume production processes (e.g., hand layup of composite parts) but will change to a high volume process (e.g., automated tape layup) during production. You may be using soft tooling to build the product. At this time the fabrication is often done by highly skilled personnel vs. production personnel, with media different from those used for quantity production. Often, the design is not sufficiently stable to support the development of complete manufacturing instructions. Thus, the validation of the final manufacturing approach is not accomplished this early in the program and requires further maturation of the production processes leaving the program at this time with production risks.

Production risk resolution involves assessing risks through the formal technical reviews and in demonstrating the manufacturing capability and maturity. During this phase, it is not necessary that all the details of the production processes be demonstrated, but manufacturing processes that represent advances beyond the current capability should be demonstrated and validated. The focus is on determining that there is a reasonable expectation that the manufacturing materials and processes which will be required can be obtained or fabricated in sufficient quantity and quality to meet EMD and production requirements.

3.6.6.7 Complete Manufacturing Technology Developments

Many new technologies and emerging manufacturing processes that are identified during the MSA phase carry risks. Manufacturing technology development needs to be accomplished in phased approach to define and demonstrate capabilities. The technology developer should demonstrate that the required process or material capabilities can be achieved in a production relevant environment for the TD phase. Failure to demonstrate materials and processes may increase the risk that the material or process may not meet the weapon system design, performance and affordability requirements.

3.6.6.8 Plan for Use of Competition

If the program's manufacturing strategy includes the use of competitors in the Production Phase then specific plans for achieving competition must be established now. Competition requires provisions for the government to receive the necessary technical data and rights to its use. Planning should include a focus on identifying the potential limits on competition which may result from the various design solutions and on means for reducing their impact. Decisions should be made relative to the timing of the introduction of competition and the basis on which the competition will be held. If there are plans for later government component breakout for competition, this should be clearly described in the contract to ensure that contractor plans use the same presumptions as the government plans.

3.6.6.9 Evaluate Long Lead Procurement Requirements

For many defense systems the time span between release of production funds and the required first delivery is less than the required lead times for some of the materials or subsystems. In developing the EMD phase plans and the data for the Decision Coordinating Paper/Integrated Program Summary, the requirements for 1ong lead material; or subsystems, both contractor and government furnished, should be identified. The funds required for these long lead items should be identified during the budget process. Determining the specific requirements for long lead funding is made difficult by the volatile nature of lead times for many defense materials. Where possible the analysis should be based on expected availability and lead times which are forecast to be in existence at the time of production start.

3.6.6.10 Determine Need for Limited Production

During the TD Phase the Program Manager needs to make a determination of what quantity of articles of that system should be procured at the end of the EMD Phase. The Low Rate Initial Production (LRIP) quantity should be the minimum number of articles necessary in order to:

- Provide production-configured articles for operational testing;
- Establish an initial production base for the system; and
- Permit an orderly increase in the production rate to lead to full-rate production.

Low Rate Initial production (LRIP) enables a systematic manufacturing ramp-up and provides decision makers with confidence in your manufacturing processes, cost and performance. Planning for LRIP must begin now.

3.6.6.11 Develop Manufacturing Risk Assessment Plan

Assessing manufacturing risks is a critical and continuous activity. It is critical that the specific requirements for contractor planning and support to the risk assessment process are included in the TD and EMD contracts. There is also a need to ensure that the necessary government evaluation skills are available during these phases. These needs can only be met if the major readiness issues are identified during the CE Phase and the methods for evaluating readiness are clearly defined. The readiness issues must cover both the defense system design and the production planning and execution required. Many of these risks are normally evaluated as part of the technical review and audit process, and manufacturing considerations need to be a part of the Technical Review planning and assessment process.

3.6.6.12 Develop Contract Requirements for EMD Phase

The EMD Phase will involve the definition of the full detailed design for the weapon system; the logistics support structure and the manufacturing system. Specific statement of work language needs to be developed to cover those manufacturing areas which have been determined to be necessary during EMD. Typical areas to be considered for inclusion are:

Manufacturing Management Plan	Trade Studies
Quality Assurance Management Plan	Manufacturing Technology Investments
Producibility Engineering Plan	Award Fee/Incentive Fee Criteria
Make/Buy Plan (Competition)	Process Capability Study
Technical Reviews	Environmental Risk Assessment (PESHE)
Material Availability/Long Lead Procurement	Work Measurement/Learning Curve
Technical Data/Manufacturing Data	Manufacturing Reporting & Control Systems

Table 3-2 Manufacturing Management Contract Considerations for EMD

3.7 Engineering and Manufacturing Development (EMD) Phase

3.7.1 Manufacturing Task: Mature Critical Manufacturing Processes

The purpose of EMD is to complete the development of a system or incremental capability. One of the key tasks is to mature critical manufacturing processes. Manufacturing Process Demonstration includes the development of affordable and executable manufacturing processes, the completion of system fabrication, the production of test articles so that you can demonstrate system integration, interoperability, supportability, safety and utility.

A primary focus is on risk reduction. EMD typically includes the demonstration of production prototype articles or engineering development models. These items are typically built in a pilot line environment. And when the industrial capabilities are in place and the prototype items achieve their requirements as validated through testing, then the program can exit EMD and enter Production and Deployment. Milestone phase objectives and manufacturing considerations are outlined in Figure 3.6.

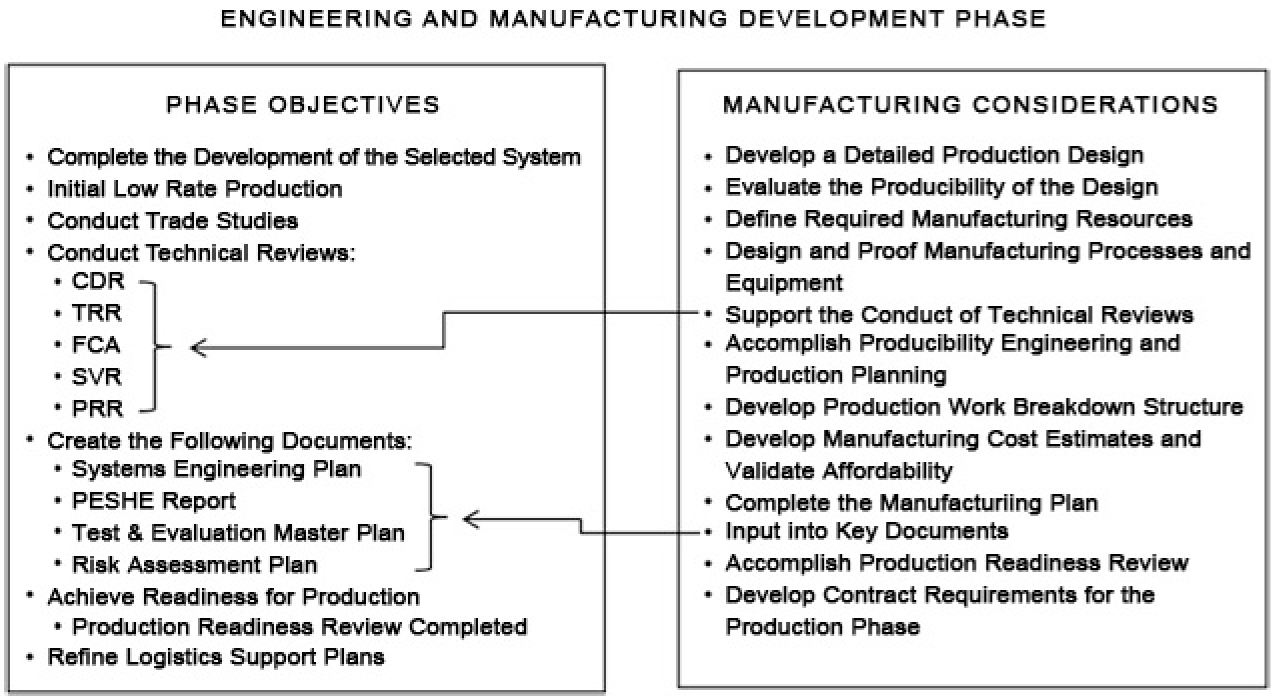

Figure 3-6 Manufacturing Considerations for the EMD Phase

3.7.2 Inputs

The following information sources provide important inputs to the EMD phase systems engineering process and should contain manufacturing considerations:

- A PDR Report;
- System Performance Specification;
- Acquisition Program Baseline;
- Capability Development Document;
- Systems Engineering Plan;
- Test and Evaluation Master Plan;
- Programmatic Environment, Safety, and Occupational Health Evaluation (PESHE); and
- Life-cycle Sustainment Plan.

3.7.3 Key Activities

Key activities during the EMD phase include the following:

Top-Down Design:

- Evolve Configuration Item Design Specifications into System Product Baseline.

Bottom-up Realization:

- Fabricate, Assemble, Code to Product Baseline;
- Developmental Evaluation Verifies Individual Configuration Items;
- Integrated Test for Developmental and Live Fire Evaluation, and Operational Assessments verify Performance Compliance to Specifications;
- Integrated Test for Developmental and Live Fire Evaluation, and Operational Assessments verify System Functionality and Constraints Compliance to Specifications; and
- Integrated Test, Developmental Evaluation, Operational Assessments, and Live Fire Evaluation Demonstrate System to Specified User Needs and Environmental Constraints.

3.7.4 Technical Reviews

3.7.4.1 Integrated Review (IBR)

The IBR establishes a mutual understanding of the Performance Measurement Baseline (PMB) and provides for an agreement on a plan of action to evaluate risks inherent in the PMB and the management processes that operate during project execution.

3.7.4.2 Critical Design Review (CDR)

The CDR is conducted to ensure that the system under review can proceed into system fabrication, demonstration, and test, and can meet the stated performance requirements within cost (program budget), schedule (program schedule), risk, and other system constraints. At this time Producibility Engineering activities should be complete.

The CDR assesses the system ***final*** design as captured in product specifications for each configuration item in the system (product baseline), and ensures that each product in the product baseline has been captured in the detailed design documentation.

3.7.4.3 Test Readiness Review (TRR)

The TRR is a multi-disciplined technical review designed to ensure that the subsystem or system under review is ready to proceed into formal test.

3.7.4.4 System Verification Review (SFR)

The SFR is conducted to ensure that the system under review can proceed into Low Rate Initial Production (LRIP) and Full Rate Production (FRP) within cost (program budget), schedule (program schedule), risk, and other system constraints.

3.7.4.5 Functional Configuration Audit (FCA)

The FCA is the formal examination of the tested characteristics of a configuration item (hardware and software) with the objective of verifying that actual performance complies with design and interface requirements in the functional baseline.

3.7.4.6 Production Readiness Review (PRR)

The PRR is an examination of a program to determine if the design is ready for production and the producer has accomplished adequate production planning without incurring unacceptable risks that will breach thresholds of schedule, performance, cost, or other established criteria.

3.7.4.7 Technology Readiness Assessment (TRA)

The TRA scores the current readiness level of selected system elements, using defined Technology Readiness Levels (TRLs), highlighting critical technologies and other potential technology risk areas requiring Program Manager (PM) attention.

3.7.5 Outputs

The following information sources provide important outputs to the systems engineering process supporting the EMD phase that should contain manufacturing considerations:

- Test and Evaluation Master Plan;
- Product Support Element Requirements;
- Risk Assessment;
- Systems Engineering Plan;
- Technology Readiness Assessment;
- Production Readiness Review;
- Programmatic Environment, Safety, and Occupational Health (PESHE);
- Capability Production Document; and
- Cost and Manpower Estimate.

3.7.6 Other Considerations

3.7.6.1 Define and Proof Manufacturing Processes and Equipment

Among the critical elements to be defined during EMD phase are the manufacturing processes which will be utilized to build the defense system. The sequence of manufacturing processes begins with the receipt of the raw material, where special handling and storage may be required. Additional processes requirements may include such items as cleaning, heat treatment, clean room controls, controlled testing and special handling (i.e., personal grounding requirements for electronic components). Identification of all processes must be a part of the design documentation. Where the selected processes contribute manufacturing risk to the program, the processes should be proofed during EMD. The purpose of proofing is to ensure that the process can repeatedly produce conforming hardware within the cost and time constraints of the production phase. It is important that the proofing be accomplished in an environment that simulates actual production conditions (typically a pilot line environment). These conditions include the physical facilities, personnel and manufacturing documentation. It may also be necessary for the contractor to establish training and certification programs for the shop personnel to ensure that the process capabilities can be attained on a recurring basis.

3.7.6.2 Complete Manufacturing Plan

At the end of the EMD, all of the information necessary to plan the detailed manufacturing operations for the system should be available. This information should be described in a manufacturing plan covering the issues of manufacturing organization, make or buy planning, subcontract management, resources and manufacturing capability, and the detailed fabrication and assembly planning. The plan should also describe the types of Government Furnished Property (GFP) required and the specific need dates for it. The contractor management control systems, including those for configuration management, the control of subcontractors and manufacturing performance evaluation should be described in sufficient detail for the program management office to determine their expected utility. The plan developed should also include consideration of the potential requirements for industrial preparedness planning, including surge capability during the production phase and the post production phase requirements for support to employment of the system in combat situations. The development of this formal manufacturing plan contributes value to the program from two standpoints. The primary benefit accrues from the fact that the contractor has to crystallize the manufacturing planning to a point where it can be described in the detail required. The secondary benefit is the usability the plan provides to the program management office personnel. It serves as a basis for a structured review of the contractor approach, the expected cost of the production phase effort, and a fuller assessment of manufacturing risk. Where such a plan is not developed during the EMD Phase there is often unnecessarily high cost and schedule turbulence at the front end of the production phase.

3.7.6.3 Execute Producibility Engineering and Production Planning

Producibility, as noted above, is a measure of the relative ease of producing a product or system. Alternate manufacturing methods, materials, resources, and processes must be a consideration of the detailed design if the economics of manufacturing and assembly are to be considered. Producibility studies and analysis of the alternatives are conducted by the contractor with consideration of the impact on cost, schedule and technical performance. Early production planning based on design and schedule requirements is essential if production delivery schedules are to be fulfilled. Production planning must include identification of potential problems with an assessment of the capability required to produce the item and industry's current capability to manufacture the system as designed. Potential production problems that require further resolution by study or development must be identified and action for resolution initiated. The producibility engineering and planning effort also results in the definition and design of the special tooling and test equipment required to execute the production phase effort, as well as the preparation and release of the manufacturing data required for the start of manufacture.

3.7.6.4 Evaluate Producibility of Design

There are a number of factors to be considered in ensuring the producibility of a design:

- Liberal tolerances (dimensions, mechanical, electrical);
- Use of materials that provide optimum machinability, formability and weldability;
- Shapes and forms designed for castings, stampings, extrusions, etc., that provide maximum economy;
- Inspection and test requirements that are the minimum needed to assure desired quality and maximum usage of available and standard inspection equipment;
- Assembly by efficient, economical methods and procedures; and
- Minimized requirements for complex or expensive manufacturing tooling or special skills.

There should be evidence that the contractor has accomplished producibility analyses of various options for the manufacturing task. The EMD phase results in the system design for entering production. As the design evolves during EMD, its producibility should be subjected to regular review (probably as part of the normal design review process).

3.7.6.5 Identify Required Manufacturing Resources

One of the most important elements of any production design is the definition of the manufacturing resources. No matter how good a design may be, it is useless if system or product cannot be built. It is therefore essential that availability of manufacturing resources be a consideration during the design review process. Manufacturing engineers should be a part of each design team to assure adequate consideration of availability of required manufacturing resources.

Manufacturing resources should not be limited to manufacturing methods, but should include materials, capital, manufacturing technology, facilities, qualified labor, and the management structure to effectively integrate them. The successful competitor, of the production phase will depend upon the efficient application of the full spectrum of these resources to the task of fabricating and delivering the defense system design.

3.7.6.6 Develop Detailed Production Design

Prior to release of drawings to manufacturing the detailed design drawings, bills of material and product and process specifications must be completed. Further, it is essential that design reviews be conducted to assure that the contractor is complying with the design requirements and meeting the cost/design goals. The final design definition is the result of the performance requirements, the outcomes of the testing accomplished, producibility studies and other design influences. The production phase effort requires that the design be specified to a very low level of detail so that the required processes and resources can be identified and obtained.

3.7.6.7 Develop Production Work Breakdown Structure

The planning, execution and control of the production phase activities require that the work be divided into manageable tasks that are compatible with the existing manufacturing and performance measurement systems. Often, the work breakdown structure (WBS) used during the development phases will not be appropriate for the production phase. Consequently, the contractor should, as a basis for production planning, identify the WBS which is to be used. While this was may differ from the EMD structure, the two should be such that production phase costs can be related to the development WBS. This is critical for those programs which have utilized a design-to-unit production cost management approach during development.

3.7.6.8 Develop Manufacturing Cost Estimates

As the definition of the system design and the manufacturing approach are completed during the EMD phase, the information necessary for more precise estimates of production phase manufacturing cost becomes available. During the EMD phase the initial manufacturing cost estimate should be updated on a regular basis to reflect the increasing degree of detail available. These estimates should be based upon application of detailed manufacturing standards to the operations to be performed and adjusted, as necessary, by realization factors and/or learning curves to develop the time phased manufacturing cost. If the contractor(s) does not have a system for development and application of labor standards, strong consideration should be given to including a contract requirement (e.g., MIL-STD-1567A, Work Measurement) in the EMD phase contract. If there is to be an Industrial Modernization Incentives program accomplished, the manufacturing cost estimate should be structured to reflect the expected benefits of this program.

3.7.6.9 Accomplish Production Readiness Reviews

The objective of a PRR is to verify that the production design planning and associated preparations for a system have progressed to the point where a production commitment can be made without incurring unacceptable risks of breaching thresholds of schedule, performance, cost, or other established criteria. PRRs should be conducted by the program manager, as a time-phased effort that will span EMD and encompass the developer/producer and major subsystem suppliers. The PRR examines the developer's design from the standpoint of completeness and producibility. It examines the producer's production planning documentation, existing and planned facilities, tooling and test equipment, manufacturing methods and controls, material and manpower resources, production engineering, quality control and assurance provisions, production management organization, and controls over major subcontractors. The result of the PRR supports the program manager's affirmative decision at the production decision point, that the system is ready for efficient and economical rate production.

3.7.6.10 Develop Contract Requirements for Production Phase

Specific requirements must be identified for inclusion in the statement of work for the production phase. The particular requirements reflect the areas that have been determined to be of importance, given the acquisition strategy of the program. Typical areas to be considered for inclusion are:

- Manufacturing management systems,
- Work measurement,
- Manufacturing data (including manufacturing plan updates),
- Initial production facilities,
- Production and material control systems,
- Manufacturing reporting systems (especially line of balance),
- Control of subcontractors and vendor,
- Make or Buy program,
- Government Furnished Property,
- System audit,
- Technical data, and
- Competition.

Production phase incentives may be included to motivate contractors to improve performance and control costs. The benefits attainable through use of multiyear contracting should also be explored.

3.8 Production and Deployment (P&D) Phase

3.8.1 Manufacturing Task: Manufacturing Processes Are Under Control

The purpose of P&D is to produce items for the warfighter that achieve operational capability and satisfy mission needs. In order to achieve those goals the items being produced must have achieved design stability, had their technologies matured and their manufacturing processes must be capable, stable and under control. There are essentially two related production efforts during the PD phase: Low Rate Initial Production (LRIP) and Full Rate Production (FRP). LRIP is often identified as up to 10% of the estimated production volume.

Low Rate Initial Production typically demonstrates the production of articles beyond a pilot line environment. These items are typically built in a pilot line environment. All systems engineering/design requirements should have been met such that there are minimal system changes. Major system design features are stable and have been proven in test and evaluation. Materials are available to meet planned rate production schedules. Manufacturing process capability in a low rate production environment is at an appropriate quality level to meet design key characteristic tolerances. Production risk monitoring is ongoing. LRIP cost targets have been met, and learning curves have been analyzed with actual data. The cost model has been developed for FRP environment and reflects the impact of continuous improvement. Milestone phase objectives and manufacturing considerations are outlined in Figure 3.7.

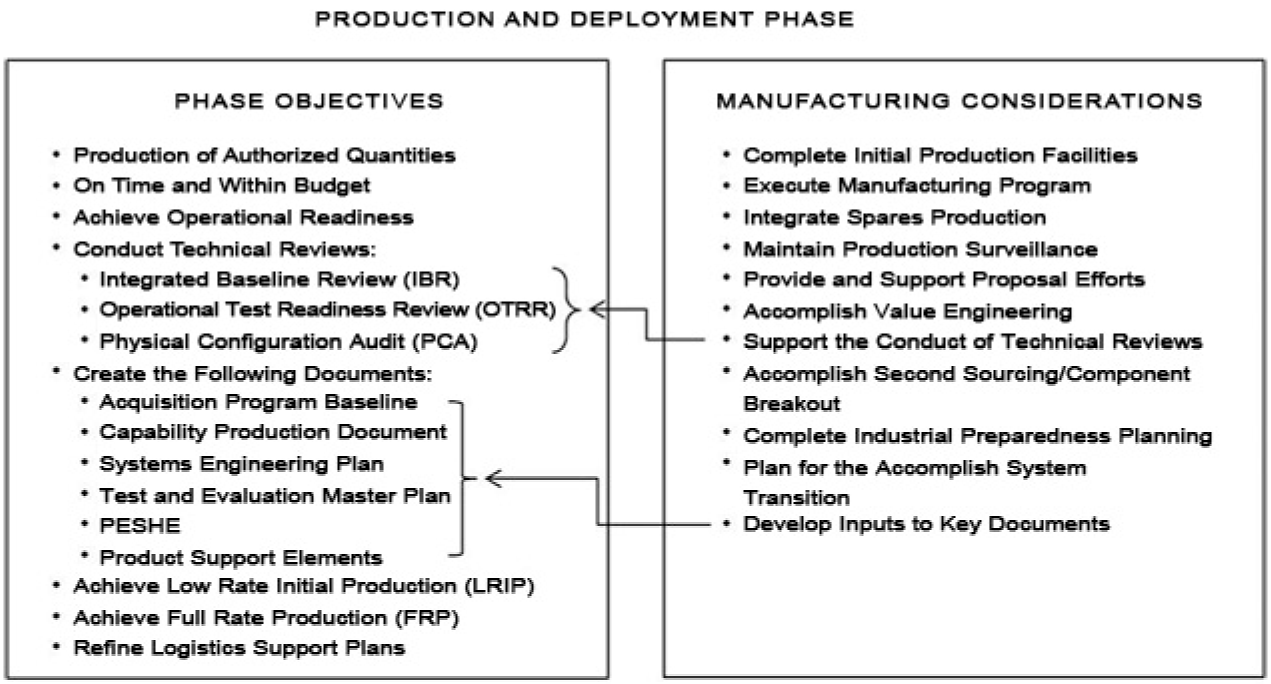

Figure 3-7 Manufacturing Considerations for the P&D Phase

3.8.2 Inputs

The following information sources provide important inputs to the P&D phase systems engineering process and should contain manufacturing considerations:

- Acquisition Program Baseline;
- Capability Production Document;
- Systems Engineering Plan;
- Test and Evaluation Master Plan;

- Programmatic Environmental, Safety, and Occupational Health Evaluation (PESHE); and,
- Product Support Elements.

3.8.3 Key Activities

Key activities during the P&D phase include the following:

- Analyze Deficiencies to Determine Corrective Actions;
- Modify Configuration to Correct Deficiencies; and
- Verify and Validate Production Configuration.

3.8.4 Technical Reviews

3.8.4.1 Integrated Baseline Review (IBR)

The IBR establishes a mutual understanding of the Performance Measurement Baseline (PMB) and provides for an agreement on a plan of action to evaluate risks inherent in the PMB and the management processes that operate during project execution.

3.8.4.2 Operational Test Readiness Review (OTRR)

The OTRR is conducted to ensure that the "production configuration" system can proceed into Operational Testing (OT) with a high probability of success.

3.8.4.3 Physical Configuration Audit (PCA)

The PCA examines the actual configuration of an item being produced in order to verify that the related design documentation matches the item as specified in the contract. In addition, the PCA confirms that the manufacturing processes, quality control system, measurement and test equipment, and training are adequately planned, tracked and controlled.

3.8.5 Outputs

The following information sources provide important outputs to the P&D phase systems engineering process and should contain manufacturing considerations:

- Updated Product Baseline;
- Test and Evaluation Master Plan;
- Risk Assessments;
- Life-cycle Sustainment Plan;
- Systems Engineering Plan;
- Programmatic Environmental, Safety, and Occupational Health Evaluation (PESHE);
- National Environmental Policy Act (NEPA) Compliance Schedule; and
- Cost and Manpower Estimates.

3.8.6 Other Considerations

3.8.6.1 Production

The release for production normally involves a significant financial commitment for the developer. The manufacturing system must be adapted to the new product and often a significant amount of production tooling must be built and put in place. These efforts are often hindered by a need to incorporate some level of change to the design reflecting either shortcomings identified in test or recognized opportunities for improvement. Limited production involves establishing a base line design, a plan for change introduction and the organization of the manufacturing resources required to execute the design. The primary resources which must be acquired and applied are personnel, capital and capital equipment, technology and materials. One of the critical challenges in this phase is the control of the manufacturing process. It is of paramount importance to ensure that: a.) the design capabilities are not degraded in the as-built product, and b.) the cost to execute the design remains within target.

3.8.6.2 Execute Manufacturing Program

The primary function of the production phase is to complete the manufacture of the system within the established time and cost constraints. Normally, the production rate is structured to start slowly and build to a defined steady state rate. Evaluation of contractor planning for initiation of the production phase needs to be focused on the contractor planning to increase from low rate to full rate production. The program manager also needs to focus attention on the levels of engineering change activity. An excessive number of engineering changes can disrupt the structure of the manufacturing planning and result in high manufacturing costs. Also, attention needs to be given to ensuring that acceptance criteria for the product or system are clearly specified and that there is minimum use of waivers, deviations and Material Review Board actions during the acceptance process. The program office manufacturing personnel should participate in the Physical Configuration Audit (PCA) when the "as built" item is compared with the technical documentation. Upon satisfactory completion of the PCA, the primary acceptance criteria will be the physical and test requirements listed in the technical documentation. The completion of the production phase normally involves a series of contract actions which will need to be planned and completed to fill the system acquisition objective. For each of these contracts, a decision will need to be made on the contract type, the incentive structure, if any, the level of government control and the desired program visibility.

3.8.6.3 Complete Initial Production Facilities

The Initial Production Facilities (IPF) includes the special tooling, special test equipment and plant rearrangement cost necessary to accomplish cost-effective manufacturing. The design of the IPF should have been accomplished as part of the Producibility Engineering and Planning (PEP) accomplished during full-scale development. The PEP output includes a description and design of the required facilities and is based upon the production plan developed during FSD. Changes to that facility definition and design may be required if the production plan has been rendered obsolete by program changes or test problems. The timing of the IPF may pace the initiation of the production units if the manufacturing approaches are tooling dependent.

Failure to initiate and complete IPF in a timely manner generally results in greatly increased direct labor unit cost for the early units, delayed completion of early units and delays in the start of progress along the expected program learning curve. The increase in early unit cost results from the fact that the investment in special tooling and special test equipment is justified on the basis of unit cost reductions. There may also be unforeseen additional cost for the revision of the manufacturing process documentation developed during PEP since the documentation was developed on the presumption that the IPF would be in place.

Although claims of large unit cost reductions may be made, the average unit cost over the total production quantity will be higher when FSD tasks are incomplete. A well developed production plan will be more economical in terms of total program cost or average unit cost even though it may follow a higher value learning curve. The number of change proposals will also be less for a well-planned program.

3.8.6.4 Integrate Spares Production

As the system is deployed and enters training and operational use, there is a continuing requirement, on many systems, for spare and repair parts. To the extent possible, the manufacture of these parts should be integrated with the basic system production to take advantage of the lower cost associated with larger fabrication lots within the facility. The spares items to be produced can also impact the cost estimate where learning curve analysis is used at lower levels of the system hardware, since the spares quantities can increase the number of units built above that shown on the end item schedule. Failure to consider the capacity needs for spares can result in diminished capability to support the fielded system, thus reducing its availability, or a drain on production parts as they are diverted to support of the deployed systems.

A second source for spare parts may be desired to ensure future delivery or for enhanced competition. The production phase is an opportune time to solicit second source bids and identify possible spare parts suppliers. The data package is complete and quantity requirements for quantity buys may be sufficient for a supplier to tool up for the parts.

3.8.6.5 Maintain Production Surveillance

One of the primary program management tasks during this phase is to establish and maintain a system for accomplishing surveillance over the progress of the contractor performing the manufacturing tasks. Generally, the program manager will want to ensure that information is available to measure contractor effectiveness from time, cost and technical achievement standpoints. The program manager must also choose between a formally structured and contractually specified management control system or a currently existing contractor system. When problems occur during the production phase, the management control system should provide timely information to the program manager in a format that will support decision making and action processes.

3.8.6.6 Implement Product Improvement

The Follow-On Operational Test and Evaluation (FOT&E) and the initial user feedback on the system often identify areas where improvements can be made to the system to allow it to better meet the constantly changing operational environment. The challenges for the program manager involve the decisions on which of these improvements to make, and the method of incorporating them on the production line. To minimize production cost, the number of engineering changes should be kept to a minimum, but operational requirements often militate in favor of change. A program may also involve preplanned product improvement. If this acquisition strategy applies, when and how to incorporate such improvements must be resolved early in the program.

3.8.6.7 Provide and Support Government Furnished Property (GFP)

Where a decision has been made to provide use to the contractor, the program manager must ensure that the property, conforming to the technical description, is delivered to the contractor in accordance with the agreed to schedule. The primary motivations for providing government property to contractors are to reduce cost and increase standardization within the logistics system.

The trade-off for these benefits is the acceptance by the government of some of the responsibility for contract performance. When GFP is involved, the contract clause provides that if the GFP is late or defective there may be an adjustment to the contract schedule, or price, or both. It is, therefore, incumbent upon the program office to ensure that an effective management control system is established to; a.) validate contractor need dates; b.) budget for the GFP; and c.) acquire the GFP and deliver it to the contractor on time.

3.8.6.8 Accomplish Value Engineering

Value engineering (VE) is an organized effort directed at analyzing the function of a product or system for the purpose of achieving the function at the lowest overall cost. During the production phase, the value engineering effort amounts to a reappraisal of the design from both a functional and cost standpoint. There are two ways to include value engineering in the production phase contract: by a Value Engineering Incentive Clause or by a Value Engineering Program Clause. The VE Incentive Clause provides the contractor with the opportunity to submit Value Engineering Change Proposals (VECPs) and to share in the savings accrued from approved VECPs. The VE program clause requires the contractor to establish a VE program within his facility to identify potential applications of VE and prepare VECPs.

VE has the potential to significantly reduce acquisition and support costs for those elements of the product or system to which it is applied. In addition to including the appropriate contract language, the success of a VE program is critically dependent upon the level of program office support which is provided. This support can be provided in two ways. First, the decision makers in the program office can encourage the identification and submission of VECPs. Second, the personnel evaluating VECPs can approach the task with an open mind.

Accomplish Second Sourcing/Component Breakout: As noted above, competition has been shown in a number of studies to have a beneficial effect in reducing program cost. The plan for introducing competition during the production phase can involve either the establishment of a second source or the breakout of selected components of the system for direct government (preferably competitive) procurement. Accomplishing government objectives in these two areas requires that the data and data rights are obtained from the developing contractor. These rights should have been obtained during the development phases with data delivery late in FSD or early in the production phase. Since the introduction of new sources will involve contractors who may not have the benefit of the development experience, a careful plan for technology transfer must be established. Many times, successful manufacture of a product or system is dependent upon processing factors not disclosed in the technical data package.

3.8.6.9 Complete Industrial Preparedness Planning

The Industrial Preparedness Planning (IPP) program focuses on establishing the capability to support increased levels of usage of equipment resulting from combat operations. The primary emphasis during the production phase is the evaluation of the ability of the contractor base to surge production to meet higher levels of consumption. As the production phase is nearing completion, action needs to be taken to determine if any of the subsystems or components of the defense system will be critical to support of wartime operations. If so, the mobilization requirements for the items must be identified, contractor plans for accomplishing the mobilization must be established, and the capability to execute the mobilization must be created or retained from the production phase equipment.

3.8.6.10 Plan for and Accomplish System Transition

As the system acquisition process is completed with the attainment of the acquisition program objectives, the responsibility for the product or system acquisition functions: procurement, engineering, finance, and logistics is dispersed through the respective Service organizational structure. The effort focused on the program management approach is no longer needed. The program manager must ensure that documentation of the system is complete, and the support requirement is properly defined and structured.

3.9 Operations and Support (O&S) Phase

3.9.1 Manufacturing Task: Continuous Improvement And Change Management

The objective of this phase is the execution of a support program that meets operational support performance requirements and sustains the system in the most cost-effective manner over its total life cycle. When the system reaches the end of its useful life, the department should dispose of it.

During the sustainment effort of the Operations and Support phase, systems engineering processes support in-service reviews including identifying root causes and resolutions for safety and critical readiness degrading issues. This effort includes participating in trade studies and decision making relative to the best resolution (e.g., changes to the product support package, manufacturing process improvements, modifications, upgrades, and future increments of the system), considering the operational needs and the remaining expected service life. Interoperability or technology improvements, parts or manufacturing obsolescence, aging aircraft (or system) issues, premature failures, changes in fuel or lubricants, joint or service commonality, etc. may all indicate the need for a system upgrade(s) or process improvements.

The last activity associated with the Operations and Support acquisition phase is disposal. Early systems engineering processes should include and inject disposal requirements and considerations into the design processes that ultimately facilitate disposal. System disposal is not typically a systems engineering activity.

3.9.2 Inputs

The following information sources provide important inputs to the O&S phase systems engineering process and should contain manufacturing considerations:

- Systems Engineering Plan;
- Programmatic Environmental, Safety, and Occupational Health Evaluation (PESHE); and
- Life-cycle Sustainment Plan.

3.9.3 Key Activities

Key activities during the P&D phase include the following:

- Monitor and Collect All Service Use Data;
- Analyze Data to Determine Root Cause of Problem;
- Determine the System Risk/Hazard Probability and Severity;
- Develop Corrective Action;
- Assess Risk of Improved System; and
- Implement and Field.

3.9.4 Technical Reviews

3.9.4.1 In-Service Review (ISR)

The ISR is a multi-disciplined product and process assessment to ensure that the system under review is operationally employed with well-understood and managed risk. This review is intended to characterize the in-service health of the deployed system. It provides an assessment of risk, readiness, technical status, and trends in a measurable form.

3.9.5 Outputs

The following information sources provide important outputs to the O&S phase systems engineering process and should contain manufacturing considerations:

- Capability Development Document;
- Systems Engineering Plan;
- Programmatic Environmental, Safety, and Occupational Health Evaluation (PESHE);
- National Environmental Policy Act (NEPA) Compliance Schedule; and

- Updates to Maintenance Procedures through the Reliability Centered Maintenance Analysis.

3.9.6 Other Considerations

3.9.6.1 Product Improvement

As production of the system continues and feedback is received from the users, there is often a series of product improvements which are defined and executed. When the product is competitive with similar products, these improvements are often driven by the action of competitors. The challenge in this phase of the cycle is to integrate these changes into the production system with minimum disruption and cost. The changes introduced reflect both improvements in the ability of the product to meet the original design objective and extensions of capability to meet increased or broadened performance objectives.

The term "transition" is analogous to many terms used throughout the Services to describe the attainment of the acquisition program objectives and the dispersion of product/system acquisition functions -- procurement, engineering, production finance, logistics, and facilities -- in whole or in part throughout the respective Services, organization structures. A sample of such terms includes "transition planning," "program transition," and "turnover management."

Program management documents and master schedules must include transition considerations. While the mechanics involved in transition will vary among the Services, the end result is the availability of the system for use by the operating forces in consonance with DOD objectives.

Emphasis in weapon system acquisition has been on early production and delivery and the establishment of support capability to coincide with initial fielding of the system. This has often forced provisioning to be accomplished in a very short time. While some success has been achieved in having spare parts on hand, it has virtually eliminated our ability to establish competitive sources or assure fair and reasonable pricing of these spare parts. If the Services are to support weapon systems as they are delivered into the inventory, and obtain spare parts at fair and reasonable prices, some radical changes in the weapon system acquisition process will be required.

3.9.6.2 Interface Questions

With considerable resources now invested in the product/system, many interface questions become extremely crucial. Are organizational force and equipment tables, allocation of units, and field support plans compatible with the production planning? Have the production rates been established for support program requirements, support and test equipment, spares support, storage and transportation, and training? Have test and demonstration requirements been established and a methodology developed for incorporating user changes in documentation for release to production? Are plans formulated for updating specifications and drawings to reflect the production design and for obtaining suitable technical documentation packages necessary for considerations such as competitive procurement and component breakout?

As noted above, a host of program transition considerations confront the program manager in the production and deployment phase. While relatively dormant earlier in a program, these considerations suddenly become critical at the very height of the production process. Has a risk analysis identified potential production plan and rate deficiencies? Is the producibility plan adequate for full and follow-on production? Are the various facilities, tooling, industrial capacity and related schedule plans current? Have Foreign Military Sales (FMS) and other Service requirements as well as related production processes, rates and quantities been validated, documented and kept current?

As the focus shifts from the PM to the internal Service interface, those seeds sown early on in the product development process will mature and will ensure program integrity to the system user.

3.9.6.3 Changing Production Capability

The program manager should be aware of changing production capability as the transition from production to spare parts provisioning will severely reduce opportunities for future spares procurement if production facilities are changed to accommodate a new product line, material needs change or new tooling for special purpose machines is installed. If extended production runs did not provide a spare parts inventory, the cost of parts produced at a later date can be significantly higher than the original procurement. Conditions which drive up spare parts prices include:

- Smaller order quantity requirements;
- Orders for earlier configuration units which require special documentation;
- Parts requiring special purpose tooling;Unique or scarce material requirements;
- Lack of production capability due to a number of factors: Out of business, discontinued facilities, lack of available production capacity, etc.; and
- Special handling, packaging and shipping requirements.

3.9.6.4 End Item Production Endangered

DOD Directive 4005-16 establishes policies and assigns responsibilities to assure that timely action is initiated when essential end item production capabilities are endangered by the loss or impending loss of manufacturing sources, by material shortages, or that have been reduced to a single source with inadequate production capabilities. DOD components have a responsibility to coordinate with operational activities within other government agencies on the identification of critical items and possible solutions, when faced with a material shortage or manufacturing phase-out.

3.9.6.5 Implementing Procedures

In accordance with DOD Directive 4005.16, each DOD component shall develop implementing procedures by the initiation of prompt and timely actions to assure the availability of critical materials and manufacturing capabilities to support current and planned defense requirements. Component responsibility includes:

- Establishing and maintaining a single organizational focal point to monitor all material shortage and diminishing source situations.
- Developing plans and simplified coordination mechanisms to deal with existing and potential diminishing manufacturing sources and material shortages, including interaction with government activities.
- Taking rapid remedial action when faced with a material shortage or manufacturer phase-out.
- Initiating actions to reduce reliance on sole source manufacturers and suppliers through the development of additional sources or coordination of substitute items with equipment users.
- Maintaining close contact with industrial/scientific and engineering organizations and industry through a system of follow-ups to discern future trends.
- Using engineering standardization and technical organizations to assure that the most current standard or preferred parts are used in systems design and development.
- Reviewing the efforts of other government departments in the area of material shortages and production phase outs. Using output from their system where possible and ensuring that a compatible data interchange method is established.
- Developing compatible management techniques through coordination with other DOD components and ensuring that there is adequate information and controls for material shortage and diminishing source situations.
- Ensuring that diminishing manufacturing sources and material shortages are recognized in the DAB proceedings.
- Developing a technique, where feasible, to identify "end item application" for those critical or weapon system essential items affected by shortage/phase-out conditions.
- Seeking manufacturer's and supplier's commitments to provide maximum advance notice prior to phasing out production or supply of material.
- Advising using military departments and other users of date(s) beyond which support will no longer be provided for item(s). The DOD components are responsible for notifying International Logistics (IL) customers.

While the mechanics involved in transition will vary among the Services, the end result is the availability of the system for use by the operating forces in consonance with DOD objectives. Transitioning the system to the operational forces while developing, monitoring and controlling transition milestones becomes especially important in the production phase of the system acquisition process.

3.9.6.6 Support for Out-of-Production Systems

Support for out-of-production systems should provide an organized approach and methodology for attaining competition and fair and reasonable prices for spare parts no longer in production.

For out-of-production systems, the weapon system program manager should consider the value to DOD of establishing post-production support agreements for those systems. This can ensure that costs for required spares do not reflect source constraint circumstances leading to unreasonable prices. Procedures also need to be established to qualify additional manufacturing sources to provide competition on specific parts. These procedures should be consistent across the procuring agencies and should allow for qualification across general groups of items built using the same manufacturing process.

3.9.6.7 High Value Spare Parts Breakout Program

For items which represent recurring spare parts requirements and substantial annual buy value, aggressive action to develop alternative sources of supply is required. These sources ensure continuing part availability and competitive sources for these parts. The process of establishing competitive sources for these parts starts early in the production phase and continues as long as they are in the supply system.

During the provisioning process, decisions are made in consonance with the Maintenance Concept, including what spare parts will be specified, and what spare parts new to the inventory must be identified and purchased to meet initial support requirements. After spare parts required to support the Maintenance Concept have been identified, decisions must be made as to how those parts will be procured in terms of competitive postured. The High Value Spare Parts Breakout Program is intended to identify those high dollar spare parts which offer the greatest potential savings through competitive procurement or "breakout." High Dollar Value Replenishment Spare Parts can be defined as spare parts included in those items ranked in descending order of annual buy value (computed by multiplying the unit price times the annual buy quantity) which represent at least eighty percent (80%) of all dollars expected to be spent in the 12-month period when measured in descending order from the highest annual buy value item.

Usually, the developing contractor is asked (required by the contract) to provide the contractor technical documentation as a basis for government decision on the method of purchase. Each item is screened by the government and the item is assigned an Acquisition Method Code (AMC) and AMC Suffix Code in accordance with DOD FAR Supplement 6. The AMC will determine how the item will be purchased unless changed by subsequent review. The suffix code explains the basis for assignment of the AMC. During the life of the part or item, regular screening intervals (often three years) are established. At each screening, the item management organization reviews the forecast buy and the item to determine if action could be and should be taken to develop competitive sources for the item.

3.9.6.8 CAO Involvement

Significant improvements can be attained by greater involvement of the Contract Administration Offices (CAOs) in the spare parts acquisition process. This involvement should include review of prime contractor vendor competition, source identification for direct purchase, limited rights assertions and price reasonableness of prime and subcontracted spare parts. This effort should be implemented through use of support and interface agreement consummated between the CAOs and the involved buying activities. The increased CAO involvement will add to the spare parts acquisition program the knowledge and access that result from the continuing relationship between the CAO and the prime contractor. Specific management attention must be directed to the identification and quantification of price pyramiding on spare parts. Removing situations in which prime contractors and upper tier subcontractors add cost to an item without adding value can make a significant contribution to achieving fair and reasonable prices for spare parts. This can be achieved by breaking these parts out for direct purchase from the actual manufacturer (or possibly for open competition).

3.9.6.9 Life of Type Buy

When all other alternatives have been exhausted for an item no longer to be produced, life of type buy, a one-time procurement may be necessary. Procurement quantity, according to DOD Directive 4005.16, will be based upon demand and/or engineering estimates of mortality, sufficient to support the applicable equipment until phased out of the system.

Post production support will, by focusing organizational resources on improving the process by which spare parts are acquired, assure a more efficient and responsive logistics support program, as well as normalize the price paid for each part.

3.10 Summary

The acquisition environment for manufacturing is the Life Cycle Acquisition Framework (Figure 3.1) model of the process by which products are developed and produced. Program managers along with their integrated product teams (IPTs) use the systems engineering (SE) process to turn requirements into hardware and software solutions for the warfighter. The overarching outcome of early and continuous technical planning is the design, development, and fielding of systems that meet the contractual and performance requirements of the warfighter at an affordable cost. The SE process serves as a basis for integrating manufacturing management into systems engineering activities.

A program manager should be able to:

- Define the development process for acquisition programs;
- Identify the roles and activities of manufacturing during the various phases of an acquisition program;
- Identify the various inputs and output documents that should contain the appropriate manufacturing considerations for that phase of the program; and

- Identify the opportunities and investments requirement in order to mitigate acquisition risk early.

3.11 Related Links and Resources

Numerous reference documents impact the manufacturing management function throughout the acquisition process. These documents originate from many sources and range across academic disciplines, functional activities, and job specialties.

The following is a reference list of DOD Directives (D), Instructions (I) Manuals (M), Pamphlets (P), Military Standards (MS), and other documents. The documents listed contain DOD policy guidance applicable to the manufacturing management function. They are listed as sources of DOD manufacturing management information.

Note: Many of the documents listed are no longer required (due to acquisition reform), but still contain some very valuable information.

Number	Title
GAO-11-233SP	Defense Acquisitions: Assessments of Selected Weapon Programs
	Systems Engineering Fundamentals
	Systems Engineering Plan Preparation Guide
	Creating Manufacturing Plans
GAO-02-701	Capturing Design and Manufacturing Knowledge Early Improves Acquisition Outcomes

4.1 Objective

The acquisition strategy is a business and technical approach designed to achieve program objectives within the resource constraints imposed. It is the framework for planning, directing, contracting for, and managing a program. It provides a master schedule for research, development, test, production, fielding, modification, postproduction management, and other activities essential for program success.

Acquisition strategies must be executed within limits of cost, schedule, and performance and often these strategies are tied to a "best value" approach. Current budget constraints and a strong focus on affordability are driving programs to look closer at the determinants or drivers of cost. A producible design that uses mature manufacturing processes can be a significant factor in achieving cost targets. This chapter describes ways in which a well structured manufacturing strategy can be used to achieve program objectives. A number of manufacturing strategy alternatives will be presented to aid the program manager (PM) in the strategy development and definition process. In addition, specific elements of the alternative strategies are described to establish the basis for application and their conditions for use.

At the end of this chapter a program manager should be able to:

- Define the role and goal of manufacturing;
- Identify the elements of a manufacturing strategy;
- Describe the various production related competition models that can be used by the program manager to increase competition and reduce cost and risk; and
- Describe how multi-year contracting can be used to reduce cost and risk.

4.2 Background

Under Secretary of Defense for Acquisition, Technology and Logistics Edward C. Pete Aldridge Jr. announced on the afternoon of 26 October 2001 the decision to proceed with the Joint Strike Fighter program. This approval advanced the program to the next phase, the System Development and Demonstration (SDD) phase. The Secretary of the Air Force James G. Roche announced the selection of Lockheed Martin teamed with Northrop Grumman and BAE to develop and then produce the Joint Strike Fighter (JSF) aircraft. Pratt and Whitney Military Engines, East Hartford, Connecticut, was awarded a contract for to develop the F135 propulsion system.

The Joint Strike Fighter acquisition strategy called for the development of two propulsion systems. The Pratt & Whitney system will compete, in production, with one developed by the team of General Electric and Rolls Royce. The P&W and GE/RR engines will be physically and functionally interchangeable in both the aircraft and support systems. All JSF aircraft variants will be able to use either engine. The competition was scheduled to continue through the life of the program to reduce risks and foster affordability.

4.3 Introduction

Congress passed the National Manufacturing Strategy Act of 2011 to assist in the turnaround of America's industrial base and get the economy back on track. The bill would require the Commerce Secretary to conduct a comprehensive analysis of the nation's manufacturing sector and submit a National Manufacturing Strategy to Congress. The goals would be to increase manufacturing jobs, identify emerging technologies to strengthen U.S. competitiveness, and strengthen the manufacturing sectors in which the U.S. is currently most competitive.

Congressman Dan Lapinski (D-IL) has noted that "The American economy has been thrust into crisis primarily because of the erosion of our industry due to failed 'free' trade agreements. At the end of 2009, the U.S. manufacturing sector employed more than 11.5 million people- compared to 17.3 million people in 1999-resulting in a reduction of 5.8 million people employed in the sector over the 10 year period. All this while slipping to the world's fourth largest exporter. If we have any dreams of maintaining our current standard of living, we must work to stop these trends."

According to Stephen Ezell and Robert Atkinson in their study *The Case for a National Manufacturing Strategy* , manufacturing plays a critical role in the U.S. economy for five key reasons:

1. It will be extremely difficult for the United States to balance its trade account without a healthy manufacturing sector;

2. Manufacturing is a key driver of overall job growth and an important source of middle-class jobs for individuals at many skill levels;

3. Manufacturing is vital to U.S. national security;

4. Manufacturing is the principal source of R&D and innovation activity; and

5. The manufacturing and services sectors are inseparable and complementary.

The ability of the United States to defend itself and support its allies has always been dependent in great part on the strength of its industrial base. Our capacity to wage war on two fronts during World War II began long before we declared war on either Germany or Japan. It began with H.R. 1776, the "Lend-Lease Act of 1941," in which President Roosevelt exchanged 50 destroyers for 99-year leases on British bases in the Caribbean and Newfoundland. Prime Minister Winston Churchill called America "the great arsenal of democracy." Our warfighters today are dependent on our industrial base to provide them the weapon systems they need to conduct operations. Manufacturing, engineering, contracting, and logistics strategies get integrated into the program's overall management strategy and are major factors in achieving program goals for cost, schedule, and operational effectiveness and suitability.

4.4 The Roles and Goals of Manufacturing

The role of manufacturing is threefold; influence the design; prepare for production (plan); and execute the manufacturing plan. The manufacturing plan should reflect the design intent, ensure repeatable processes, and focus on continuous process and product improvement. The goal of manufacturing is to deliver "uniform, defect-free product that provide consistent performance at an affordable price (life cycle cost). Figure 4-1 illustrates how the role and goal of manufacturing fits into the acquisition life cycle framework. In the early phases the role is to influence the design, that is to accomplish the producibility engineering tasks. Producibility engineering is recognized as one of the major factors in being able to achieve affordability targets. The second role is to plan for production. This requires an assessment of manufacturing feasibility and the identification of manufacturing risks and gaps. Then the development of a manufacturing strategy and plan for reducing the risks, maturing the manufacturing processes and for filling the gaps. As you move out of R&D you need to continue to reduce manufacturing risks by maturing the manufacturing processes to the point that as you approach Milestone C and Low Rate Initial Production you should have demonstrated all manufacturing processes in a pilot line and by now should have "no significant manufacturing risks." Then once you enter production it is a matter of executing the manufacturing plan and delivering uniform, defect-free product. Product that delivers consistent performance (predictable) and is affordable. Many manufacturing and quality assurance processes, such as variability reduction, have a direct correlation to long term performance (reliability) and to the ability to get a product back into serviceable condition after a failure (maintainability). Achieving high reliability with low maintenance costs will drive down life cycle costs and the logistics tail required by the warfighter.

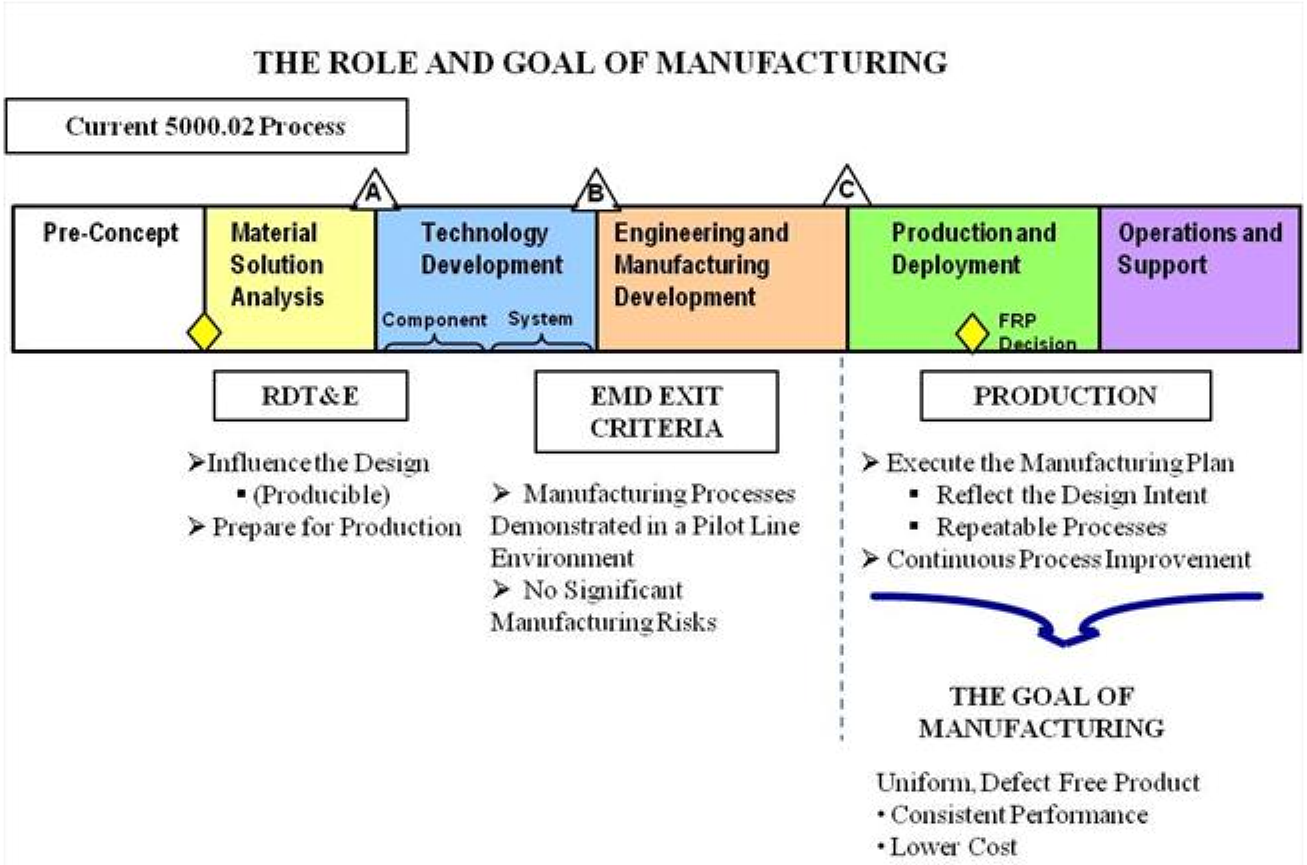

Figure 4-1 The Role and Goal of Manufacturing

4.5 Elements of a Manufacturing Strategy

A manufacturing strategy is a detailed plan for assuring timely and cost effective production of an item which meets all operational effectiveness and suitability requirements. To be effective the strategy must be developed in consonance with program engineering, contracting, test, and logistics strategies, considering current and projected constraints, risks, and opportunities in the industrial-technological base. The strategy needs to address several constraints and risks as identified in Figure 4-2.

- Industrial Base Capabilities
- Capacity
- Material Availability
- Critical Manufacturing Technologies
- Manufacturing Investments
- Producible Design
- Mature Processes
- Special Tooling
- Special Test Equipment
- Manufacturing Skills
- Manufacturing/QA Plan
- QA System Program

Figure 4-2 Manufacturing Constraints and Risks

Manufacturing strategy development must begin during the earliest stages of system development. Acquisition decisions such as system design approach and production rate are intimately intertwined with manufacturing strategy. Manufacturing strategy will affect design and production rate decisions, and design and production rate decisions will affect manufacturing strategy.

While only the most general definition of manufacturing strategy may be possible during the early stages of system development, this general definition will provide a foundation for early acquisition decisions and for later, more detailed, strategy definition. The strategy should grow increasingly more detailed as the program progresses through the acquisition life cycle. The manufacturing strategy must be flexible enough to identify and adapt to changes in the product and the manufacturing environment. Changing constraints, risks, and opportunities can affect even mature system production.

Clear manufacturing strategy development will affect government and contractor actions. Both government and contractor management will be motivated to adopt options that minimize the effect of manufacturing constraints and risks and pursue beneficial manufacturing opportunities.

Table 4-1 lists the major elements of the manufacturing strategy for a particular program. For each element in the strategy, decisions must be made relatively early in the acquisition process to ensure that the required actions are taken in a timely manner. Tradeoffs are made, often within the context of the development of the program acquisition strategy.

- Level of production competition
- Type of production competition
- Role of producibility engineering and planning
- Quality planning
- Quality assurance approach
- Manufacturing process proofing
- Role of industrial modernization incentives program
- Manufacturing technology insertion
- Government manufacturing review process
- Tooling and test equipment
- GFP and component breakout approach
- Contract provisions and reporting
- Production rate

Table 4-1 Major Elements of a Manufacturing Strategy

Each element has associated with it a set of costs and risks which need to be assessed against the specific program realities and technological challenges. Detailed discussion of each of these topics is provided elsewhere in this guide, but the major decision issues in the strategy development process are described below.

Normally certain decisions are already made and serve as input to the strategy development process shown in Figure 4-3. The requirement has been defined, the system to be developed and produced is described to some level of detail and some of the major milestones such as Initial Operational Capability (IOC) have been established. The total quantity to be produced and the estimated total funds forecast to be available are often established. Within these constraints, the detailed strategy is developed. But the constraints have many interdependencies and may even have conflicting dependencies. For example, if there is a lot of technology to be developed, then there may be associated manufacturing processes and inspection techniques that need to be developed. This will add risk, cost and drive a longer schedule. On the other hand you may have a compelling situation where an emerging threat drives the schedule as in the case of the need to develop, produce and field the Mine Resistant Ambush Protected (MRAP) fighting vehicle to help counter the growing threat of Improvised Explosive Devices (IEDs). The MRAP acquisition strategy included a dual path for contracting: a best-value competition with plans to award firm-fixed-price indefinite delivery/indefinite quantity production contracts to all vendors considered capable of meeting test requirements (survivability and automotive performance) with maximum production output; and award of a sole source contract to Force Protection Industries for enough Cougar vehicles to cover the time estimated to conduct the competition, award the production contracts, and ensure quick delivery of proven vehicles to theater. The MRAP used mature technologies, mature design and mature manufacturing processes and a strong focus on production throughput (rates and quantities) to achieve quality and delivery goals.

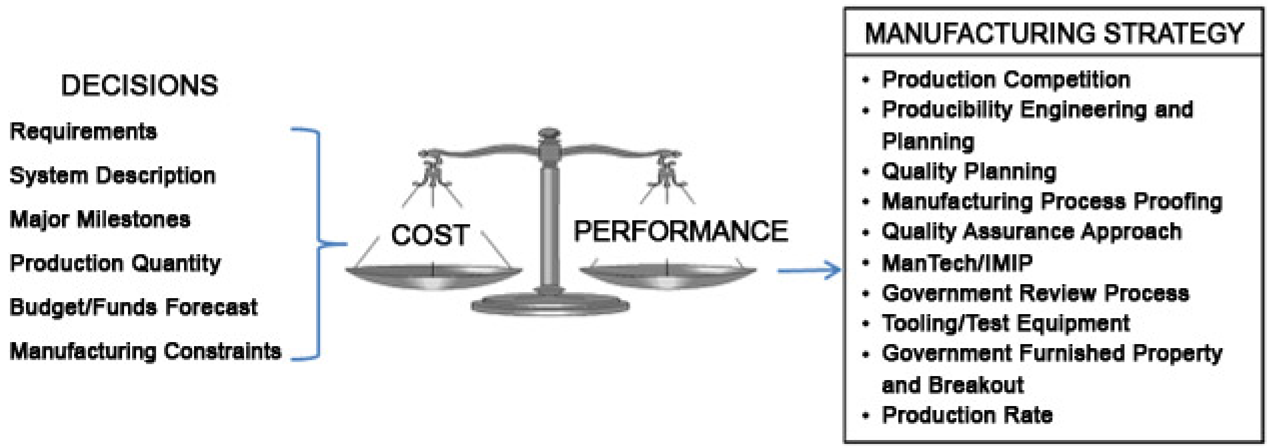

Figure 4-3 Strategy Development Process

Perhaps the most important business issue related to implementation of a manufacturing strategy is how to properly fund programs with these new requirements, especially the funding of activities that reduce manufacturing risks. Those programs that incorporate manufacturing strategies may require earlier funding, but the benefits of this earlier investment will greatly reduce life cycle costs, including non-recurring production costs, through the substantial elimination of errors and change orders later in the program.

4.5.1 Producibility Engineering and Planning

Decisions must be made on the structure and funding levels of the formal Producibility Engineering and Planning (PEP) program. The timing of initial formal Producibility Engineering and Planning (PEP) actions must be established and the objectives for the contracts in each acquisition phase need be determined. Planning and funding for PEP must begin prior to the Preliminary Design Review (PDR) and execution of the PEP needs to occur pre-PDR through the Critical Design Review (CDR) or until the design is completed. Figure 4-1 indicates that if you are going to "influence the design" and achieve a producible design then you need to begin your PEP activities during the Material Solution Analysis Phase. The activities in each acquisition phase need to build on the preceding activities and set the foundation for transition from development to production.

4.5.2 Quality Planning and Approach

An effective quality management system is required if you plan on delivering operationally safe, suitable and effective weapon systems. The quality system assures the as-delivered configuration is the same as the as-designed and as-tested configuration. The quality system serves as the management and control function within the systems engineering process. It requires basic controls over requirements reviews, design inputs, verification and validation of design outputs, and control of design changes. It also requires monitoring and measuring of processes and products to ensure they conform to requirements.

A basic quality management system compliant with industry standard ISO 9001-2008 or, preferably, AS9100 (which is enhanced for aerospace applications), is foundational to producing products that meet contractual requirements. However, it is often necessary to implement tools and techniques that go beyond the basic quality management to ensure the final product meets user needs. Some of these quality tools include Continuous Process Improvement (CPI), Total Quality Management (TQM), Lean, Six Sigma, Theory of Constraints, and Advanced Quality Systems.

4.5.3 Manufacturing Process Proofing (Manufacturing Maturation Plan)

The manufacturing strategy should include the criteria for determining which production processes will require proofing and the timing of such proofing activity. These processes are often identified during a manufacturing risk assessment or during the design as Key Characteristics are identified. Process proofing can make a major contribution to risk reduction, but it may involve cost and/or potential schedule impacts during the development phase. Maturing manufacturing processes should be documented in a formal Manufacturing Maturation Plan.

4.5.4 Industrial Modernization Incentives Program (IMIP)

The Industrial Modernization Incentives Program (IMIP) is an example of government/contractor partnership for mutual strategic benefit. Industrial modernization incentives may be negotiated and included in contracts for research, development, and/or production of weapons systems, major components or materials. The purpose is to motivate the contractor to invest in facilities modernization and to undertake related productivity improvement efforts that it would not have otherwise undertaken or to invest earlier than it otherwise would have done. Incentives may be in the form of productivity savings rewards, contractor investment protection, and/or other appropriate forms. They may be used separately or in combination. Contractor investment protection by government assumption of part of the investment risk is the keystone of IMIP. Program details including specific goals and limitation are presented in Chapter 8.

The Industrial Modernization Incentives Program (IMIP) and the Manufacturing Technology (ManTech) Program are separate sub elements of industrial preparedness. Both programs seek to assure productivity, readiness and responsiveness of the defense industrial base through modernization of the manufacturing and management processes of the enterprise.

IMIP aims at improvements on a factory-wide basis by providing industrial incentives for modernizing the total enterprise through implementation of well established and proven state-of-the-art technologies. Although many IMIP projects have been established on an individual weapon system program basis, the government's preference is for a factory-wide approach that is applicable to all weapon systems and DOD product lines within the enterprise because it offers the greatest potential benefit to the DOD. Perhaps the most important distinction of IMIP is that it uses a business agreement to accelerate implementation of modern manufacturing technology across product lines and production contracts. IMIP couples contractual incentives with technology implementation.

4.5.5 Manufacturing Technology Insertion (ManTech)

The ManTech Program develops technologies and processes for the affordable, timely production and sustainment of defense systems. The program impacts all phases of acquisition. It aids in achieving reduced acquisition and total ownership costs by developing, maturing, and transitioning key manufacturing technologies. Investments are focused on those that have the most benefit to the warfighter and include quick-hitting, rapid response projects to address immediate manufacturing needs. ManTech focuses on the needs of the warfighters and weapon system program by helping to find and implement affordable, low-risk solutions. Mantech:

- Provides the crucial link between technology invention and development and industrial applications;
- Matures and validates emerging manufacturing technologies to support low-risk implementation in industry and DOD facilities, e.g., depots and shipyards; and
- Addresses production issues from system development through transition to production and sustainment.

The ManTech focuses on advancing state-of-the-art manufacturing technologies and processes from the research and development environment (laboratory) to the production and shop floor environment. Technologies with generic application required for defense systems and having high technical and financia1 risk characterize the projects with the highest priority for ManTech funding. ManTech projects demonstrate production application of emerging technologies. Figure 4-4 identifies the DOD ManTech Strategic Thrust for 2010. Proven technologies resulting from the ManTech program are candidates for implementation under IMIP.

Figure 4-4 DOD ManTech Structure

ManTech and IMIP work together to enhance productivity, reduce weapon system cost, improve industrial base capacity, and peacetime capability, surge and mobilization.

4.5.6 Government Review Process

The Government Program Office is required to ensure that contractors supply the government with the goods and services as stipulated in contractual documents. Good oversight ensures that contractors are accountable, poor oversight can lead to uncontrolled growth in spending, poor quality and a warfighter that is not satisfied with their product. Competitive contracting is an excellent tool for ensuring that contractors limit their cost growth and deliver the product on time and with the appropriate quality levels.

Decisions need to be made concerning the amount of PMO and other government involvement during the life of the program. These decisions include the type and quantity of data items, on-site reviews, and issues and contractor decisions which will require PMO or other government organization approval. In addition to identifying the government reviews, initial decisions need to be made on the depth and extent of the reviews to serve as a basis for contractor and government resource planning.

4.5.7 Tooling and Test Equipment

Special tooling and test equipment required for a program can be very expensive and take a long time to develop and procure. The general guidelines for planning for tooling and test equipment need to be established and established early. The issues include contractor investment, the level of rate tooling and test equipment to be utilized, the transition from limited life to rate tools and the degree of similarity between production test equipment and depot test equipment to be required. Also, guidelines for calibrating and maintaining tools and test equipment need to be set forth.

4.5.8 Govenment Furnished Property/Equipment

Providing equipment or subsystems to the prime contractor as Government Furnished Property (GFP) or Government Furnished Equipment (GFE) may reduce the acquisition cost and contribute to greater commonalty in deployed systems. There is however, a corresponding shift of responsibility for system performance and delivery from the contractor to the government. Consideration needs also to be given to the potential for later breakout of equipment of subsystems from Contractor Furnished Equipment (CFE) to GFP.

4.5.9 Contracting Provisions and Reporting

The Technology Development Strategy, Acquisition Strategy, Source Selection Criteria, Contract Language to include Sections L and M need to address manufacturing strategies and considerations. Each of the choices made in developing the manufacturing strategy must be supported by the selection or development of appropriate contract clauses. Where specific actions may be planned for later phases for the acquisition process, it is often necessary to include enabling or planning provisions in the earlier phase contracts to create the proper environment and relationship for the later actions.

4.5.10 Production Competition

The winnowing down of major prime contractors has resulted in the reduction in competition, especially during the production phase. Decisions must be made on whether to utilize more than one source for manufacturing during the production phase and these decisions should be based on sound business practices and a Best Value approach. Best value is a process used in competitive negotiated contracting to select the most advantageous offer by evaluating and comparing factors in addition to cost or price, in this case could and should include manufacturing considerations. Normally, competition in this phase will act to reduce recurring manufacturing cost. The trade off is the increased non-recurring cost to establish the other source(s). Schedule and technical risk are reduced with multiple sources; however, the problem of end item variability will probably increase if not properly managed and controlled.

4.6 Competition

Part of strategy development involves definition of the long term relationship between contractors and the government. Research and field experience indicate that competition between contractors can provide real benefits by encouraging contractor innovation and cost reduction. At the same time, a true strategic approach implies a long term partnership. Several approaches have been used to balance these apparent conflicts in the development of a strategic government/contractor approach to system development and production. These approaches include: leader/follower contracting; component breakout, and multi-year contracting.

4.6.1 Design Competition

DOD acquisition programs face a high risk of failure at the outset of the design process. While some level of risk associated with a new technical concept may be unavoidable, historically this risk has been magnified by the misunderstanding of the industrial design disciplines necessary to turn the concept into a mature product. The government and its contractors must share equal responsibility for this misunderstanding. The contractor's proposal and government source selection process provide the last cost-effective opportunity to ensure application of these critical disciplines during design and the achievement of design maturity.

A mature design meets operational requirements without additional government or contractor intervention - no further field modifications or additional equipment and spares are required to overcome design shortfalls. In the factory, design maturity might be indicated by the tapering off of engineering change proposal (ECP) traffic, once the test phase is underway, if it can be assumed that contract requirements are being met. But what constitutes design maturity at the conclusion of the design effort before entering the formal test phase? This is the question faced at the critical design review (CDR), when a decision to proceed with fabrication of formal test articles must be made, a decision on which this matter of risk hangs.

It must be economically feasible to manufacture a quality product at a specified rate and to deliver end items capable of achieving the performance and reliability inherent in the design. This design requirement is not always well understood and historically has taken a back seat to the more popular objective of high performance. The results of this neglect have ranged from factory rework rates in excess of 50 percent to the suspension of government acceptance of end items pending major redesign for producibility. A strong producibility emphasis early in design will minimize the time and cost required for successful transition to production.

DOD 4245.7-M, Transition from Development to Production specifically identifies the importance of the design disciplines enumerated in Table 4-2. Contractor performance in these disciplines should be an important source selection evaluation criterion. Accordingly, competition should be maintained in the acquisition process until contractor performance in these critical design disciplines can be properly assessed.Design reference mission profile identification

- Design requirements identification
- Trade off studies
- Design policy documentation and use
- Design process consideration of manufacturing and operations
- Design analysis including stress and strength analysis
- Parts and materials selection considering special system requirements
- Software function and logic design analysis
- Computer aided design utilization
- Design-for-testing
- Configuration control
- Design review discipline
- Realistic design release scheduling

Table 4-2 Critical Design Disciplines

DOD 4245.7-M and NAVSO P-6071, Best Practices, provide general guidelines which may be used in developing criteria for design effort evaluation. Specific criteria must be tailored to individual system requirements.

4.6.2 Leader/Follower

Approach: Awarding a prime contract to the leader company which obligates the leader to subcontract a designated portion of the total number of end items to the follower company and to assist the follower in manufacturing.

The objectives presented in Table 4-3 represent a general outline of the elements that must be evaluated in considering the use of leader/follower contracting. Consideration of these objectives and individual program differences is essential to the successful application of this approach. Vital program considerations include: supply restrictions; manufacturing quantities; program relationship to other programs; and potential improvement of product quality and/or cost reduction from the introduction of competition. Consideration of the relationship between program requirements, funding, and economic production quantities is vital, particularly when only small quantities are required.

- Shorten the time for delivery
- Establish additional sources of supply for reasons such as geographical dispersion or broadening the manufacturing base
- Make maximum use of scarce tooling or special equipment
- Achieve economy in manufacturing
- Assure uniformity and reliability in equipment performance, compatibility or standardization of components, and interchangeability of parts
- Eliminate problems in use of proprietary data
- Effect transition from the full-scale development phase to the production phase and to subsequent competitive procurement
- Improve the competitive status of major acquisitions

Table 4-3 Leader/Follower Contracting Objectives

There are several policy limitations to be considered by the program manager. For example, leader/follower contracting should be used only when the circumstances identified in Table 4-4 are present.

- The leader company possesses the necessary manufacturing know-how and is able to assist a follower company
- No source, other than a leader company, could meet the governments requirements without leader company assistance
- Assistance of the leader company is required to produce the items
- The government reserves the right to approve contracts between the leader and follower companies

Table 4-4 Leader/Follower Conditions for Use

4.6.3 Component Breakout

The term "component breakout" can be defined as a program management decision of whether or not subsystems, assemblies, subassemblies, and other major elements of end items or systems should be purchased directly by the government and provided to the prime contractor as government furnished material. Here consideration of component breakout will be limited to components that have been contractor-furnished material in a previous system buy. The approved and current acquisition plan should identify those milestones at which component breakout decisions should be made. These decisions include those which must be made early in the contracting cycle on such matters as initial program support levels of government furnished versus contractor furnished equipment and the contract provisions covering spare parts provisioning.

4.6.3.1 Objectives of Component Breakout

Whenever a prime contract for a weapons system or other major end item will be awarded without adequate price competition and the prime contractor acquires components without such competition, DOD policy is to break out those components if substantial net cost savings can be obtained without jeopardizing the quality, reliability, performance or timely delivery of the end item. Additionally, the desirability of component breakout should also be considered whenever substantial net cost savings will result from greater quantity purchases or improved logistics support. Component breakout also provides a firm basis for later direct purchase or competitive purchase of the required spare and repair parts.

4.6.3.2 Component Breakout Issues

There are many issues of importance to the program manager in the implementation of a component breakout program. How are breakout candidates to be identified? What logistics system risks are involved? How will economic and quantity change factors influence cost? What responsibilities will the government share or assume as a result of providing government-furnished components? Will the item be purchased competitively or on a sole source basis? The answers to these questions cross many disciplines including production, engineering, finance, and contract administration. Most weapon systems involve relatively large numbers of end items procured over the program life cycle which often extends over a number of years.

4.6.3.3 Component Breakout Guidelines

The program manager should base each component breakout decision on an assessment of the potential risks of degrading the end item through such contingencies as delayed delivery and reduced reliability of the component, calculation of estimated net cost savings over the program life cycle, and analysis of the technical, operational, logistic and administrative factors involved. Particular emphasis should be placed on assessing the stability of the design, the availability of item data required to support the breakout decision, and the ability of the government to transfer the design description to a potential source.

4.6.4 Production Rate

While the production rate will be constrained by the available funds profile, some allowance for variation may remain, in addition, total program cost may be significantly impacted by changes in production rate. These impacts need to be assessed and presented to the involved decision makers.

4.7 Multi-Year Contracting

A multi-year contract is a contract covering more than 1-year's but not in excess of 5-year's requirements, unless otherwise authorized by statute. Total contract quantities and annual quantities are planned for a particular level and type of funding as displayed in a current 5-year development plan. Each program year is annually budgeted and funded and, at the time of award, funds need only to have been appropriated for the first year. The contractor is protected against loss resulting from cancellation by contract provisions which allow reimbursement of costs included in the cancellation ceiling.

This technique offers significant potential for cost savings by enhancing program stability and providing contractors with the capability to optimize schedules, stabilize their workforce, purchase economic lot buys of material, and plan for investing in cost reducing capital improvements. Although multi-year contracts can benefit the government by saving money and improving contractor productivity, it can also entail certain risks, including increased cost to the government, should a multi-year contract later be changed or terminated.

4.7.1 Multi-Year Contracting Objectives

The primary objective for multi-year contracting is the potential for lower weapon system costs. Estimates of potential savings have been made in the range of 10 to 30 percent. Experience indicates that specific savings are difficult to calculate but that savings of 10 to 15 percent appear to be reasonable. Multi-year contracting is encouraged to take advantage of one or more of the objectives presented in Table 4-5.

- Lower costs
- Enhancement of standardization
- Reduction of administrative burlen in the placement and administration of contracts
- Substantial continuity of production or performance, thus avoiding annual startup costs, preproduction testing costs, make ready expenses, and phase out costs
- Stabilization of contractor work forces
- Avoidance of the need for establishing and proving out quality control techniques and procedures for a new contract each year
- Broaden the competitive base with opportunity for participation by firms not otherwise willing or able to compete for lesser quantities, particularly in cases involving high start up costs
- Provide incentives to contractors to improve productivity through investment in capital facilities, equipment and advanced technology

Table 4-5 Multi-Year Contracting Objectives

4.7.2 Guidelines

Multi-year contracting may be used when Congress authorizes funds for up to 5 years for the procurement of specified quantities. Although appropriations are still granted annually, the service agreements with the congressional committees almost guarantees the multi-year procurement (MYP) term and allows significant advanced procurement of long lead items. Multi-year contracting must make it possible to attain one or more of the objectives in Table 4-5 (above) where all the criteria in Table 4-6 are present.

- Multi-year contracting will result in lower total costs
- Minimum requirements for the item to be purchased will remain unchanged during the contract
- There is a reasonable expectation that the DoD will request necessary funds
- Item design is stable cost estimates and savings estimates are realistic

Table 4-6 Multi-Year Contracting Criteria

4.8 Summary

The role of manufacturing is to influence the design; prepare for production (plan); and execute the manufacturing plan. The goal of manufacturing is to deliver "uniform, defect-free product that provides consistent performance at an affordable price (life cycle cost). The manufacturing plan and execution of the plan should be accomplished by focusing on the major elements of the manufacturing strategy and using competition, when possible, to drive down cost while improving quality and reliability.

4.9 Related Links and Resources

Numerous reference documents impact the manufacturing management function throughout the acquisition process. These documents originate from many sources and range across academic disciplines, functional activities, and job specialties.

The following is a reference list of DOD Directives (D), Instructions (I) Manuals (M), Pamphlets (P), Military Standards (MS), and other documents. The documents listed contain DOD policy guidance applicable to the manufacturing management function. They are listed as sources of DOD manufacturing management information.

Note: Many of the documents listed are no longer required (due to acquisition reform), but still contain some very valuable information.

Number	Title
	Acquisition Strategy Decision Guide (Navy)
Mil-Std-1528A	Manufacturing Management Program

Defense Manufacturing Management Guide for Program Managers
Chapter 5 - Continuous Process Improvement (CPI) / Lean / Six Sigma (LSS)

5.1 Objective

DOD Directive 5010.42, dated 15 May, 2008, outlines the DOD policy and responsibilities for the implementation of a DOD -Wide Continuous Process Improvement (CPI)/Lean / Six Sigma (LSS) Program. The key objectives of DOD's CPI/LSS approach are to strengthen military capabilities by making improvements in:

- Productivity,
- Performance (availability, reliability, cycle time, investment and operating cost),
- Safety,
- Flexibility to meet mission, and
- Energy efficiency.

The role of the program manager (PM) is to direct the development, production, and initial deployment of a new defense system. This must be done within limits of cost, schedule, and performance, and as approved by the program manager's acquisition executive. The CPI tools outlined in this chapter can be used to support the achievement of these capabilities. A program manager should be able to:

- Define quality and identify the various forms and structures associated with quality;
- Describe a few of the more significant quality initiatives;
- Identify several continuous process improvement tools;
- Describe the connection between quality and reliability/maintainability (R&M); and
- Describe how quality can be addressed in contract language.

5.2 Background

The use of improvised explosive devices (IEDs) in the wars in Iraq and Afghanistan greatly accelerated the demand for the Mine Resistant Ambush Protected (MRAP). However, the demand for the vehicles significantly outpaced the ability to produce and deliver. SPAWAR Systems Center Charleston was the final stopping point for the MRAP where the command, control and communications systems were integrated into a variety of vehicle configurations. The original production pace at Charleston was averaging five vehicles a day. The demand was for fifty vehicles/day and lives were at stake. Personnel riding in MRAPs, in forward areas, had a much higher survivability rate if attacked with explosive devices. Through a coordinated CPI/LSS effort among the contributing systems commands, suppliers, acquisition communities and industry partners, the goal to deliver over 3,500 vehicles into theater before the end of calendar year 2007 was achieved with production peaking at over 75 vehicles per day at one point.

5.3 Introduction

The goal of manufacturing is to deliver uniform, defect-free products to the warfighter, products that provide consistent performance and are affordable.

According to experts, quality is defined as follows:

Dr. W. Edwards Deming defines quality as "meeting or exceeding customer expectations." He is credited with reviving the Japanese economy after World War II using statistical tools. His total quality management philosophy was expressed in his 14-Points for improving quality, productivity and competitive position. In 1960, Emperor Hirohito awarded Dr. Deming with the prestigious Second Order Medal of the Sacred Treasure. Dr. Deming notes that "only the customer can define quality."

Dr. Joseph M. Juran defines quality as "fitness for use." He is considered by many quality professionals as "the father of quality." He literally wrote the book on quality, " *The Quality Control Handbook* ," and was awarded the Order of the Sacred Treasure. Dr. Juran came up with the Juran Trilogy, which focuses on quality through three managerial processes; planning, quality control, and quality improvement. Dr. Juran is also credited with establishing corporate

Quality Councils, giving senior management the responsibility for establishing the overall strategy for achieving a culture of quality improvement.

Philip Crosby defined quality as "conformance to requirements." He made quality easy to understand and came up with several well known quality terms to include, " *Do it right the first time, zero defects, quality is free and the cost of quality* ."

Another definition of quality is "meets requirements (implies that the requirements are reasonable, feasible, and affordable) with a goal of zero defects."

Quality Assurance and Quality Control are often used to mean the same thing, but they are in fact different.

Quality Assurance (QA) is the planned and systematic activities implemented in a quality system so that the quality requirements for a product or service are fulfilled. QA focuses on the entire quality system including suppliers and ultimate consumers of the product or service. It includes all activities designed to produce products and services of appropriate quality. QA begins before a product is made or before a project is even started.

Quality Control (QC) refers to the activities used during the production of a product that are designed to verify that the product meets the customer's requirement. QC focuses on the process of producing the product or service with the intent of eliminating problems that might result in defects. QC begins as the product is being produced. Another way to look at it is that:

- QA makes sure you are doing the right things, the right way
- QC makes sure that the results of what you have produced meet your specifications.

Quality management includes all the functions involved in the determination and achievement of quality (this includes QA and QC). As managers, we know that quality (excellence) is a matter of culture and behavior. We must change those cultural aspects that impede production of high quality systems and foster those cultural aspects that promote positive change. DOD is working with the services and industry to identify the key approaches to enhance quality. Many excellent quality management tools have been developed and will be discussed later in this chapter.

What does quality have to do with consistent performance and affordability?

Products perform better when there is less variation on the key and critical characteristics. For example, there are about 10,000 dimensional characteristics on a typical automotive transmission. However, engineering studies have shown that only a few of those characteristics are considered key characteristics. By controlling the quality of those few key characteristics the transmission will not only operate smoother, it will last longer and require less maintenance and repair. Thus, by controlling quality positively impact both performance and affordability.

5.3.1 Quality of Design

Quality of design is a "customer driven standard." The quality of a particular design is the inherent capability of the product to meet user's needs given the design. This means that the customer's requirements must be captured and then translated into a design solution. This means all of the customers and all of the requirements. The unit commander may be concerned about availability, the warfighter may want performance, the maintainer reliability, the taxpayer affordability, and the EPA may be concerned about the dumping of hazardous waste when the item reaches its useful life. These requirements or attributes often become Key Performance Parameters (KPPs) and are normally expressed as a threshold, representing the required value, and an objective, representing the desired value. The KPPs are categorized as measures of effectiveness (MOEs) which are further decomposed into Measures of Performance (MOP) and Measures of Suitability (MOS). MOPs are a measure of a systems' performance and may be expressed as speed, payload, range, time on station, or other distinctly quantifiable performance features. MOSs are a measure of an item's ability to be supported in its intended operational environment. MOSs typically relate to readiness or operational availability, and hence reliability, maintainability, and the item's support structure.

The objective of the DOD acquisition process is to provide to the operational forces cost-effective products that are mission-capable upon receipt and throughout their operational life all the way through to disposal. The following quality of design issues are integral to achieving this requirement:

- Performance,
- Reliability,
- Availability, and
- Maintainability.

Many factors are important to reliability, availability and maintainability (RAM): system design; manufacturing quality; the environment in which the system is transported, handled, stored, and operated; the design and development of the support system; the level of training and skills of the people operating and maintaining the system; the availability of materiel required to repair the system; and the diagnostic aids and tools (instrumentation) available to them. All these factors must be understood to achieve a system with a desired level of RAM. During pre-systems acquisition, the most important activity is to understand the users' needs and constraints. During system development, the most important RAM activity is to identify potential failure mechanisms and to make design changes to remove them. During production, the most important RAM activity is to ensure quality in manufacturing so that the inherent RAM qualities of the design are not degraded. Finally, in operations and support, the most important RAM activity is to monitor performance in order to facilitate retention of RAM capability, to enable improvements in design, or of the support system. Measures of quality of design may be characterized in terms of the emphasis on each of these issues received during design of the complete product - including design effort to reduce exceptional manufacturing or support burdens.

Performance: Performance is the demonstrated level of military capability of the end system. It is those attributes or characteristics of a system that are considered to be a critical or essential military capability. In this regard, we look to those characteristics that give the item military utility - such as payload, range, thrust, probability of kill, speed, or any of a vast array of quantitative parameters. The quality of design is reflected in the level of the performance characteristics that can regularly be obtained under field conditions without damage or excessive wear and tear on the equipment. This perspective of the quality of design is intimately related to our military strategy regarding use of technology as a force multiplier and, thus, it is a significant element in successful design evolution.

Reliability: Reliability is the probability of an item to perform a required function under stated conditions for a specified period of time. Reliability is further divided into mission reliability and logistics reliability. Mission reliability addresses the probability of carrying out a mission without a mission-critical failure (e.g. mean time between mission critical failure or MTBMCF). Logistics reliability is the ability of a system to perform as designed in an operational environment over time without any failures (e.g. meant time between failure or MTBF). Reliability is a function of the design complexity and the inherent ability of the parts of the system to continue functioning properly under operational conditions. It is influenced by design decisions on quantitative issues such as stress levels, design margins, part selection, part simplicity, redundancy, and operating temperatures. When the system as designed interacts with its use environment, the inherent reliability of the design is the basis for prediction of the duration and probability of failure-free service - assuming that the design has not been degraded by the manufacturing processes. In this sense, the quality of design can be viewed as a boundary because the system, as produced, cannot be better than the theoretical quantitative quality of design.

Availability: Availability is a measure of the degree to which an item is in an operable state and can be committed at the start of a mission when the mission is called for at an unknown (random) point in time. Availability as measured by the user is a function of how often failures occur and corrective maintenance is required, how often preventative maintenance is performed, how quickly indicated failures can be isolated and repaired, how quickly preventive maintenance tasks can be performed, and how long logistics support delays contribute to down time.

Maintainability: Maintainability is the ability of an item to be retained in, or restored to, a specified condition when maintenance is performed by personnel having specified skill levels, using prescribed procedures and resources, at each prescribed level of maintenance and repair and its measurement can be expressed as "mean time to repair (MTTR)." Maintainability of the design measures such quality of design choices as complexity, accessibility, and testability in the installed condition. The measures provide a quantitative relationship among quality of design decisions and the resulting skill level requirements, special equipment requirements, and related resource requirements for resolving test, repair and other similar issues.

The combined effect of the inherent reliability and maintainability quantifies the operational availability of the system. By "availability" we refer to the proportion of time in which the system is capable of performing its defined mission. Where the availability inherent in the design is low, it can be improved by special support and maintenance action or by restriction on system use, but these actions incur penalties in cost to support the system. Reliability and maintainability emphasis in design means that an operational availability approach to quantifying system parameters can result in higher quality of design than a fragmentary suboptimized approach would produce.

In developing designs that will exhibit the requisite quality, the program management office (PMO) must continually evaluate the design as it evolves to determine the adequacy of contractor attention to quality issues and to determine the expected level of the resulting quality of the design. In their participation in the design process, the PM office should focus on the quality characteristics of the design. A quality characteristic can be defined as a basic element that is determined to be one of the requirements for arriving at a configuration or design that will satisfy the user need or mission involved. In one sense, all of the descriptors and characteristics of the design could be defined as quality characteristics, since the eventual performance is a composite of all the design details. This definition is too cumbersome to be of value in prescribing design review activity. The PMO should limit the field of definition to only that set of design elements or features that have quantitative and theoretically auditable impact on the system's performance and availability. This set could include issues such as parts' relative stress levels, materials, test parameters, dimensions and tolerances, grade of parts used, system and subsystem complexity, controlled manufacturing processes, system producibility, and inspectability. These elements represent characteristics that must be controlled during the production of the system to ensure that the quality of conformance is not degraded.

5.3.2 Quality of Conformance

Quality of conformance is the degree to which a product or service meets or exceeds its design specifications and is free of defects or other problems that could degrade its performance. The manufacture, processing, assembling, finishing, and review of the first article and first production units, is where failure or success in the area of quality of conformance is first measured. Any operation which causes the characteristic to be outside of the specified limits will render the configuration of the product different from that which was originally intended, and this could impact cost, schedule, and performance.

Most major system acquisition programs require a quality program requirement in accordance with ISO 9001:2008 or AS 9100 (replacement to MIL-Q-9858A). ISO 9001 provides a standard quality management system that organizations can adopt to help ensure the quality of their products or services. ISO 9001 requires the contractor to establish and maintain a quality program acceptable to the government in accordance with the commercial specification. The contractor, during the earliest practical phase of contract performance, shall conduct a complete review of the requirements of the contract to identify and make timely provision for the special controls, processes, test equipment, fixtures, tooling and skills required for assuring product quality. This initial planning will recognize the need and provide for research, when necessary, to update inspection and testing techniques, instrumentation and correlation of inspection and test results with manufacturing methods and processes. This planning will also provide appropriate review and action to assure compatibility of manufacturing, inspection, testing and documentation.

5.3.3 Contracting Office Roles and Responsibilities

The Defense Contract Management Agency (DCMA) is the Department of Defense (DOD) component that works directly with Defense suppliers to help ensure that DOD, Federal, and allied government supplies and services are delivered on time, at projected cost, and meet all performance requirements. DCMA provides a broad range of contract-procurement management services. Before contract award, DCMA provides advice and services to help construct an effective solicitation, identify risks, select the most capable contractors and write contracts to meet the needs of their customers. After contract award, DCMA monitors contractor performance and management systems to ensure compliance to the terms and conditions of the contract.

One of DCMA's core competencies and processes is in the area of quality assurance. Quality Assurance Specialists at DCMA are responsible for assuring contract technical performance and the inspection, testing, and acceptance of products, supplies, and services being produced by the nation's defense contractors. They also conduct risk assessments and develop risk plans to mitigate the risks to successful program performance and execution.

The contract must specify the proper contract quality requirements, stipulate the place of performance, and the place of acceptance of the supplies or services. DCMA typically has the responsibility for assuring contractor compliance with all of the contract provisions including the contract quality requirements and accomplishes most source inspections.

The CAS component Quality Assurance Representative (QAR), who is assigned the responsibility for the contractor facility, is the individual charged with responsibility for assuring that the contractor complies with all contract quality requirements, including evaluating and determining the acceptability of contractor's inspection system or quality program, and for performing product inspection to assure quality of conformance. It is helpful to work with the on-site QAR in determining the best approach to product testing and acceptance. Critical and key product characteristics should be identified early and made a mandatory government inspection point.

5.3.4 Quality Feedback

The last element which affects the product quality is the feedback of quality and other data during production and after the item has been fielded and is in use. The results of the design and manufacturing efforts receive their real test when the item or system is actually placed in use under rigorous field conditions. If all of the prior efforts have been adequately performed, the resulting product should meet the user's needs. The goal is to strive for no failures and full user satisfaction. If this is not achieved, then corrective action must be taken to remove the cause of failure and of the user discontent. Of course, this is more difficult at this late stage of the acquisition cycle then if action were taken to identify and correct the root cause of the problem early in design or production. If the root cause of the problem requires a design change then engineering changes after this point cost more to implement than those discovered during initial design; therefore, it is important that all quality actions take place during design, development, and manufacture of the product. It is essential that manufacturing/QA personnel are involved in all aspects of any program, and are involved early in the process.

5.3.5 ISO 9001/AS 9000

5.3.5.1 ISO 9000

The ISO 9000 series of International Quality Standards are an outgrowth of efforts by the European Committee for Standardization and the International Organization for Standardization (ISO). The forming of the European Union in 1992 was the major factor in forcing the harmonization of the nineteen different European country standards into one. ISO 9001has been adopted by over 150 countries making it the standard for companies doing business internationally. ISO 9000 was adopted in the U.S. as ANSI/ASQC Q90. The aerospace industry modified ISO 9000 and came up with their version known (AS 9000).

ISO 9000 is a series of standards outlined below:

- **ISO 9000 (Q90):** Guideline for selection and use of quality system standards. It provides insight for various situations and conditions as well as definitions and explanations.
- **ISO 9001 (Q91):** Defines minimum quality system requirements for design/development, production, installation and servicing. It is the most complete standard. It applies to manufacturing and service businesses engaged in all these activities.
- **ISO 9002 (Q92):** A subset of 9001. It applies only to production and installation activities.
- **ISO 9003 (Q93):** Applicable to final inspection and test.
- **ISO 9004 (Q94):** Guideline for quality system elements.

ISO 9000 standards define the required elements of an effective Quality Management System (QMS). The twenty elements of the QMS are listed below.

• Management responsibility	• Management responsibility
• Resource management	• Resource management
• Quality System	• Quality System
• Contract Review	• Contract Review
• Design Control	• Design Control
• Document Control	• Document Control
• Purchasing	• Purchasing
• Purchaser-Supplied Product	• Purchaser-Supplied Product
• Product Identification and Traceability	• Product Identification and Traceability
• Process Control	• Process Control

Table 5-1 Quality Management System Elements

It is interesting to note that the DOD MIL-Q-9858 for Quality Programs, released in 1958, was a model for the British Standard BS-5750, which was released in 1979. BS-5750 was the model used for development of ISO-9000 in 1987. Thus, there is a great deal of commonality between MIL-Q-9858 and ISO 9001.

It is not unheard of for quality management certificates to be sold by unscrupulous firms or to have provided prepared boilerplate manuals, training documents etc., especially overseas. Such a practice is quite prevalent in the People's Republic of China and has affected numerous US commercial firms. Certification by a 3rd party auditor should be viewed as a bare minimum and a starting point for managing quality not the end in and of itself. Managers should also be aware that many 3rd party registrars allow the customer to select their auditor by name this arguably has an effect on the objectivity of the auditor. Finally, ISO 9000/AS9100 describe a quality management system. They do not guarantee product quality.

5.3.5.2 AS 9000

AS 9000 was developed by a group of aerospace engineers from the United States so that there would be one standard that was harmonized for use by aerospace prime contractors and their sub-tier suppliers and vendors. AS 9000 is a basic quality standard that was based on ISO 9000 and Boeing's D1-9000 Quality Program and was first published in March of 1998.. The standard contains the twenty (20) elements of ISO 9000, as listed above, and another twenty-seven (27) clarifications and eight (8) notes. AS 9000 had strong backing from the U.S. government as well as by the Aerospace Industries Association (AIA). AS 9000 meets the needs of civil and military aviation by providing a comprehensive quality system for safe and reliable products. AS 9000 is in fact a family of standards to include the following:

- AS9101 - Quality System Assessment (the checklist corresponding to AS9100);
- AS9101A - Quality System Assessment (the checklist corresponding to AS9100A);
- AS9102 - Aerospace First Article Inspection Requirement;
- AS9006 - Deliverable Aerospace Software Supplement for AS9100A;
- AS9110 - Quality Maintenance Systems - Aerospace - Requirements for Maintenance Organizations; and
- AS9120 - Quality Management Systems - Aerospace Requirements for Distributors.

5.3.6 Baldrige Performance Excellence Program

The Malcolm Baldrige National Quality Award program was established in 1987 with a goal to enhance the competitiveness of U.S. businesses. The National Institute of Standards and Technology (NIST) developed and manages the Baldrige program now called the Baldrige Performance Excellence Program. The Baldrige Performance Excellence Program is a customer-focused federal change agent that enhances the competitiveness, quality, and productivity of U.S. organizations. Its scope has since been expanded to health care and education organizations (in 1999) and to nonprofit/government organizations (in 2005). Congress created the Award Program to:

- Identify and recognize role-model businesses;
- Establish criteria for evaluating improvement efforts; and
- Disseminate and share best practices.

The Baldrige Criteria for Performance Excellence provides a framework that any organization can use to improve overall performance. The Criteria are organized into seven Categories:

Leadership; Strategic Planning; Customer Focus; Measurement, Analysis, and Knowledge Management; Workforce Focus; Process Management; and Results. Currently there are six sectors that can apply for the Baldrige Performance Excellence Award, these include, Education, Health Care, Manufacturing, Small Business, Nonprofit/Government, and Service.

5.4 Continuous Process Improvement (CPI)

Continuous Process Improvement or CPI is an integrated system of improvement that focuses on doing the right things right. CPI is also an enterprise-wide "way of thinking" for achieving lower cost, shorter lead and cycle times, and higher quality. CPI has a focus on enhancing the satisfaction of the customer, often the warfighter, by improving the processes that are used to develop and deliver the product or service.

CPI is being used by the DOD to achieve a business transformation that is being used to help improve combat readiness and the warfighting capability of the services and agencies. This is accomplished by applying a common approach and proven support tools to continuously and incrementally improve processes. When leaders establish goals or create a vision of the future, CPI methods help achieve them. CPI results are typically measured using the following metrics:

- Improved Performance (Process Quality, Reliability, and Security);
- Reduced Process Cycle Times;
- Improved Safety;
- Improved Workplace Quality of Life;
- Improved Affordability;
- Improved Flexibility or Ability to Meet Emergent Requirements; and
- Improved Customer (Warfighter) Satisfaction.

CPI is an outgrowth of the Total Quality Management initiatives started in the 1980's and it embraces many of the current quality tools and initiatives that have been so successful in the commercial sector. These tools include Lean, Six Sigma, Theory of Constraints, and the seven quality assurance and quality management tools. These tools will be discussed later in this chapter. Within the DOD there are five areas that have been identified by the Deputy Under Secretary of Defense (Logistics and Material Readiness) for application of CPI, these include:

1. Material acquisition,

2. In-service engineering,

3. Materiel maintenance,

4. Supply support, and

5. Material distribution.

5.4.1 Total Quality Management (TQM)

In the early years after the industrial revolution inspectors were responsible for quality. It was their job to pass judgment on the "goodness" of the product. As manufacturing enterprises grew larger and production increased this created a need for full time inspectors and for an inspection organization. One of the problems was that there was no quality management system to follow, there was no focused training, and there was plenty of pressure to "ship the product." It wasn't until the 1920's that statistical theory began to be applied to the production environment as a quality control technique with Walter Shewhart developing the first control chart. Then in the 1950's Doctors Deming and Juran developed expanded management theories about quality assurance to include the need to "design and build" quality into the product or service rather than trying to inspect it in. The term "total quality" was first used in 1969 at an international quality conference by Armand Feigenbaum. Koru Ishikawa used the term "total quality control" at the same conference and explained that quality was different in Japan than in the U.S.

The TQM process is an organizational approach to continuous improvement of quality and productivity that impacts the entire organization, not just the production environment. TQM requires management to exercise the leadership to establish the culture and environment for the process to flourish. It involves an integrated effort toward improving performance at every level. This improved performance must satisfy goals of quality, cost, schedule, mission need, and suitability focusing on increased customer/user satisfaction.

To meet this challenge, DOD and industry must redirect the work force, change management styles, implement new processes, and most important, listen to employees, as well as their customers, the operating forces. Management must create the climate to establish challenging goals and to ensure that the work force is properly motivated. Tangible actions are necessary to stimulate changes.

Improvements in quality can provide the highest return on investment, because they involve the efficient use of existing people and material resources. The reduction of errors at every level reduces costs and improves the effective use of resources. Quality does not cost; it pays.

One of the leaders of the quality revolution, Dr. Deming, came up with a 14 Step Process for implementing Total Quality Management:

1. Create a constancy of purpose (for continuous improvement)
2. Adopt a new philosophy
3. Cease dependence on mass inspection
4. End the practice of awarding business on the basis of price
5. Continuously improve the system of production and service
6. Institute training (train and educate everyone)

7. Adopt and institute leadership
8. Drive out fear
9. Bread down barriers between staff areas (eliminate boundaries)
10. Eliminate slogans, exhortations and targets for the workforce
11. Eliminate numerical quotas
12. Remove barriers that rob people of pride of workmanship
13. Encourage self-improvement
14. Take action to accomplish the transformation

Table 5-2 Deming's 14-Points

Other quality guru's had their own approach, but in reality they all focused on using people and tools to drive continuous process improvement.

TQM is based upon recognition of the need for interactions between various disciplines. Management must have a conceptual understanding of quality technology including statistical thinking and tools. Technical personnel must understand management's role. Statisticians and other quantitatively trained personnel must avoid the pitfall that statistical thinking and tools are the total solution. The use of statistical techniques is certainly necessary, but definitely not the only condition for success. Experience has shown that use of statistics has a limited impact unless its use is supported by a larger system such as TQM. By institutionalizing TQM, the DOD program managers can help ensure the proper role and use of quality technology. Thus, TQM tools do not merely include statistical methods, but also include concurrent engineering, computer applications, CAD/CAM systems, producibility analysis, data-management and analysis systems, value engineering, transitioning from development to production templates, and several other techniques outlined in the various chapters of this guide.

5.4.2 Lean

When people talk about Lean they are really talking about the Toyota Production System and the myriad of tools and processes that were developed under the guidance of Taiichi Ohno and Shiego Shingo. Lean began in the spring of 1950 when a young Japanese engineer, Eiji Toyoda, set out on a three month pilgrimage to Ford's Rouge plant in Detroit. The Rouge plant was the largest, and most complex in the Ford family. After much study, he went back to Japan and with the help of his production genius, Taiichi Ohno, they soon concluded that mass production would never work in Japan and began to adopt a new approach. From this tentative beginning was born what Toyota came to call the Toyota Production System we now know as "lean production."

Toyota faced a host of problems in Japan. Their domestic market was tiny but still demanded a wide range of vehicles from luxury cars for executives, to large and small trucks for farmers and factories, and small cars for the crowded cities and high energy prices. The native Japanese work force also was no longer willing to be treated as a variable cost or as interchangeable parts. Japan also did not have the advantage of "guest workers" (immigrants willing to put up with substandard working conditions) such as was available in America and in Europe.

The first process that Ohno tackled was stamping of sheet metal. Until now, the standard practice had been to stamp a million or more of a given part in a year. Unfortunately, Toyota's entire production was to be a few thousand vehicles per year. Ohno concluded that rather than dedicating a whole set of presses to a specific part and stamping these parts for months or even years without changing dies, he would develop simple die change techniques, and change dies frequently (every two to three hours, versus two to three months) using rollers to move dies in and out of position. This way he would need only a few presses rather than a large number of them, and he found it was actually cheaper to produce a smaller number of parts and not have to inventory them. Not only did he save on the cost of inventory, but mistakes were also caught much earlier in the process allowing Toyota to make corrections to processes earlier.

Ohno then went on to rethink the assembly process. He chose to regroup the assembly workers into teams. Where Ford had given the jobs of housekeeping, tool repair and quality checking to independent specialists, Ohno gave these responsibilities to each team. Where Ford had felt that it would be better to let a mistake go through to the end and have a rework specialist correct an error, Ohno felt that rework was merely a costly addition that was unnecessary and needed to be corrected immediately. Thus Ohno placed a cord above every workstation and instructed workers to stop the whole assembly line immediately if a problem emerged that they couldn't fix. Then the whole team would come over to work on the problem and implement corrective action.

Ohno also instituted a system of problem solving called "the five whys." Workers were taught to trace every error back to its root cause, then to devise a fix so that it would never occur again. By the time Ohno's system hit its stride, the amount of rework needing to be done was minimal. Workers were able to catch almost every error as it occurred. The quality of cars shipped steadily improved, reliability went up and costs went down. This was because quality inspection, no matter how diligent, simply cannot detect all the defects that can be built into today's complex vehicles.

Below are some "Basics of Lean:"

- Make only what is needed (min inventory, NOT zero inventory),
- Never make a defect, never pass a defect on,
- Eliminate all waste, and
- Focus on flow and cycle time reduction.

Today, Lean thinking goals have emerged to include:

- Improve quality,
- Eliminate waste (muda),

- Reduce cycle time and lead time, and
- Reduce total cost.

5.4.3 Six Sigma

Carl Frederick Gauss introduced the concept of the normal curve in the 1800's. Later Walter Shewhart showed that three sigma (standard deviations) from the mean is the point where a process requires correction. This gave rise to many measurement standards such as Cpk, Zero Defects, etc. But the credit for coining the term "Six Sigma" goes the Motorola Corporation. In the 1970's Motorola found that it was unable to compete on consumer electronics against the Japanese because of cost and quality problems. Motorola's CEO at the time was Bob Gavin and he set a goal of a 10X improvement in quality. Motorola, like many companies, was measuring defects in thousands of opportunities, but this did not give them the quality and reliability they needed to compete. Motorola developed this new standard, one that measured defects per million opportunities. Bill Smith, a senior quality engineer, presented his plan for improvement using a statistical approach called "Six Sigma." Six Sigma helped Motorola realize tremendous improvements documenting over $16 billion in savings as a result of Six Sigma efforts.

Interesting factoids:

- It should be noted that Bill was a graduate of the U.S. Naval Academy, class of 1952.
- "Six Sigma" is a registered trademark of the Motorola Corporation.
- Lean looks at eliminating waste or non-value added activities.
- Six Sigma looks at eliminating variation or the causes of variation that lead to quality, reliability and cost problems.

Figure 5-1 The DMAIC Cycle

DMAIC is considered a basic component of the Six Sigma methodology that is uses five steps to improve efficiency and eliminate defects. It is a way to improve work processes by identifying and eliminating defects. DMIAC is widely used by many organizations and corporations.

1. **Define (the problem):** It is important for to define the current state and identify specific achievement goals that are consistent with customer's demands (voice of the customer) and your own strategy. This problem/solution definition becomes your road map for success.

2. **Measure (the current process):** Collect measurements of relevant data so that data can be analyzed, corrective action taken, and comparisons are made in the future to determine whether or not defects have been reduced.

3. **Analyze (the data):** Understand the causes of defects or poor quality. The Toyota approach is to ask "why" five times in order to get to the root cause of a problem. Determine what the relationships are between factors ensuring that all factors have been considered. Another great tool for problem solving is the "cause and effect diagram."

4. **Improve (the process):** Continuous process improvement (processes optimization) is at the core of every successful improvement project. There are many that facilitate the improvement cycle to include design of experiment (DOE), Poke-a-Yoke (mistake proofing), and statistical process control (SPC).

5. **Control (the process):** This is the last step (Control) helps to ensure that any variances do not creep back into a process causing defects. Statistical process control can be used to both improve a process and to continuously monitor the process to ensure it stays in control.

5.4.4 Theory of Constraints (TOC)

Theory of Constraints (TOC) helps to identify the constraints in a process so that the constraint on the system can be minimized. In order to make money, throughput and productivity must be improved, and resources (inventory and other expenses) must be closely controlled. Dr. Eliyahu Goldratt developed TOC in the mid-80's as a way of uncovering constraints or bottlenecks in the system. A constraint is a factor that limits an organizations ability to achieve its goal. Further refinement of TOC has resulted in a body of knowledge, techniques and practices that have come to be known as synchronous manufacturing, which includes TOC.

In order to identify and manage constraints, TOC employs five Thinking Process tools (taxonomies) that support the change process:

1. **Current Reality Tree** : Using experienced and involved individuals, it identifies the root causes of a problem (what to change).
2. **Evaporating Cloud** : Identifies a solution to the core problem and uncovers the factors that caused the problem in the first place.
3. **Future Reality Tree** : Identifies what is missing from the proposed solution before changes (what to change to) are implemented.
4. **Prerequisite Tree** : Identifies the intermediate steps and obstacles that need to be taken to reach new goals or process (how to cause change).
5. **Transition Tree** : Identifies the actions (implementation plan) that need to be taken, given the current situation, to achieve intermediate goals (as identified in the Prerequisite Tree).

The output of a plant (or process) is dictated by the bottleneck. In TOC terms the bottleneck is called the "drum" and it paces the plant. "Buffer" is the inventory in front of the bottleneck that is there to ensure that the bottleneck is never idle. The "rope" is the communication system used to communicate the inventory needs of the bottleneck back to the material release point. Goldratt, in his book "The Goal," uses the analogy of a Boy Scout troop on a hike as a way of simplifying production or manufacturing problems. Often what happens on a hike is that the Scoutmaster often puts the slowest kid (called Herbie) at the rear of the line. That way Herbie does not slow down the hike. But in reality what happens is that the other scouts need to stop and wait for Herbie to catch up. Now that they have rested they are ready to take off and hike some more but are further slowed down by the now tired Herbie. Herbie in reality is the pacing factor, and in a production environment, the bottleneck is the pacing factor. Control the bottleneck and you control production. Improving non-bottlenecks is a waste of time and resources. The steps for using TOC to identify and improve bottlenecks are outlined below:

Step 1 : Identify the constraint.

Step 2 : Focus on how to get more production at that constraint within the existing capacity limitations.

Step 3 : Keep materials needed next from sitting idle in a queue at a non-constrained resource.

Step 4 : If, after fully exploiting this process and you still cannot produce enough product to meet the demand, find other ways to increase capacity (e.g. second shift, more machines/manpower, etc.)

Step 5 : Go back to step 1.

The application of Theory of Constraints to a weapon system program in production can result in significant reductions in cost and cycle times, and major improvements in quality, responsiveness and performance.

5.5 Continuous Process Improvement (CPI) Tools

The DOD embraced TQM in the 1980's, then Lean concepts in the 1990's. Today, DOD has rolled up all of the past quality initiatives under the umbrella of Continuous Process Improvement (CPI). CPI requires the synergistic interaction between management philosophy and procedures, and quality technologies. No single checklist or formula can be developed to institutionalize this philosophy in the DOD procurement or other communities. The next sections of this chapter will outline a few of the more important CPI tools.

.5.1 Quality Function Deployment

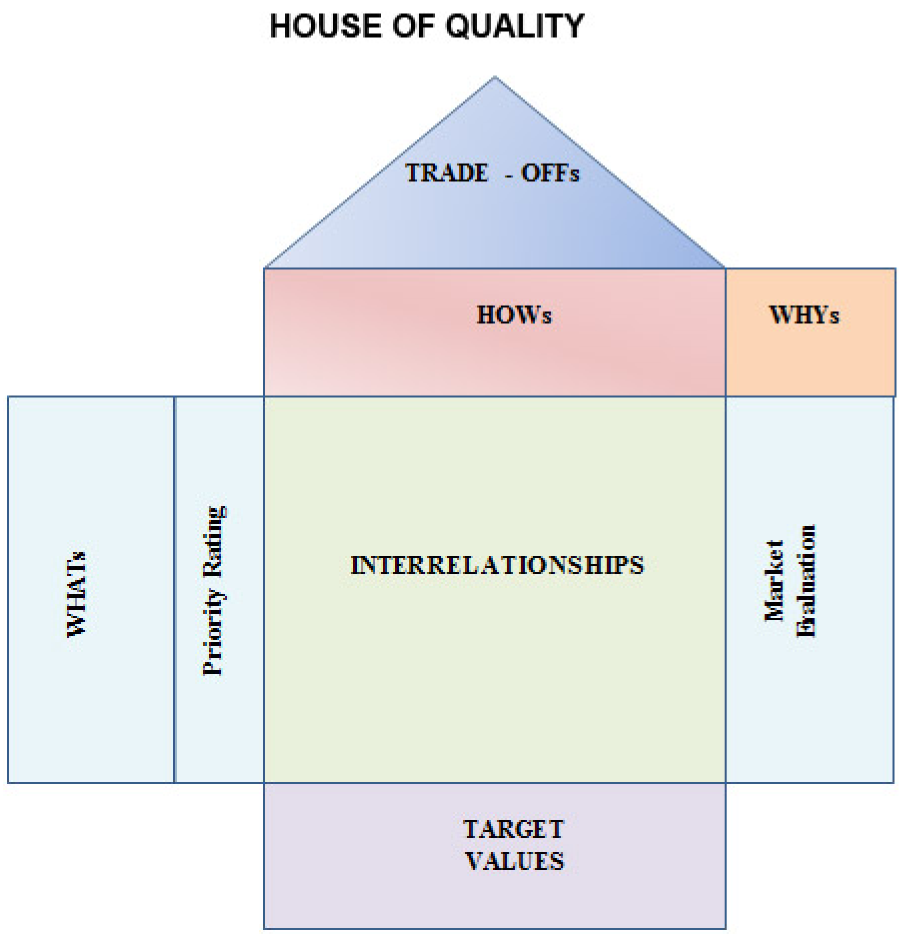

Figure 5-2 House of Quality

The systems engineering process begins with the identification of a need and then translation of that need into a technical solution. Many programs have serious problems in this area, as evidenced by the high rate of Engineering Change Proposal (ECP) activity all the way through production.

How is the requirements process done today? First, someone from a requirements group (e.g. TRADOC) identifies a need and generates a requirements document. The program office translates that requirement into an RFP that a contractor responds to. The real user is not directly involved in the process and does not talk directly with the contractor creating many opportunities for errors.

World-Class companies use Quality Function Deployment (QFD) in the front end of the design process to capture the requirements. QFD use many proven tools to capture what is called the "voice of the customer." These tools help to ensure that the requirements are not missed, misinterpreted, or not prioritized. The requirements then get put into a matrix called a House of Quality.

The matrix gives the engineers a structure for examining all of the requirements to ensure they develop solutions to meet the needs. The matrix also ensures that everyone on the team has the same definition for the terms and requirements. It forces the team to prioritize the requirements.

The roof of the House identifies any conflicting technical solutions. For example, you may want an aircraft to fly fast and get good fuel consumption. This could result in a conflict in the technical solution. Engineers need to know if there are technical conflicts early in the design phase so that they can resolve the conflict. QFD has been credited with reducing design times by as much as 40 percent while optimizing the design, providing better operational performance, and smoother production startup.

5.5.2 Design of Experiments (DOE)/TAGUCHI

As the aircraft design emerges from the system, subsystem, and down to the piece part decisions are continuously being made on the 150 million characteristics. Which material will provide the best performance at the lowest costs? Which characteristics are important and must be controlled? Which processes should be used to fabricate parts? What factors need attention to control the process? The engineers 1st work to get a design to yield the right performance parameters, this includes attention to product characteristics, tolerance and process parameter design. But, often the factory floor cannot fabricate parts without high defect rates and low yields. What the engineers need is a way to make the design robust, that is, a design that takes into considerations the inherent variations of the factory floor in a way that does not negatively impact product performance.

R. A. Fisher, an English scientist and statistician, used statistical experimentation (DOE) to identify key characteristics (factors or causes) that contribute the most to agricultural output. A characteristic is key if variation causes problems with fit, function, or service life. Fisher found that certain factors within their control had more influence on crop output than other factors. This Dr. Deming would say was "profound knowledge" that farmers could use to increase crop yields. The same statistical techniques can be used to improve manufacturing yields.

Dr. Genichi Taguchi is credited with simplifying DOE. His approach required only a few experimental runs to capture most of the knowledge about a process and its factors. His experiments build on a concept of an orthogonal (balanced) array as illustrated in Figure 5-3.

	FACTOR LAYOUT ON L ORTHOGONAL ARRAY								
		FACTORS OF THE EXPERIMENT							
FACTOR	A B C D E F G	PREHEAT	TIME	TEMP.	SPEED	PRESSURE	SOLDER	FLUX	NUMBER DEFECTS PER 1000 UNITS
COL NO.	1 2 3 4 5 6 7	1	2	3	4	5	6	7	
1	1 1 1 1 1 1 1	HIGH	HIGH	LOW	10 RPM	HIGH	LOW	LOW	21
2	1 1 1 2 2 2 2	HIGH	HIGH	LOW	8 RPM	LOW	HIGH	HIGH	17
3	1 2 2 1 1 2 2	HIGH	LOW	HIGH	10 RPM	HIGH	HIGH	HIGH	12
4	1 2 2 2 2 1 1	HIGH	LOW	HIGH	8 RPM	LOW	LOW	LOW	47
5	2 1 2 1 2 1 2	LOW	HIGH	HIGH	10 RPM	HIGH	LOW	HIGH	5
6	2 1 2 2 1 2 1	LOW	HIGH	HIGH	8 RPM	LOW	HIGH	LOW	46
7	2 2 1 1 2 2 1	LOW	LOW	LOW	10 RPM	HIGH	HIGH	LOW	23
8	2 2 1 2 1 1 2	LOW	LOW	LOW	8 RPM	LOW	LOW	HIGH	4

Figure 5-3 Design of Experiment Orthogonal Array

Most experimentation today is in response to problem solving. That is, you have a process that is not providing the necessary yields, so you run an experiment to find out what the causes are. While this type of experimentation has its place, the real value is up front, making the product and processes robust. That way you identify and control the key/critical factors all the way from design to the factory floor and fielding.

5.5.3 Statistical Process Control (SPC)

One key element of the CPI concept is process control. SPC is based on the premise that all processes exhibit variation; in other words, it is an analytical technique for evaluating the processes and taking action based on stabilizing the process within the desired limits. SPC is one of the most widely used statistical quality control techniques in the United States.

SPC came into existence in the early 1900's, as a result of the work done by Walter Shewhart, a physicist at Bell Labs. Shewhart's studies of manufacturing variation led him to develop the control chart and thus provided his engineers with a tool for reducing manufacturing variation and for the establishment of process control.

Key characteristics need to be put under SPC. Key characteristics flow from key customer requirements, down to assembly characteristics, which generate key product characteristics, which generate key process characteristics, which become key test or inspection characteristics.

A manufacturing process is not, by nature, in a state of statistical control. Control can only be achieved through dedicated effort. One of the 1st requirements of manufacturing is to study a process and see what that process yields. By collecting data and arranging that data into a histogram, the engineer is able to get a picture of the process. A process has three features: how much variation (spread), where (centering), and shape (normal, skewed, bimodal, etc.). If the process is stable, then these features will remain constant and predictable over time. If the process is unstable, then these features will change, and the output will become unpredictable. If the goal of manufacturing is to achieve uniform, defect-free products, then it becomes the job of the engineering team to reduce or eliminate the sources of variation.

A process is considered stable (Figure 5-4) when all special causes of variation have been eliminated, and only common (random) variation is present. Common causes are due solely to chance and represent the best that the people operating the factory can attain. Management must take action on the system in order to improve output. Note that just because a process is stable does not mean you are producing good product, it only means your output is predictable.

A process is unstable (Figure 5-5) when special causes of variation are present. Special causes come from outside the system and must be removed or prevented from occurring in order to achieve stability.

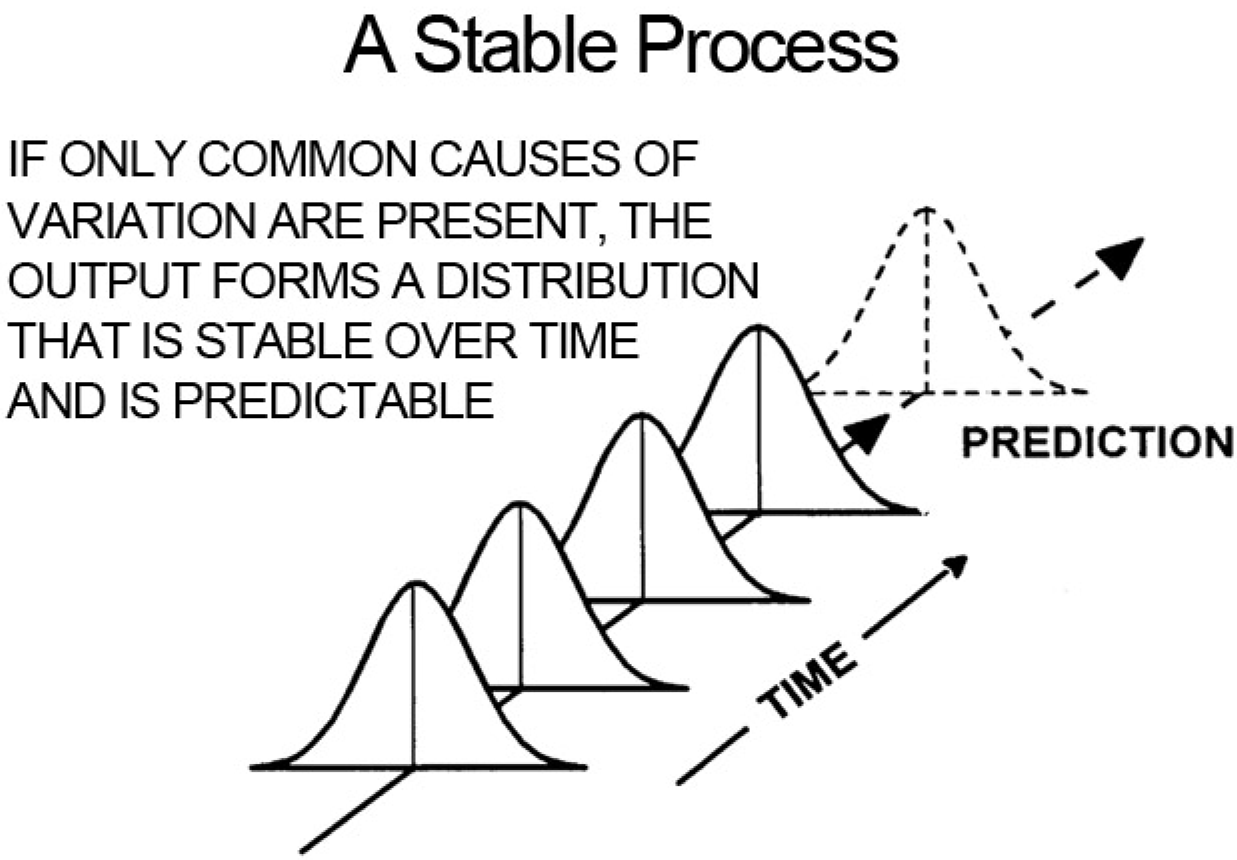

Figure 5-4 A Stable Process

The ideal state for a process is to be both stable and capable (Figure 5-8) producing 100 percent conforming product. The control chart can be used to ensure that the process stays in control and to give warning if anything in the process is changing that will cause the process to go out of control.

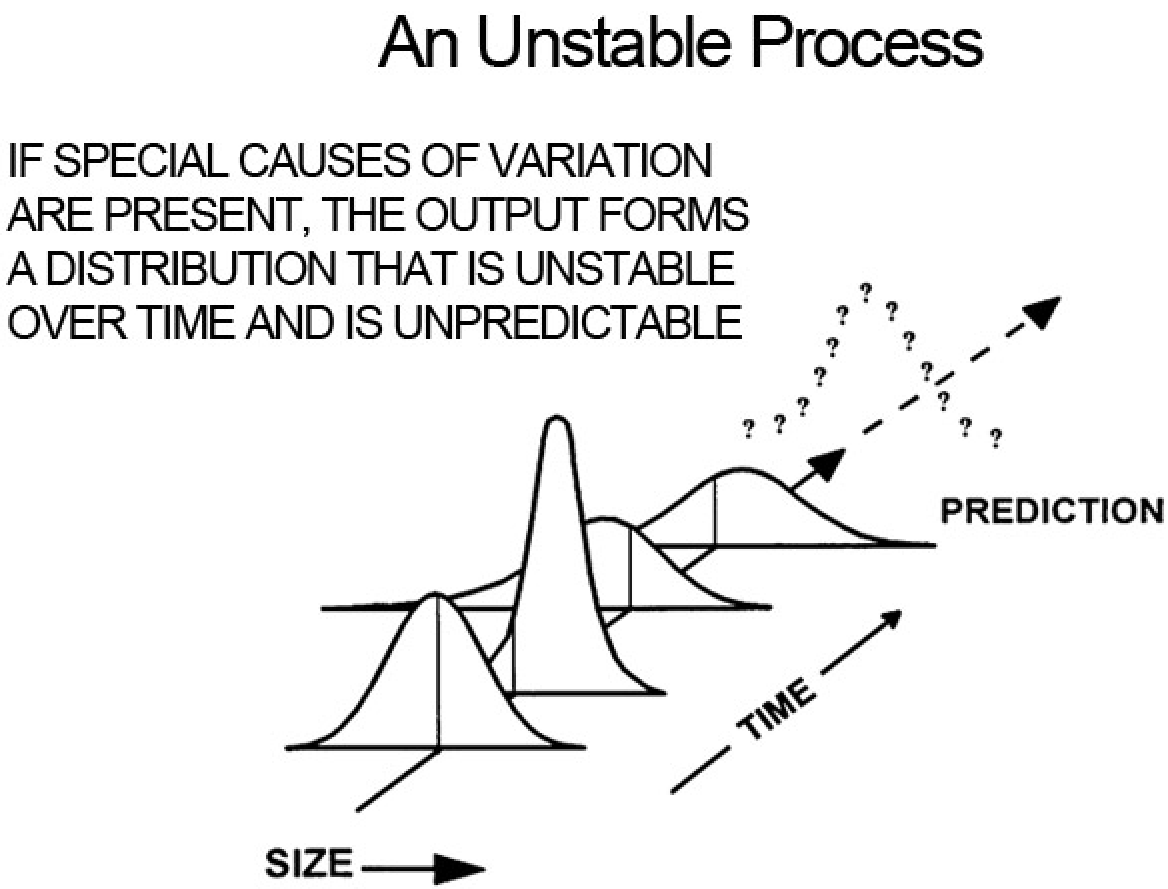

Figure 5-5 An Unstable Process

A second state for a process is when the process is stable and in control, but is producing some nonconforming product. You could inspect the product and sort the good from the bad, but that is expensive and not 100 percent effective. You could tighten the spec limits, which would give you better product in the field, but would raise your scrap rates. Or you could manage the process using control charts and make process improvements based on profound knowledge.

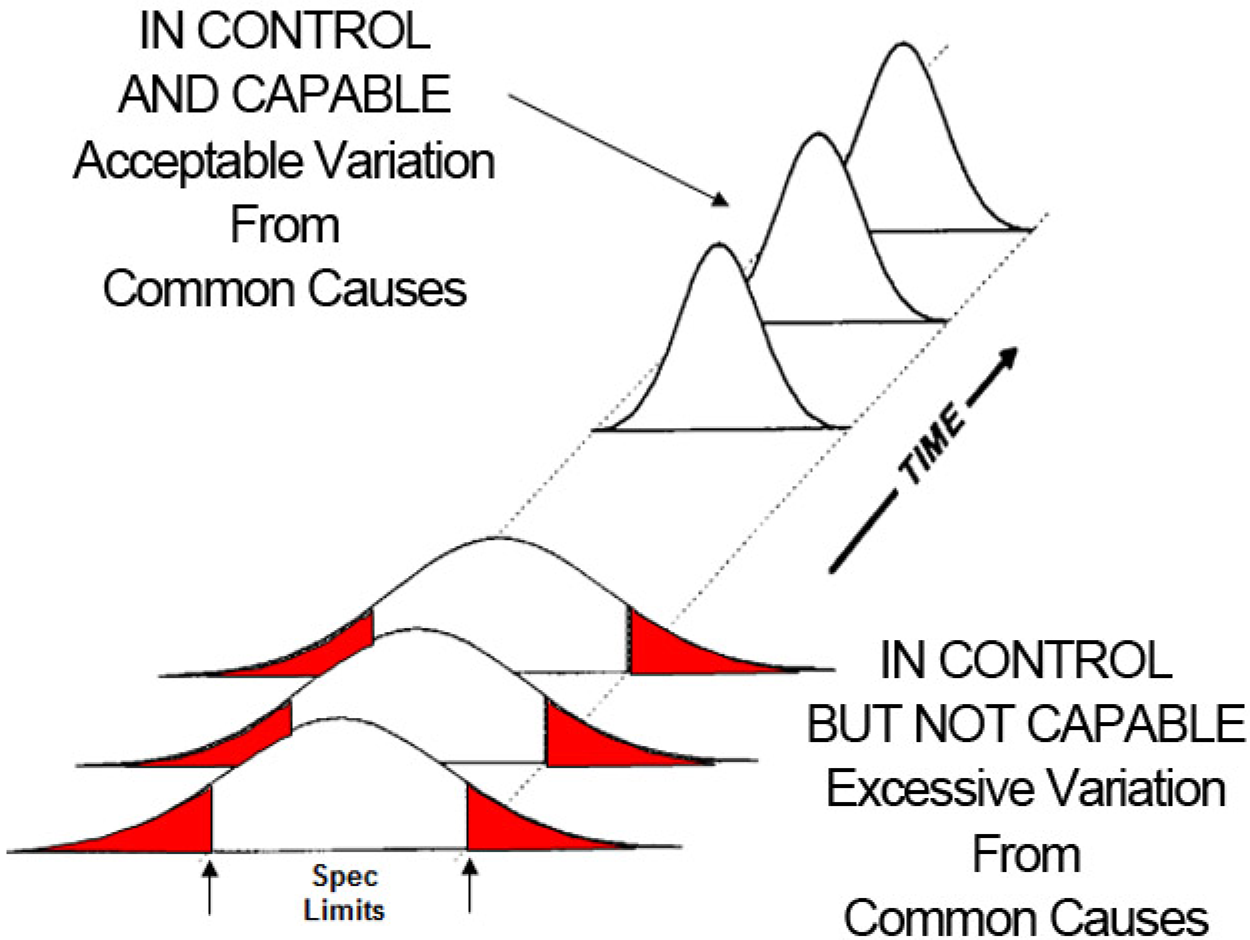

Figure 5-6 Capable Process

SPC is an operator's tool. It assists the operator in making timely decisions about the process: adjust, leave alone, or shutdown and take corrective action before defects are produced. SPC provides evidence of how a process is performing. SPC helps distinguish between patterns of natural variation (expected), and the non-desirable, unexpected variations (assignable to malfunction). SPC provides a better understanding of how the processes affect the products. Assurance of conformance is, therefore, obtained through defect prevention by control of the various processes, rather than after the fact. Clear understanding of the causes and extent of variation can also be used as a basis for reducing the process variability, thus improving the quality of the output.

5.5.4 Seven Quality Control Tools

The Japanese have trained a large portion of their work force in the use of seven basic quality control tools. These tools and are used by the production workers to solve day-to-day shop floor quality problems, mainly through their quality improvement teams and employee suggestion systems. The number of suggestions turned in by Japanese workers is legendary. A survey by the Japanese Suggestion Association showed that the average Japanese employee submits 32 suggestions a year, while the number is .17 for the average American worker. This is with 72 percent of the Japanese workers participating in the suggestion program while only 6.6 percent participate in the U.S. Finally, 87 percent of the Japanese suggestions are adopted, while less than 35 percent are adopted here in the U.S. This is mainly because Japanese workers are trained in the basic tools of quality control and thus experiment with their own ideas, pilot runs, and submit their suggestions to management only when they are reasonably sure of success. Thus, instead of having a few professionals to tackle problems, they have an army of problem solvers.

5.5.4.1 Cause and Effect Diagram

The cause and effect diagram (Figure 5-7) is used to identify possible causes of a problem (variation). Once the major causes are known, the problem can be corrected. This technique was developed by Dr. Kaoru Ishikawa, one of the foremost authorities on quality control in Japan. The Ishikawa Diagram is also known as cause-and-effect diagram or, by reason of its shape, a fishbone diagram. It is probably the most widely used quality control tool for problem solving among blue-collar workers in Japan. Typically you begin by identifying the "end state" and then add causes that could contribute to the variation or defects in the end state. Use the 5Ms (measurements, materials, manpower, methods, and machines) as major branches to analyze a factory floor problem.

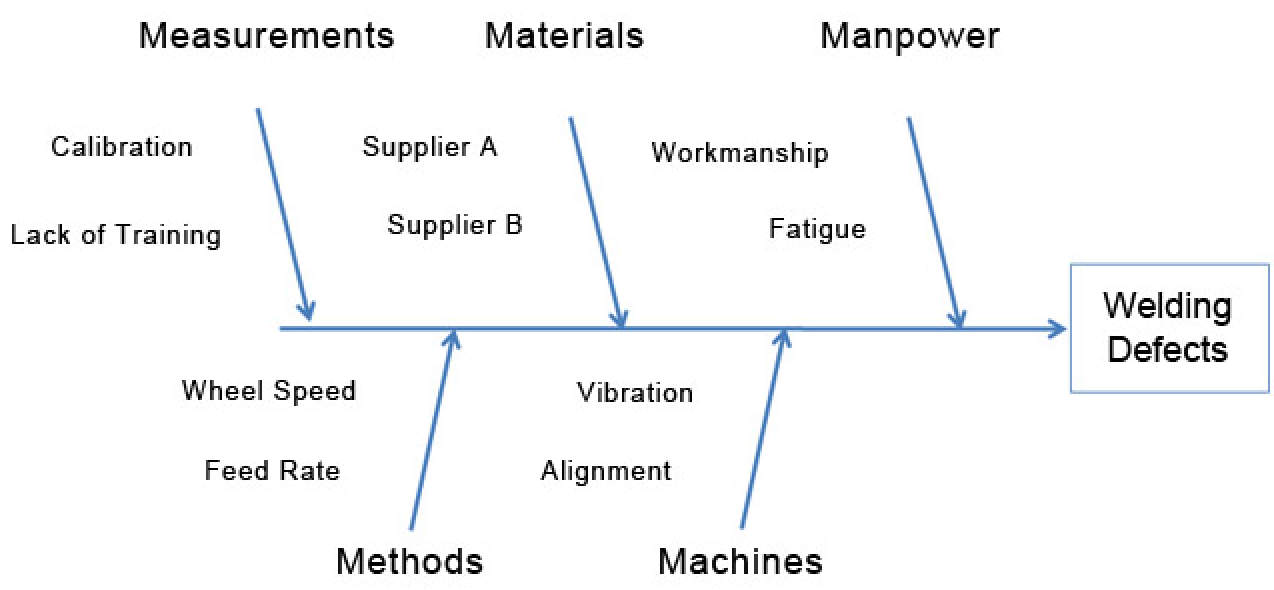

Figure 5-7 Cause and Effect Diagram

5.5.4.2 Check Sheet

The check sheet (tally sheet) is used to easily collect real time data. A check sheet is a table or a form used to log data as it is collected. Check sheets help organize data by category and show how many times each particular value occurs. The information is increasingly helpful as more and more data is collected. A check sheet can register how often different problems occur and the frequency of incidents that are believed to cause problems. There are several types of check sheets; defective items, defect causes, defect locations (sometimes referred to as "measles charts"), and checkup confirmation as memory joggers for inspectors while checking products. Their main function is to simplify data gathering and to arrange data for statistical interpretation and analysis. Decision-making and actions can be taken from the data.

5.5.4.3 Control Chart

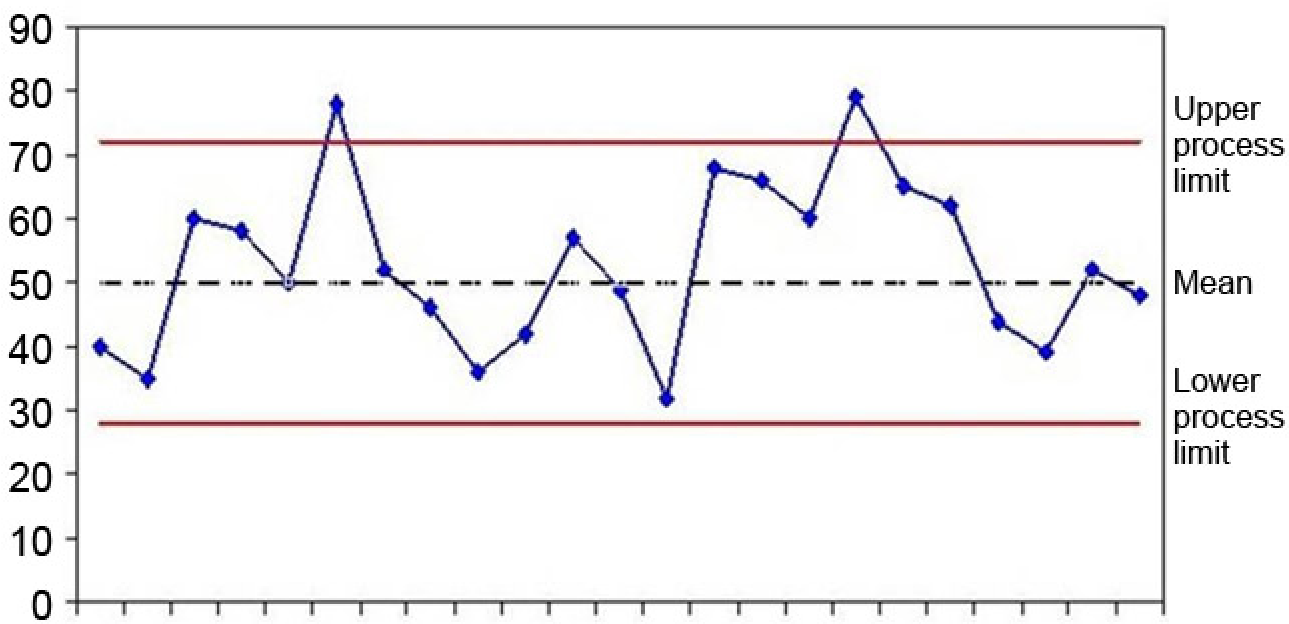

Figure 5-8 Control Chart

The control chart was developed in the 1920's by Walter Shewhart at Bell Labs as a way of improving the reliability of telephone transmission equipment. The control chart is a graphical representation depicting how a process changes over time. The control chart is constructed to show an upper and lower control limit and a center line showing the target value or average. The control limits are generally three standard deviations above and below average. The control chart is not synonymous with SPC. Control charts are simply a maintenance tool. Their main function is to maintain a process under control, once its inherent variation has been established and minimized. The most common misuse of control charts is to put them into effect in order to solve problem. If there is a known problem, the application of control charts will not solve it. It will simply confirm that a problem exists. Any improvement must come by reduction in the inherent variation in the process. This can be accomplished in a limited fashion by simple tools such as brainstorming and cause and effect diagram; or, more effectively through the use of sophisticated Design of Experiments.

5.5.4.4 Histogram

The histogram shows the frequency distribution of data as a bar chart or other graphical representation and provides an easy way to collect and analyze data. Individual data points are grouped into classes, then when the histogram is constructed, the graphical representation will show you which classes occur the most often. To build a histogram you first decide what to measure, then gather the data and then prepare a frequency table. Now you can make interpretations based on the histogram. Histograms tend to follow a normal distribution (bell-shaped curve); however, it is not unusual to have other types of distributions.

5.5.4.5 Pareto Chart

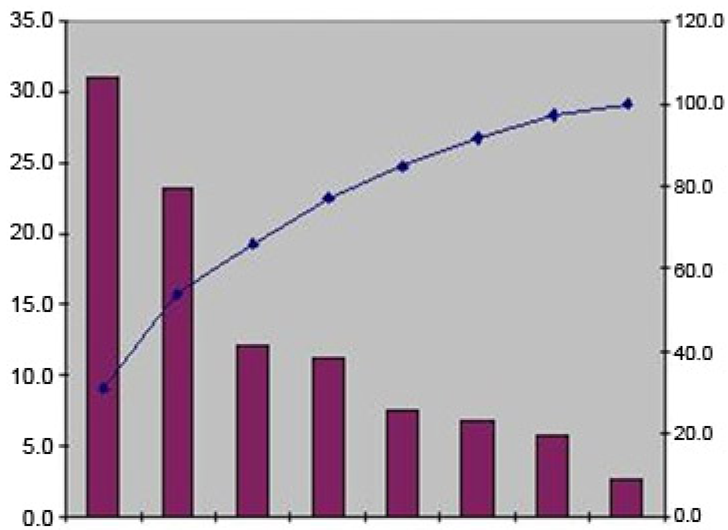

Figure 5-9 Pareto Chart

The Pareto Chart is used to define problems, to set their priority, to illustrate the problems detected, and determine their frequency in the process. It is most useful for identifying the factors that have the most impact. Vilfredo Federico Pareto was a nineteenth-century Italian economist who studied the distribution of income in Italy and concluded that a limited number of people owned most of its wealth. The study produced the famous Pareto-Lorenz normal distribution law, which states that cause and effect are not linearly related; that a few causes produce most of a given effect; and, more specifically, that 20 percent or less of causes produce 80 percent or more of effects (80/20 rule).

Dr. Joseph M. Juran, however, is credited with converting Pareto's law into a versatile, universal industrial tool applicable in diverse areas, such as quality, manufacturing, supplier materials, inventory control, cycle time, value engineering, sales and marketing. In fact, in any industrial situation, by separating the few important causes from the trivial many, work on the few causes can be prioritized. Figure 5-9 is a typical example of a Pareto chart and its usefulness. Three items, which alone accounted for $2,800 per month of loss (or over 80 percent of the total loss) as shown in a.), were prioritized and reduce to $1,400 per month as shown in b.), before the remaining problems were resolved.

5.5.4.6 Scatter Diagram

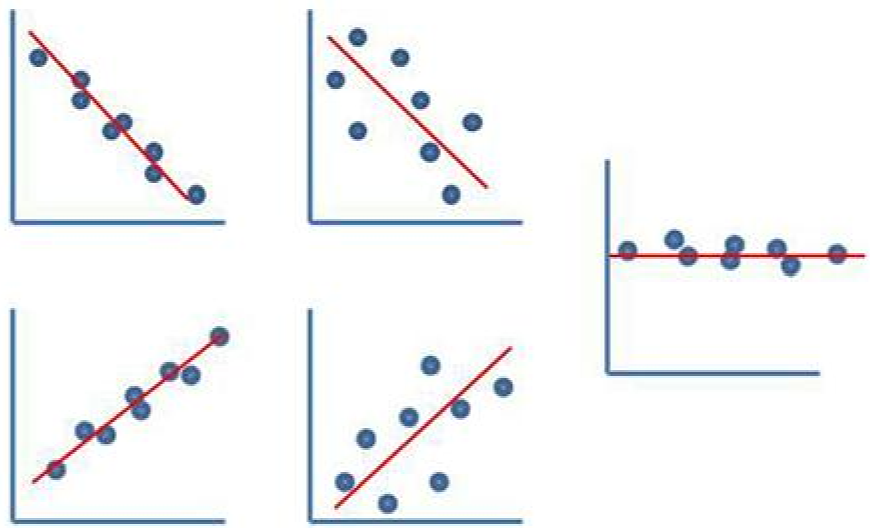

Figure 5-10 Scatter Diagrams

The scatter diagram is a graphical tool that plots many data points and shows a pattern of correlation between two variables. That is you can see the relationship (if any) between sets of variables. This relationship could be a positive, negative or neutral. The relationship is positive if the data slopes from the lower left to the upper right, and conversely, in a negative relationship the data will slope from the upper left to the lower right. If there is no slope to the line, then there is no correlation. You can construct a scatter diagram by plotting possible causes on the horizontal axis and possible effects on the vertical axis.

5.5.4.7 Flow Chart

The flow chart is a diagram that represents a process, showing the steps in the process as boxes or other shapes and connecting the boxes where there are linkages. Flowcharts are useful for documenting complex processes. This allows people to view the processes and identify process issues such as bottlenecks or other problems. Flow charts are often used to depict the current state of the process, known as the "as is" condition, and for developing or creating a new and improved process, known as the "to be" state. Value stream maps are a form of flow charts that are used as a part of the Lean implementation in which you identify process steps as "value added" or "non-value added."

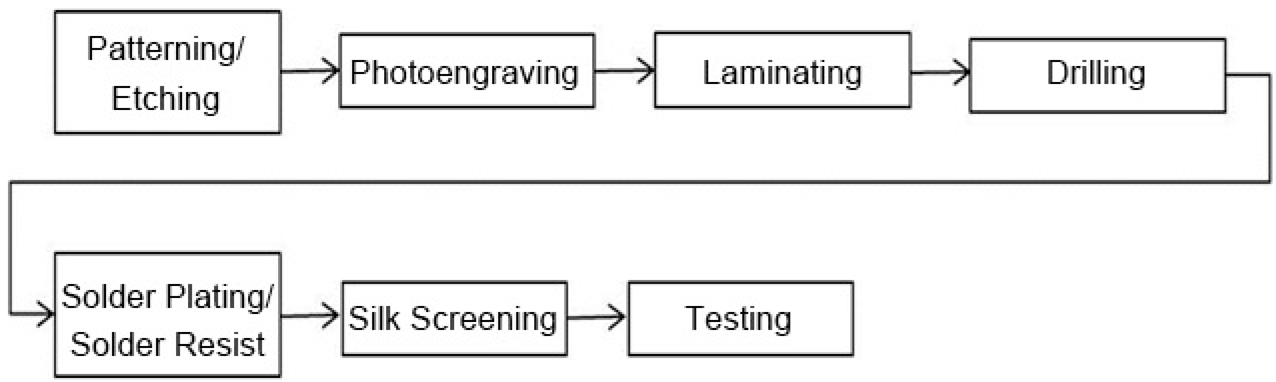

Figure 5-11 PCB Fabrication Process Flow

5.5.5 Seven Quality Management Tools

5.5.5.1 Affinity Diagram (KJ Method)

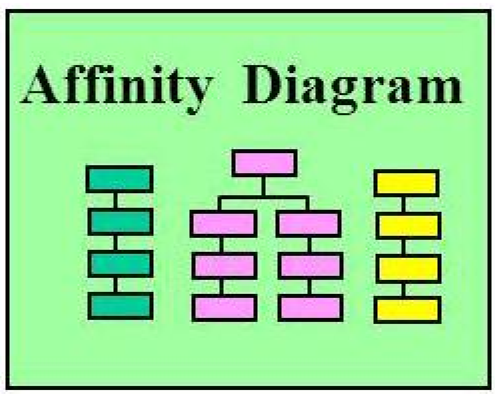

Figure 5-12.1 Seven Quality Management Tools

The Affinity Diagram is a brainstorming tool that takes a large amount of disorganized data and organizes it into their natural relationships. The affinity diagram was first used by Jiro Kawaskita, a Japanese anthropologist, and is sometimes called the KJ method or KJ diagram.

5.5.5.2 Relations Diagram (Interrelationship Diagraph)

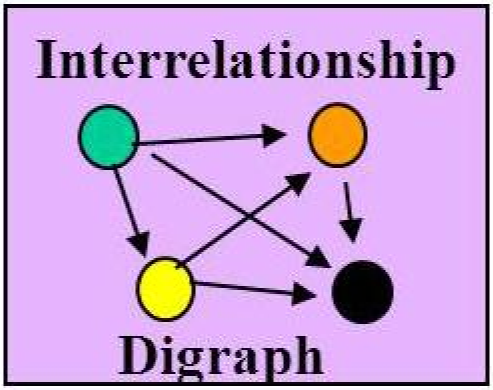

Figure 5-12.2 Seven Quality Management Tools

The Relations Diagram is used to show cause-and-effect relationships. It helps to analyze the natural links between different aspects of a complex situation and can be used to describe a desired outcome.

5.5.5.3 Tree Diagram

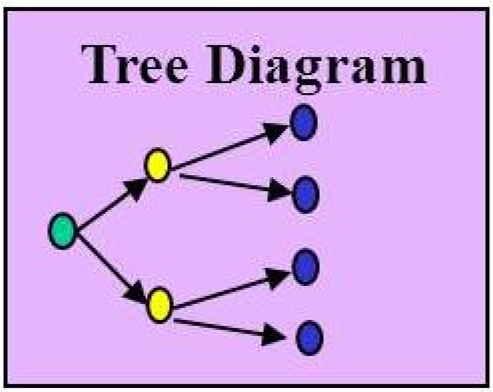

Figure 5-12.3 Seven Quality Management Tools

The Tree Diagram is used to break down broad categories into finer levels of detail, helping you move your thinking step by step from generalities to specifics. It can be used to map the details of a task in a similar manner as does a flow chart.

5.5.5.4 Matrix Diagram

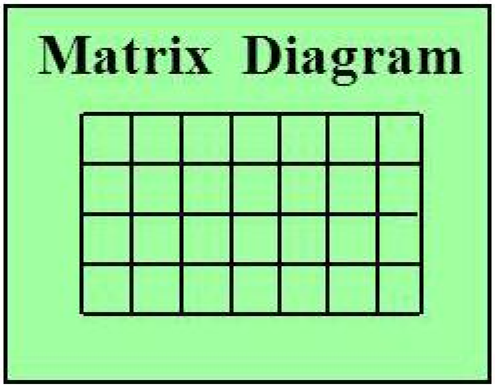

Figure 5-12.4 Seven Quality Management Tools

A Matrix Diagram shows the relationship between two, three or more groups of information and can give information about the relationship, such as its strength, the roles played by various individuals, or measurements.

5.5.5.5 Arrow Diagram

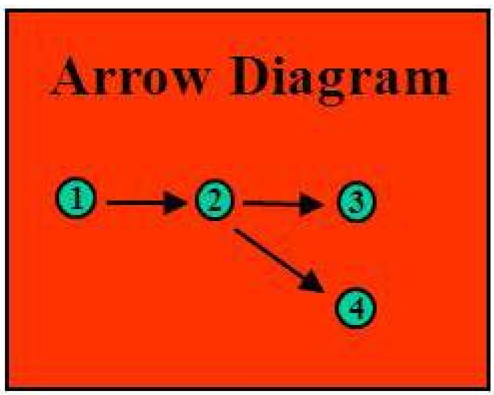

Figure 5-12.5 Seven Quality Management Tools

An Arrow Diagram shows the required order of tasks in a project or process, the best schedule for the entire project, and potential scheduling and resource problems and their solutions.

5.5.5.6 Process Decision Program Chart (PDPC)

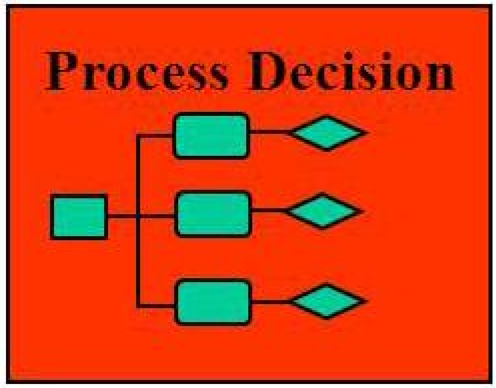

Figure 5-12.6 Seven Quality Management Tools

The Process Decision Program Chart systematically identifies what might go wrong in a plan under development. It is a technique used to plan or break down tasks into a hierarchy. It is like a tree diagram, but extends the tree down several levels to help you identify risk and potential risk mitigations.

5.5.5.7 Activity Network Diagram (PERT Chart)

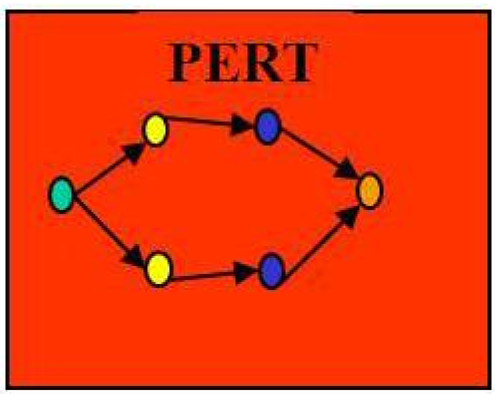

Figure 5-12.7 Seven Quality Management Tools

The Activity Network Diagram is used to plan and sequence tasks and their subtasks. The resulting diagram can be used to identify the critical path or longest complete sequence of tasks. This type of chart is often used for program or project planning and is sometimes referred to as a Program Evaluation and Review Technique or PERT Chart.

5.6 Reliability, Availability and Maintainability

The primary objective of Department of Defense (DOD) acquisition is to acquire quality products (systems) that satisfy user needs with measurable improvements to mission capability and operational support in a timely manner, and at a fair and reasonable price. The achievement of reliability, availability and maintainability (RAM) are essential elements of mission capability. Higher levels of RAM multiply force effectiveness and increase performance measures such as operational availability/readiness, dependability, and safety for users; while decreasing the demand for (and cost of) logistics support.

The Aston Carter Memo, dated 3 Nov 2010, " *Implementation Directive for Better Buying Power - Obtaining Greater Efficiency and Productivity in Defense Spending* ," outlined his strategy and guidance for achieving greater efficiency. The number one initiative was "Target Affordability and Control Cost Growth." DOD's emphasis on affordability can be set against a backdrop of the total life cycle cost of ownership and the role RAM can play in achieving affordability targets.

So what are some of the key components of RAM?

- Reliability is the probability of an item to perform a required function under stated conditions for a specified period of time. Reliability is further divided into mission reliability and logistics reliability.
- Availability is a measure of the degree to which an item is in an operable state and can be committed at the start of a mission when the mission is called for at an unknown (random) point in time. Availability as measured by the user is a function of how often failures occur and corrective maintenance is required, how often preventative maintenance is performed, how quickly indicated failures can be isolated and repaired, how quickly preventive maintenance tasks can be performed, and how long logistics support delays contribute to down time.
- Maintainability is the ability of an item to be retained in, or restored to, a specified condition when maintenance is performed by personnel having specified skill levels, using prescribed procedures and resources, at each prescribed level of maintenance and repair.
- Total Ownership Cost (TOC) is an attempt to capture the true cost of design, development, ownership and support of DOD weapons systems. At the individual program level, TOC is synonymous with the life cycle cost of the system. To the extent that new systems can be designed to be more reliable (fewer failures) and more maintainable (fewer resources needed) with no exorbitant increase in the cost of the system or spares, the TOC for these systems will be lower.
- The logistics footprint of a system consists of the number of logistics personnel and the materiel needed in a given theater of operations. The ability of a military force to deploy to meet a crisis or move quickly from one area to another is determined in large measure by the amount of logistics assets needed to support that force. Improved RAM reduces the size of the logistics footprint related to the number of required spares, maintenance personnel, and support equipment as well as the force size needed to successfully accomplish a mission.

The key to developing and fielding military systems with satisfactory levels of RAM is to recognize RAM as an integral part of the Systems Engineering process and to systematically manage the elimination of failures and failure modes through their identification, classification, analysis, and removal or mitigation. These activities start in pre-systems acquisition and continue throughout the entire life cycle.

There are four key steps that can be taken to achieve satisfactory levels of RAM. There are no milestone decisions to signify the beginning and end of each key step. Instead, the beginning and end of each step is illustrated within Figure 5-13 as a flexible time period depending on each system acquisition process.

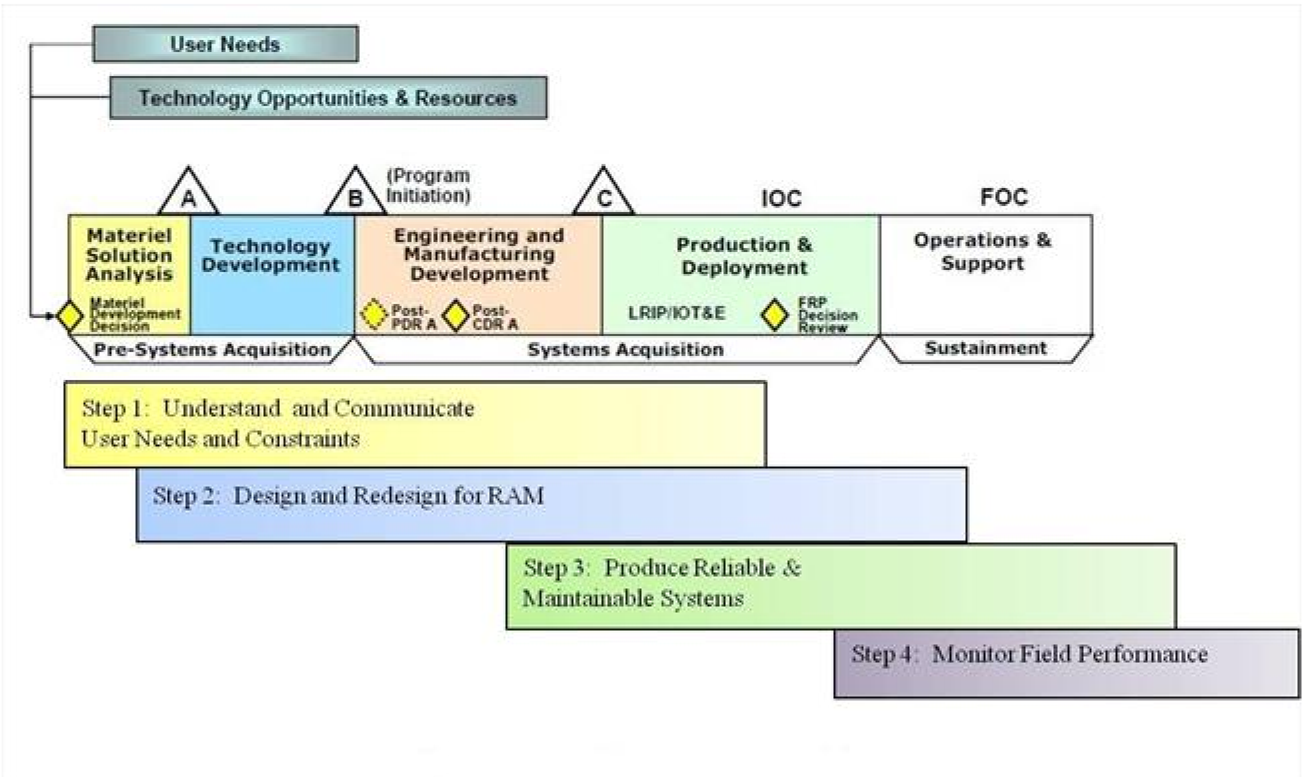

Figure 5-13 Keys to Achieving RAM

Step 1: The first priority in an acquisition program is to thoroughly understand the customers' needs and expectations (the customer includes operators, maintainers, and supporters). The user and acquisition communities collaborate to define desired capabilities to guide development. The definition of capability includes the mission, system performance, force structure, readiness and sustainability, as well as constraints such as logistics footprint and affordability. Using Quality Function Deployment (QFD) to capture requirements is a best practice.

Step 2: Designing for RAM includes the following objectives:

- Develop a comprehensive program for designing and manufacturing for RAM that includes people, reporting responsibility, and a RAM Manager.
- Develop a conceptual system model, which consists of components, subsystems, manufacturing processes and performance requirements. Use the model throughout development to estimate performance and RAM metrics.
- Identify all critical failure modes and degradations and address them in design.
- Use data from component-level testing to characterize distribution of times to failure.

- Conduct sufficient analysis to determine if the design is capable of meeting RAM requirements.
- Design in: diagnostics for fault detection, isolation and elimination of false alarms; redundant or degraded system management for enhanced mission success; modularity to facilitate remove-and-replace maintenance; accessibility; and other solutions to user-related needs such as embedded instrumentation and prognostics.

RAM activities that are recommended during the EMD phase include reliability growth testing, maintenance/maintainability demonstration and evaluation, and data collection, analysis, and corrective action system (DCACAS).

Step 3: Occurs during the Production and Deployment phase. There are two major parts to this phase: Low Rate Production (LRIP), and Full-Rate Production. The LRIP effort completes the manufacturing development process and generates the units for Initial Operational Test and Evaluation (IOT&E). The IOT&E provides information on how well the system performs and meets user needs including RAM. Full-Rate Production and Deployment provide the systems, supporting materiel and services to the users and provides the users with an Initial Operational Capability (IOC).

Step 3 focuses on process control, quality assurance, and environmental stress screening. Data collection from production articles deployed to operational units provides insight into how well production units are performing in the operational environment. Other RAM activities during the Production and Deployment phase include failure prevention and review board, production reliability qualification/acceptance tests, lot acceptance testing, and participation in software change review board (SCRB).

Step 4: Ensures that the needed levels of RAM are sustained during the life of the system, since operations and support cost are typically more than half of the Total Ownership Cost (TOC). RAM drive elements of support and the costs of support through the life cycle. The elements of support generally include maintenance at all levels; manpower and personnel to operate and support the system; supply support; support equipment and tools; technical data; training and training support; computer resource support; facilities; and packaging, handling, storage and transportation. Three performance measurements provide overall indications of field experience: mission success rates, operational availability, and operations and support costs. However, in themselves, they do not necessarily indicate the specific cause of problems. A robust data collection and analysis program, such as a continuation of the RAM review boards and DCACAS from earlier steps, will help identify and prioritize specific RAM problems for resolution.

5.6.1 Reliability of Design

Design for Reliability (DFR) encompasses a set of engineering methods, tools and best practices that can be used to support the design process to ensure that warfighter requirements for a reliable and affordable weapon system can be met. Failure of a product in the field can have disastrous consequences. For that reason it is important to distinguish between "quality" and "reliability."

Quality control is a determination that the product meets the design and will work properly after it is produced and assembled. Reliability looks at how long the item will perform under defined conditions after it has been fielded. Because they look at different outcomes, program managers and other technical practitioners need to use different suites of tools and practices to achieve each characteristic. However, do not discount that there are many considerations that impact both quality and reliability. These will be discussed later in this chapter.

Reliability focuses on the issue of the duration or probability of failure-free performance under stated conditions. System reliability is a direct function of the design. Success in achieving reliability in fielded systems is a result of two factors:

1. Attention to reliability during the design phase; and
2. Testing to measure attained reliability as part of a planned reliability growth program.

There is a growing emphasis on the need to make reliability issues a more visible part of the design process. Reliability of the system is a basic function of the specific elements of the design, and that post-design fixes are an inefficient mechanism for achieving reliability targets. Some of the specific reliability activities which should be considered during design phase include:

- Failure Mode Effects Analysis: providing an evaluation of each potential mode and mechanism of failure, probability of occurrence and probable effect on performance.
- Apportionment of Reliability Requirements: establishing the necessary subsystem, equipment and part reliability required to meet system requirements.
- Parts Derating: the use of parts with specified performance characteristics much greater than the performance limits by the design.
- Parts Control and Standardization: minimizing the number of different part configurations and using parts with known performance.
- Design Simplicity: using the minimum number of parts, thus reducing complexity and opportunities for failure.
- Minimized Terminal and Component Temperature: reducing thermal stresses.
- Redundancy: assuring mission success in the event of single system failure.
- Increased Safety Margins: allowing for continued performance in over-stress situations.

These activities may lead to design solutions which invoke penalties within other design measures such as cost, weight or performance. The ultimate objective of the design process is to achieve, through appropriate trade-off, a balance between operational effectiveness and ownership cost.

5.6.2 Reliability Testing

Reliability testing and the evaluation of test data provide tangible evidence regarding the reliability of design. The test data is very critical to the program office since they serve as the cornerstone for many decisions such as design adequacy, assurance that reliability under field conditions will be adequate, and whether or not there is the need for design changes. The utilization of test data for reliability analyses must be very carefully planned and evaluated.

In general there are two categories of tests which can be used to provide information for supporting evaluations. These are the measurement tests (i.e., tests designed to measure reliability), and evaluation tests (i.e., tests which generally result in a regression analysis designed to evaluate relationships between environments or stresses and parameters which influence the reliability of an item). Properly used, both categories of tests can be used to provide information for monitoring reliability progress or for identifying the potential areas where greater concentration is required to achieve objectives. However, it should be pointed out that the approach to planning, analysis, and use of results depends, in a large measure, on the category of test being conducted.

RAM Related Testing
• Environmental Stress Screening • Lot Acceptance Testing • Production Reliability Assurance Testing • Test-Analyze-Fix Test • 1st Article Inspection • Reliability Growth Testing Analysis • Continued Maintenance/Maintainability Demonstration and Evaluation • Continued reliability Quality Testing (RQT) and Acceptance Testing • DCACAS

Table 5-3 Keys to Achieving RAM

Since test data can be extremely valuable in monitoring, it is important to be able to identify the, types of tests that are often applied. These tests, shown in Table 5-3, can frequently be used as sources of reliability oriented information, provided of course that planning has been such that the appropriate reliability data will be recorded along with information normally obtained from these tests.

It should be pointed out that the assurance of reliability program effectiveness requires a continuous monitoring and evaluation based on various data developed either through design analysis or through test. A considerable amount of test data, which is particularly useful as a means of evaluating reliability and maintainability, can often be made available in early stages of a program through proper planning and utilization.

5.6.3 Reliability Growth

Reliability growth is a function of the maturity of design and the application of engineering and test resources. It provides visibility to the decision-makers of how reliability is improving throughout the program. In general, reliability growth is the result of an interactive design process. As the design of various items/systems matures, the designer identifies actual or potential sources of failures and proposes product redesign or manufacturing process improvements to resolve problems. Typically, the first prototypes of any new and complex weapon system will contain design and manufacturing deficiencies. These deficiencies are often found during testing and now require corrective action either to improve the design or the manufacturing processes.

Reliability growth assessments are used in controlling the growth process through examination of reliability growth curves which are generated and maintained for the items under consideration. Reliability growth curves (Figure 5-14) show both the planned and assessed growth, and a comparison of these values will indicate program progress. On the basis of these comparisons, the contractor or PMO can develop appropriate strategies involving reassignment of resources or adjustment of time frame. The monitoring of reliability growth involves comparisons of the on-going activities against the applicable reliability program plans. The activities are monitored to establish whether performance conforms to the management plan. Some of these activities are listed below:

- Reliability Risk Assessments,
- Program Management Strategy,
- Reliability Testing,
- Failure Mode Analysis, and
- Root Cause Corrective Action.

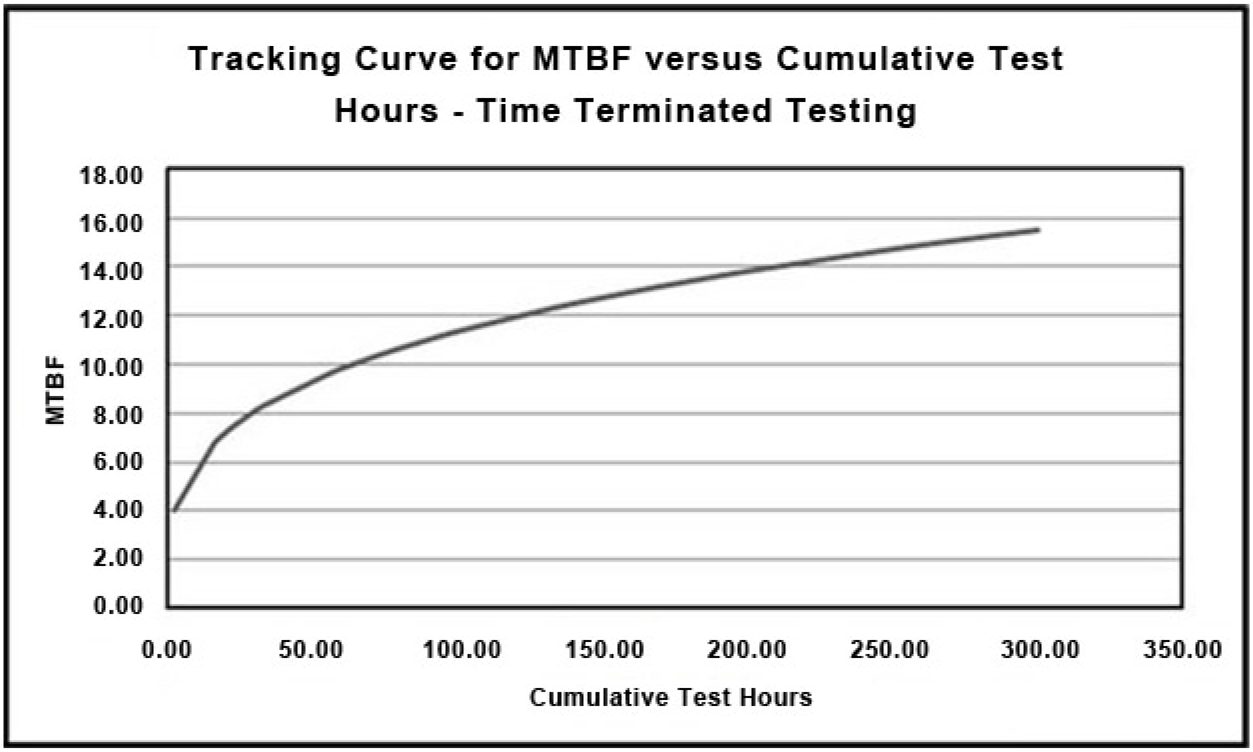

Figure 5-14 Reliability Growth Curve

Technical reviews (design and others) at various stages of the development effort to determine whether the product design adheres to the expressed and implied performance requirements are an additional area of importance for reliability monitoring.

5.6.4 Reliability in Manufacturing

The reliability of the as-built product is bounded by the inherent reliability of the design and in the control of quality of key and critical characteristics.

- A Key Characteristic (KC) is a feature of a material, process, or part (includes assemblies) whose variation within the specified tolerance has a significant influence on product fit, performance, service life, or manufacturability.
- A Critical Characteristic is any feature throughout the life cycle of a Critical Safety Item (CSI), such as dimension, tolerance, finish, material or assembly, manufacturing or inspection process, operation, field maintenance, or depot overhaul requirement that if nonconforming, missing or degraded may cause the failure or malfunction of a CSI. CSIs are parts whose failure could have catastrophic consequences. In general terms, a CSI's failure could cause loss of life, serious injury or permanent disability, loss of a weapon system, or substantial equipment damage.

Key and critical characteristics must be identified and controlled. It is critical for the design team to specify the physical and functional requirements which must be achieved in the parts and components in order to foster design reliability in the manufactured product. These requirements should be included in the company's quality planning for both in-house and subcontractor manufacturing.

Even where the controls above are specified, there is some risk that reliability of the hardware may be degraded by changes in tooling, processes and work flow. These types of changes are a normal part of most manufacturing programs. To assure that these changes do not have a negative impact on hardware reliability, Production Reliability Acceptance Testing (PRAT) can be required by the PMO. These tests are accomplished on delivered or deliverable production items under specified conditions, to assure that the manufacturer has complied with the specified reliability requirements. The PMO must specify the particular items to be tested, the test duration, frequency and test plan and environment. In addition, focused emphasis on continuous process improvement can yield significant improvements in achieved reliability and quality.

5.7 Quality in Contract Language

A 21 July 2008, DUSD (AT&L) Memo on Reliability, Availability and Maintainability noted that DOD weapon systems were not achieving the required reliability during developmental testing and subsequently were found unsuitable during Initial Operational Test and Evaluation. Also, higher than anticipated, ownership costs points to insufficient reliability engineering activities and logistics planning during the early acquisition phases to include RAM not being adequately designed into the systems. The Defense Science Board Task Force on Developmental Test and Evaluation recommended that RAM be a mandatory contractual requirement and be addressed at every program review. The memo went on to state that policy shall be developed to implement RAM practices that:

- Ensure effective collaboration between the requirements and acquisition communities in the establishment of RAM requirements that balance funding and schedule while ensuring system suitability and effectiveness in the anticipated operating environment;
- Ensure development contracts and acquisition plans evaluate RAM during system design;
- Evaluate the maturation of RAM through each phase of the acquisition life cycle; and
- Evaluate the appropriate use of contract incentives to achieve RAM objectives.

5.7.1 Sample Language

The contractor shall develop and follow a Reliability Program Plan in order to achieve the following four objectives (1) understand the customer/user's requirements, (2) design for reliability, (3) produce reliable systems, and (4) monitor and assess field reliability. The Reliability Program Plan shall, at minimum, employ each of the Reliability Activities herein and shall address reliability funding, schedule, outputs, and staffing.

The contractor shall implement each of reliability activities with appropriate reliability design and development methods and tools. Information on a variety of reliability methods and tools may be found in the DOD Guide for Achieving Reliability, Availability, and Maintainability. The contractor shall select appropriate methods and describe them in the Reliability Program Plan. The customer may elect to review, comment and negotiate regarding the methods selected by the contractor. The contractor shall identify and employ a set of design-reliability Best Practices. The contractor shall execute all of the Reliability Activities set forth herein using the approaches, methods, and tools described in the customer-approved Reliability Program Plan.

5.7.2 Quality in the Source Selection Criteria

The procedures used to award contracts have traditionally focused on the lowest bid. While this approach enhances competition; quality is not always given adequate consideration. This is especially true when considering the effort required to manage and control "key" and "critical" characteristics. If one of the goals of the DOD acquisition process is to provide the warfighter with "uniform, defect-free products that perform as expected and are affordable," then it is essential that the contractor minimize and control variation on these key/critical product characteristics and their corresponding manufacturing processes.

In using the best value approach, the Government seeks to award the contract to an offeror who gives the DOD the greatest confidence that it will best meet the warfighters' requirements affordably. This may result in an award being made to a higher priced offeror where the overall business approach or superior past performance outweighs the cost difference. The application of RAM and quality factors as a part of source selection criteria can be used to develop the "best value" criteria.

5.7.3 Warranties

Much has been said about warranties in the context of providing assurance or quality. Warranties are used successfully in the commercial world, and they do present a good tool in our quest for quality. As contrasted with the commercial market, however, the majority of DOD purchases are for unique equipments and systems produced in small quantities. Moreover, these equipments are handled and serviced by government personnel and, considering the number of people involved, the complexity of the supply system, and the various performance requirements that cannot be readily tested, it becomes very difficult to effectively administer warranties.

The primary intent for using warranties should be to motivate contractors to improve the quality and reliability of their products, so that they would reap financial benefit by avoiding the warranty cost of repairs and replacements. Warranties are no substitute for quality, and should not be used as a crutch. Simply put, when a system fails to accomplish the mission for which it was intended, the warranty can never compensate for potentially devastating results.

5.8 Summary

DOD's approach to quality has changed significantly over the past 20 years, going from:

- Using a government spec (MIL-Q-9858A), to a commercial spec (ISO 9000/AS9000) that is only used as a guideline;
- Government oversight, to government insight; and
- Total Quality Management, to Lean/Six Sigma and Theory of Constraints.

What has not changed is the requirement to put capabilities into the hands of the warfighters. A capability that is uniform, defect-free, performs as expected and is affordable. The right quality approach can foster the achievement of these goals, the wrong approach can be costly and end up taking too long to develop and deploy and then not perform as expected.

5.9 Related Links and Resources

Numerous reference documents impact the manufacturing management function throughout the acquisition process. These documents originate from many sources and range across academic disciplines, functional activities, and job specialties.

The following is a reference list of DOD Directives (D), Instructions (I) Manuals (M), Pamphlets (P), Military Standards (MS), and other documents. The documents listed contain DOD policy guidance applicable to the manufacturing management function. They are listed as sources of DOD manufacturing management information.

Note: Many of the documents listed are no longer required (due to acquisition reform), but still contain some very valuable information.

Number	Title
ISO 9001	Quality Management System
AS 9000	Aerospace Quality Management System
DI-9000	Advanced Quality Systems Guidelines (Boeing)
	Baldrige Performance Excellence Program
	Lean Enterprise Model
	Lean/Six Sigma Guidebook
	Theory of Constraints
	Quality Function Deployment
	Design of Experiments
	Statistical Process Control
	Reliability, Availability and Maintainability (RAM) Guide

Defense Manufacturing Management Guide for Program Managers
Chapter 6 - Manufacturing Planning

6.1 Objective

Manufacturing involves the process of transforming raw materials into finished products. This transformation is accomplished through the use of contractor resources which can include basic raw materials, to expensive facilities, human skills, machines and capital investments. The purpose of manufacturing planning is the identification of these resources and their integration into a structure that provides the capability to achieve production objectives. The material in this chapter identifies the actions which should be taken by the program manager (PM) and the system contractor(s) to develop that structure. The issue of manufacturing risk assessment and its application to the planning process is described. Risk assessment is intended to identify gaps in capabilities so that the PM can identify investment strategies allocate resources against those risks and gasp. Risk assessment, one of the PM's significant manufacturing tasks during development - is an element which is required to be addressed throughout the acquisition life cycle and during the various technical reviews and in the milestone review process. The primary manufacturing planning and scheduling challenge to the PM involves measuring the qualitative and quantitative manufacturing resources required for production.

After reviewing this chapter, the PM should:

- Describe how feasibility and capability assessments can contribute to the identification of manufacturing risk and investment strategies in order for a program to successfully execute a production program;
- Identify the depth and type of manufacturing analysis required in a government and a contractor manufacturing plan and schedule;
- Explain how production rates affect the various aspects of a program's cost and schedule; and
- Identify some of the types of manufacturing control systems in use today.

6.2 Background

" *After more than 9 years in development and 4 in production, the JSF program has not fully demonstrated that the aircraft design is stable, manufacturing processes are mature, and the system is reliable. Engineering drawings are still being released to the manufacturing floor and design changes continue at higher rates than desired. More changes are expected as testing accelerates. Test and production aircraft cost more and are taking longer to deliver than expected. Manufacturers are improving operations and implemented 8 of 20 recommendations from an expert panel, but have not yet demonstrated a capacity to efficiently produce at higher production rates. Substantial improvements in factory throughput and the global supply chain are needed* ."

- GAO Report 11-325, issued 7 April 2011

The GAO reports indicates that programs, like the Joint Strike Fighter, continue to move forward with immature technologies, designs that are not complete and manufacturing processes that are not proven. Successful production programs that are affordable require extensive production planning and investments in order to fully mature their production processes well before Low Rate Initial Production (LRIP) begins.

6.3 Introduction

Manufacturing planning is primarily a contractor function though there are some DOD organizations that do accomplish manufacturing tasks and as such must plan for those activities. Planning is a complex task that includes long-range plans, medium-range plans, and short-range plans (see Figure 6-1).

6.3.1 Long-Range Plans

Long-range manufacturing or production plans (2-5 years) takes into consideration Corporate Strategic Plans and long-range business forecasts to leverage core capabilities in the achievement of corporate goals. This planning, sometimes referred to as aggregate production planning, represents the role of production in the strategic business plan and aligns financial planning along with resource/capacity planning and market conditions to align production with long-term demand forecast. Corporations that do business with the DOD align their long range plans with DOD strategic plans, forecast and world politics. A good example of this is when the DOD releases its Five Year Defense Plan (FYDP) it provides contractors with DOD 's roadmap for spending and they can align their strategic plans and investment strategies to those plans.

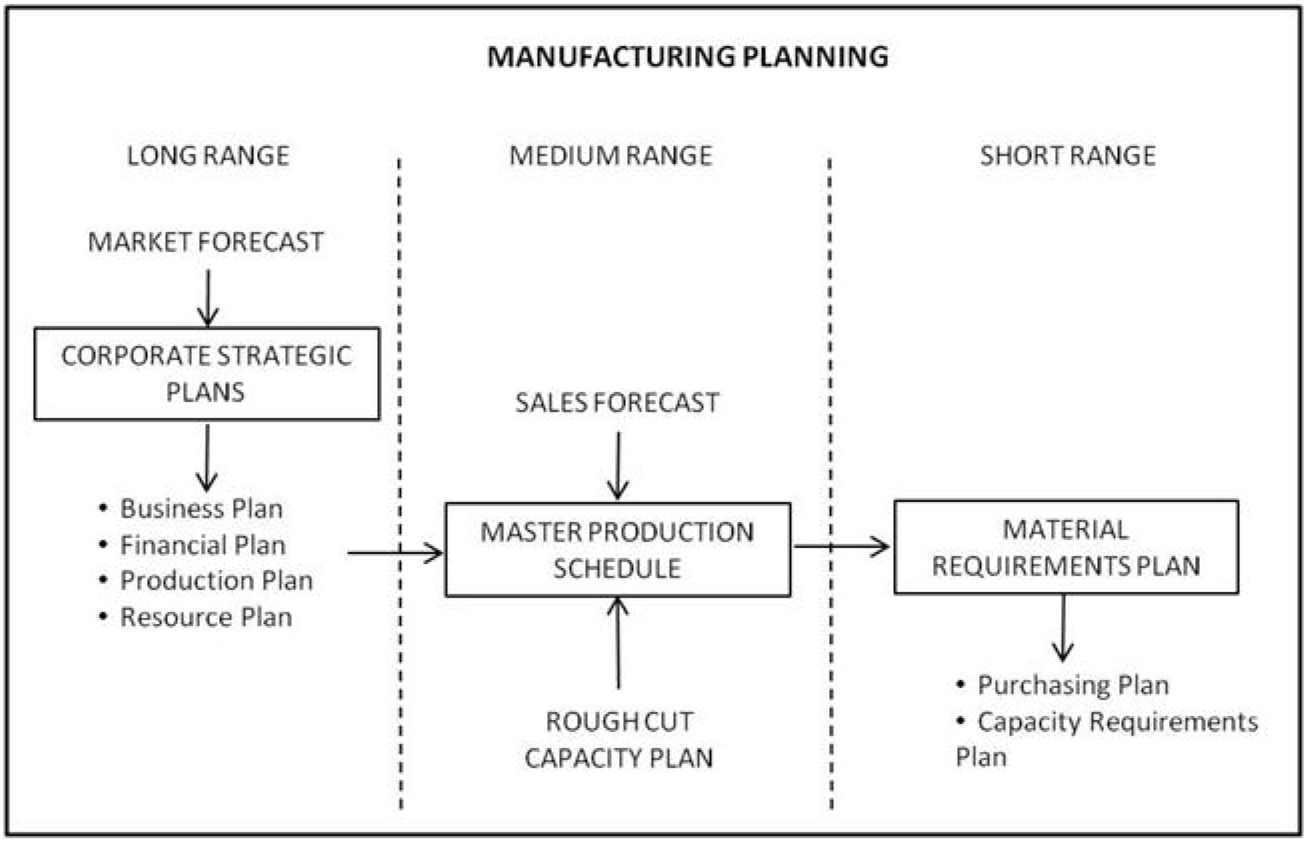

Figure 6-1 Manufacturing Planning

6.3.2 Medium-Range Plans

Medium-range manufacturing plans (6-18 months), sometimes referred to as the Master Production Scheduling (MPS), breaks down a business plan and aggregate production plan into product plans or families of products. The MPS generates schedules for specific products and the amount company intends to produce by month for the next few months. The MPS is not a detailed plan. The MPS might include medium-range demand forecasting, capacity planning, shop-floor modeling and simulation to optimize production and layout production schedules and workflow, materials planning to include supplier agreements and partnering, plans for tooling and special test equipment, and investment strategies to support the achievement of the above considerations. A good example of shifting plans to meet market conditions is when automobile manufacturers shift production from larger vehicles to smaller, more gas efficient vehicles after seeing gasoline prices rise sharply. A good DOD example of companies reacting to changing world politics is when the wars against terrorism saw a dramatic rise in the use of improvised explosive devices (IEDs) it caused the DOD to accelerate its development and production of Mine Resistant Ambush Protected (MRAP) vehicles.

6.3.3 Short-Range Plans

Short-range manufacturing plans are the day-to-day plans and activities. This could include capacity planning and scheduling; materials requirements planning; production planning which includes detailed workflow analysis from procurement to receiving through fabrication; sub-assembly; assembly; inspection/test; and packaging and shipping. Short range plans include Material Requirements Planning (MRP) and Capacity Requirements Planning (CRP).

Materials Requirements Planning (MRP) takes the product requirements from the Master Production Schedule and breaks them down into sub-assemblies and components. The MRP is used to help ensure materials are released on time to production and that the system can meet the customer's delivery or schedule requirements. The MRP helps to manage and minimize inventory and purchasing activities.

Capacity Requirements Planning (CRP) provides a detailed schedule of each operation by workstation and identifies the processing times for each operation.

Planning is carried out so that activities and resources are coordinated over time to achieve the goals with as little resource consumption as possible. Planning must be done so that the progress of the plan can be monitored at regular intervals and control over operations can be maintained. Planning in the manufacturing environment involves many elements: scheduling, labor planning, equipment planning, process planning, materials planning, quality planning, and cost planning.

- Scheduling involves specifying the start, duration, sequencing and end of the various activities.
- Labor planning involves the training and allocation of qualified personnel, distribution of responsibilities and resources.
- Equipment planning involves identification, purchasing, installation and checkout of the required equipment.
- Process planning involves the identification of processes (especially key and critical processes) and the maturing of these processes so that their cost and performance is well characterized.
- Materials planning involves could involve the entire supply chain and at a minimum should include key and critical suppliers and vendors.
- Quality planning involves the identification of methods to verify product quality (measurement) and the purchasing and proofing of that equipment.
- Cost planning involves identification of costs and when they will occur to include long term capital expenditures.

Based upon the product manufacturing demands, a business structure for the program can be developed. This structure should define the specific elements of the prime contractor organization that will be involved in the program and the numbers and types of subcontractors required. The decision regarding subcontractors should be made from the standpoint of contractor capability as well as capacity. Within the context of the defined business structure, there should be an identification of the specific resources required. Personnel should be identified in terms of both quantity and specific skill types required, and time-phased over the planning horizon. Manufacturing facilities and equipment which will be required at the prime and subcontractor locations should also be identified.

6.3.4 Integrated Master Plan

The Integrated Master Plan (IMP) is an event-based plan consisting of a hierarchy of program events, with each event being supported by specific accomplishments, and each accomplishment associated with specific criteria to be satisfied for its completion. The IMP should provide sufficient definition to allow for the tracking of the completion of required accomplishments for each event, and to demonstrate satisfaction of the completion criteria for each accomplishment. In addition, the IMP demonstrates the maturation of the design/development of the product as it progresses through a disciplined systems engineering process. IMP events are not tied to calendar dates; each event is completed when its supporting accomplishments are completed and when this is evidenced by the satisfaction of the criteria supporting each of those accomplishments. The IMP is placed on contract and becomes the baseline execution plan for the program/project. Although fairly detailed, the IMP is a relatively top-level document in comparison with the Integrated Master Schedule (IMS).

6.4 Manufacturing Feasibility Analysis

Manufacturing feasibility analysis answers the question "can you build it?" It is directed toward evaluation of the compatibility of the demands of the manufacturing task and the manufacturing environment (5Ms) required to accomplish it. The capability of a contractor (or manufacturing source) to successfully execute the manufacturing effort depends upon that contractor having:

- An understanding of the manufacturing task;
- Adequate qualitative production skills;
- Sufficient personnel (on hand or available);
- Sufficient facility floor space;
- Equipment in satisfactory condition;
- Adequate, operable test equipment;
- Assured, capable suppliers;
- Management capability; and
- A plan to coordinate all resources.

Manufacturing feasibility is first addressed in the Assessment of Alternatives (AoA). The assessment determines the likelihood that a system design concept can be produced using existing manufacturing technologies and capabilities while simultaneously meeting quality, production rate and cost requirements.

Feasibility is a bounded issue. It is bounded by existing manufacturing technology. There is a presumption that the state of current manufacturing technology relative to the system concept can be defined. There is also a presumption that the system concept will have sufficient definition to determine the technology demands embedded in it. Having determined the state of technology and the system demands, questions such as those which follow should be raised. What is the likelihood that the manufacturing task can be accomplished given your knowledge of the design and given your knowledge of the production environment in existence today? Based upon the feasibility assessment, the PMO should develop a manufacturing risk evaluation to quantify the statement of manufacturing feasibility. What is the risk level and where are those risks? A major result of the feasibility evaluation is the identification of manufacturing technology needs. The purpose of this identification is to determine which planned or ongoing manufacturing technology programs are required to achieve production phase objectives, priority can then be given to these programs to ensure that necessary capabilities can be put on line in the factory and be proven prior to the production phase.

The feasibility analysis also provides a basis for manufacturing planning because its accomplishment involves the evaluation of:

- Producibility;
- Critical manufacturing processes;
- Special tooling requirements;
- Test and demonstration requirements for new materials and processes;
- Alternate design approaches; and
- Anticipated manufacturing risks and potential cost and schedule impacts.

6.5 Capacity Analysis

Earlier in this chapter we noted that manufacturing involves the process of transforming raw materials into finished products. This transformation occurs through a series of operations. Each individual operation in the series of operations takes an input, performs a process, and delivers an output that goes on to the next operation. The output of the first process is an input into the next process.

Manufacturing capacity can be defined as the rate of output that can be achieved given the current manufacturing capabilities (5Ms). This definition may be limited to an 8 hour day/5 days a week operation, or it could include maximum capacity that takes into consideration overtime, 2nd and 3rd shifts and other production strategies.

There are several basic types of manufacturing strategies or approaches (with hybrids), each of these strategies impact the ability of the factory floor (capacity) to various types and volumes of product:

- Job Shop (jumbled flow),
- Disconnected Line Flow (batch operation),
- Connected Line Flow (assembly line),
- Cellular Shop, and
- Continuous Flow.

6.5.1 Job Shop

The job shop can be characterized as a jumbled flow operation. A machine shop or a tool and die maker are good examples of a job shop operation. Work is flowed to a machine (milling machine, lathe, drill press, etc.) as required. Not all machines need to be used, and the machines can be used in different order based on the tasks being performed. The sequencing of the tasks is based on the operations sheet or router. The shop can produce a wide variety of products, but while it is very flexible it is not very efficient. Job shops are often used to produce unique (one of a kind) items. Often quality is in the hands of the craftsman, and so you have highly skilled workers doing a wide variety of tasks. Figure 6.2 shows how these various manufacturing strategies are linked to cost, volume, and variety of products.

6.5.2 Disconnected Line Flow

The disconnected line flow can be characterized as a batch operation. The volume of product is higher than a job shop but not enough products are being produced to call for an assembly line. Products are often accumulated in batch (like cookies) and processed together. Actually food processing on a small scale is a good example of batch operations (except for high volume food processing). The volumes go up from the job shop and the unit cost go down and your ability to produce a wide variety of product goes down. Workers are still highly qualified, though now may focus on a few skill areas and may start relying on jigs, fixtures and templates to aid in the production and assembly process. You may also invest more in capital equipment to assist in the batch processing operations.

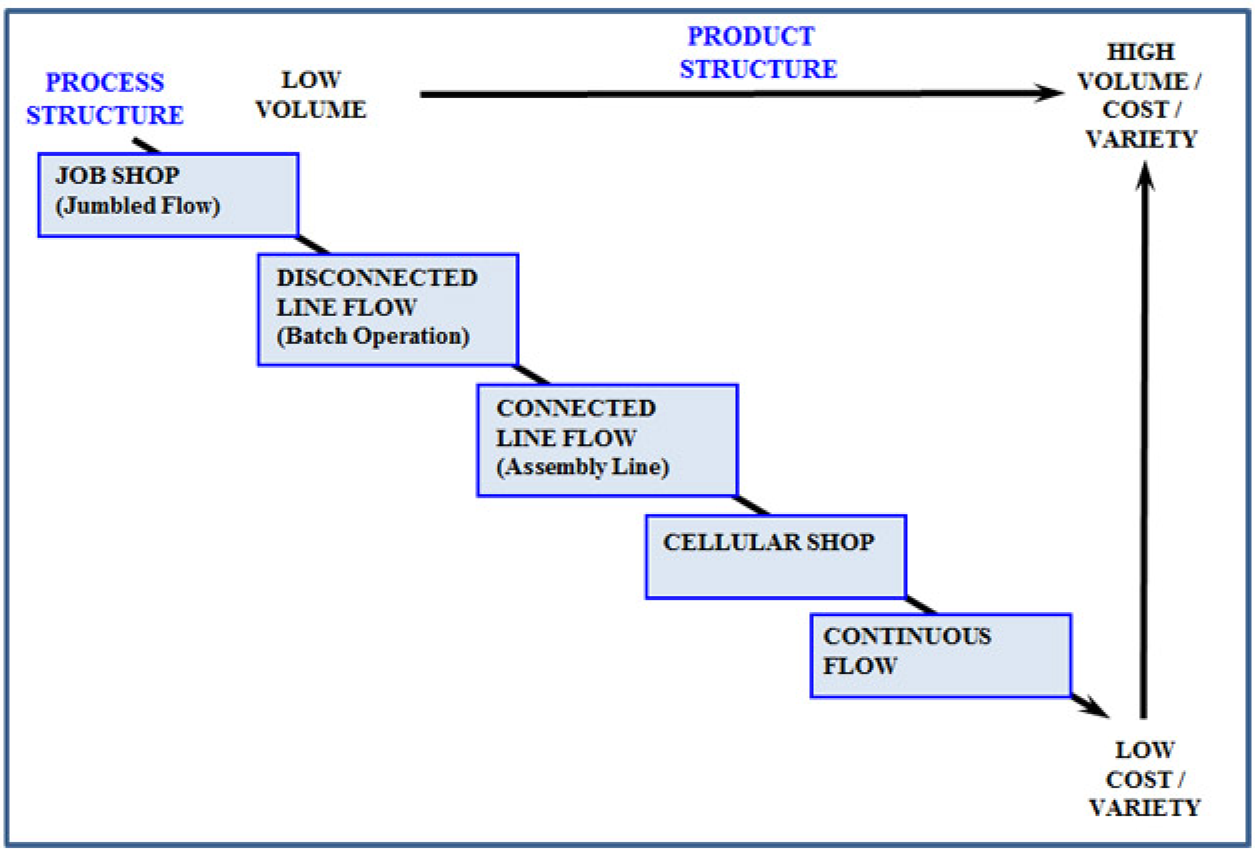

Figure 6-2 Manufacturing Strategies

6.5.3 Cellular Shop

The cellular shop can be characterized as an intermediate volume producer, somewhere between batch processing and an assembly line. Each shop or cell is grouped into families with its own processing technologies. The machines or workstations can move product from one machine to the next once processing is done without having to wait for the rest of the batch to be completed. Cells can be dedicated to producing a sub-component, an entire product or even dedicated to a single process. Cellular manufacturing is arranged to minimize material movement and handling and is often associated with lean production.

6.5.4 Connected Line Flow

The connected line flow can be characterized as an assembly line operation. The volume of the product again goes up, cost and flexibility go down. The automotive industry is perhaps the best example of an assembly line operation. In an assembly line or mass production setting the workers often are limited to a few repetitive tasks and thus are not highly trained. The quality is now driven more by the quality of the work instructions, materials and processes. Product variety goes down, unit goes down and volume goes up. Again there is a large investment in facilities and capital equipment.

6.5.5 Continuous Flow

The continuous flow shop can be characterized as a fixed pace operation, one that can go around the clock, seven days a week. Petroleum refining and pharmaceutical manufacturing are two good examples of continuous flow operations. In a continuous flow operation the pace is fixed and the flow of the process is fixed. It is often a very capital intensive operation with direct labor very low. Unit cost is low, as is product variation, but volume is high.

How does one select the correct manufacturing strategy? Often that decision is driven by product volume and complexity. The analysis of capacity begins with the assessment of the type of manufacturing strategy being employed or to be employed on the product. Capacity analysis looks at the designed capacity for product flow, which should be the most efficient production rate or the maximum designed capacity. The next step is to address capacity utilization. Often the factory is not being used to its capacity, so there is some room for surge operations. In addition to utilization look at flexibility. Can more people or equipment be added, or can work be subcontracted out to build in more capacity. If so how easy is it to do, what are the costs and can you maintain your levels of quality? Capacity analysis today is aided by the availability of many factory simulation programs. These simulation programs allow contractors to layout a factory floor (machines and workstations), layout workflow, identify machine usage and operations processing times. This allows contractors to optimize operations and material flow long before a plant or a product is even built.

6.5.6 Manufacturing Resources

The classic manufacturing resources required are illustrated in Figure 6-3 and are often referred to as the 5Ms (measurement, materials, machines, methods and manpower).

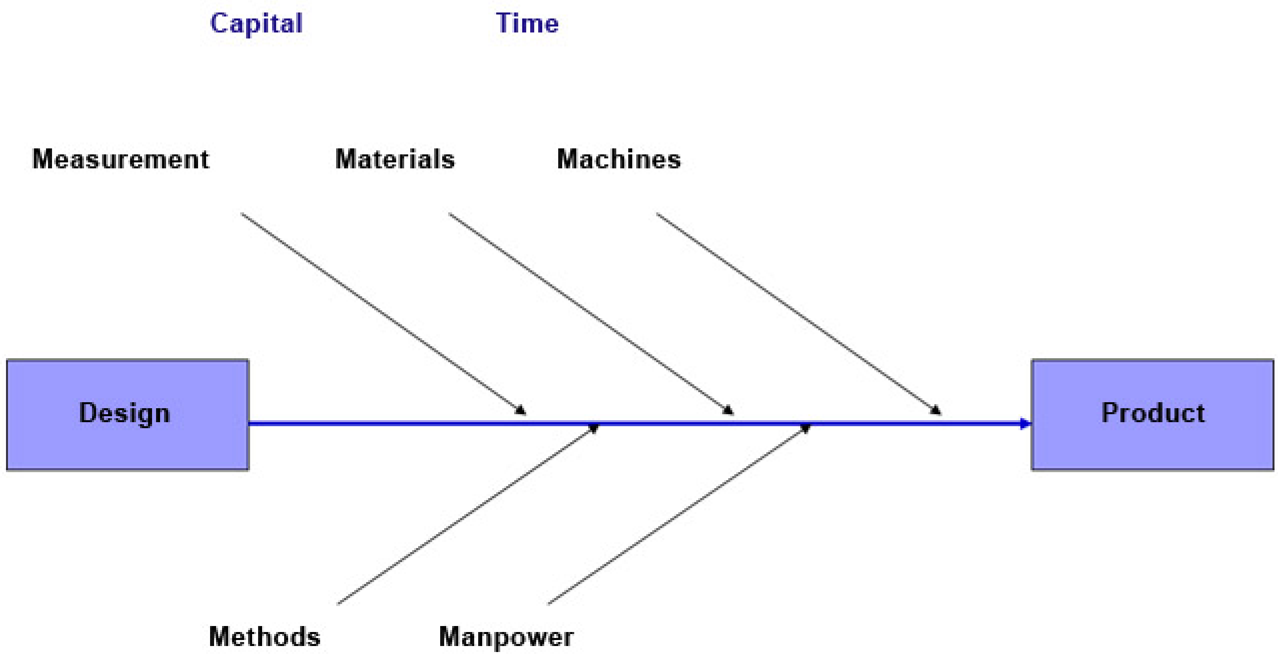

Figure 6-3 Manufacturing Resources

6.5.6.1 Capital

Capital represents the monetary assets which are available to the contractor. Capital can be used to finance ongoing work, for investment to improve capacity or capability, pay for long lead items, to broaden the market base, or for any of the number of competing uses within the contractor's organization. But capital, like all assets, is limited and investments must be weighed against other competing requirements.

6.5.6.2 Measurement

Measurement includes all the equipment and processes required to measure, test, verify and assure that product meets all requirements from raw materials to finished product. This could include such things as inspection equipment, gages, calibration equipment and processes, test equipment and statistical process control.

6.5.6.3 Materials

Materials includes all materials that are used in the manufacturing process. This includes raw materials, components, sub-systems and the entire supply chain. The focus of the government and contract effort should be on the most efficient utilization of the required materials and a consideration of sources of these materials to include concerns with sole sources, foreign sources and diminishing sources.

6.5.6.4 Machines

Machines include the real property, plant and equipment in the factory in which the products are built. The term includes the industrial equipment, machine tools, robotics, and shop aids to manufacturing.

6.5.6.5 Methods

Method represents the way that raw materials are formed, shaped, assembled and held together. This area involves advancements in the way things are done in the factory, including the processes that are available to take raw material, enter it into a productive process, and transform it into something useful that meets DOD needs.

6.5.6.6 Manpower

Manpower is the utilization of people to include those managing the program, design engineers, manufacturing engineers, and factory operations - the direct and indirect labor personnel. Manpower includes training and certification of personnel so that they will have the necessary skills required to complete their assigned tasks.

6.5.6.7 Time

Time is a resource available to all contractors. But it is limited and provides a constraint on the contractor since performance and delivery commitments are related to specific due dates. Complex products may have a prime contractor integrating multiple complex subsystems and components, each with their own lead times and schedules, making the management of time a key and critical management responsibility.

6.6 Risk Assessment

Risk is a measure of ***uncertainty*** , uncertainty that you will achieve program goals (cost, schedule, and performance).

A risk has three components:

1. A **future root cause** (yet to occur) the most basic reason for the existence of the risk; which, if eliminated or corrected, would prevent a potential consequence from occurring;

2. A **probability** , or **likelihood** (greater than zero and less than 100 percent), assessed at the present time of that future root cause occurring; and

3. The **consequence** , or effect (such as a loss, injury, disadvantage or gain), of that future occurrence, expressed qualitatively or quantitatively.

Manufacturing risk assessment is a supporting tool for the contractor and program office decision-making process. It seeks to estimate the probabilities of success or failure associated with the manufacturing alternatives available. These risk assessments may reflect alternative manufacturing approaches to a given design or may be part of the evaluation of design alternatives, each of which has an associated manufacturing approach.

Risk management is an overarching process that begins during the earliest stages of a program and continues throughout its entire life cycle. Risk encompasses the following steps (see Figure 6-4):

- Risk identification;
- Risk analysis;
- Risk mitigation planning;
- Risk mitigation plan implementation; and
- Risk tracking.

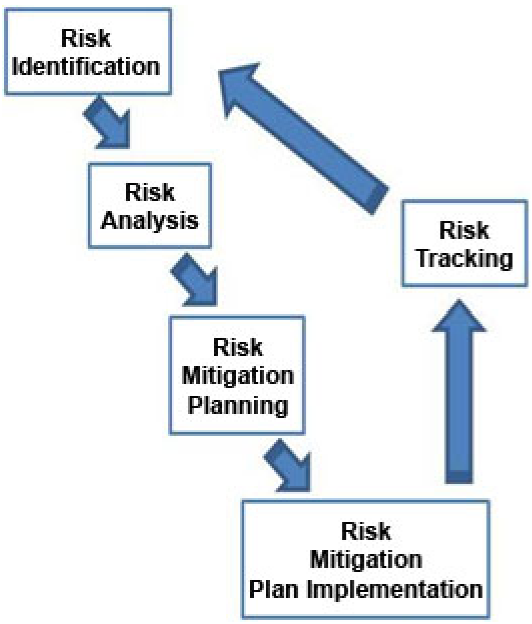

Figure 6-4 Risk Management Process

6.6.1 Risk Identification

Risk identification examines each element of the program to identify associated risk root causes, begin their documentation, and prepare for further risk management actions. Risk Identification answers the question: "What can go wrong?"

- Begins as early as possible in the acquisition process.
- Applied continuously throughout the acquisition process.
- Risk identification is the responsibility of each IPT member.

The Risk Management Plan should describe the methods to conduct risk identification.

6.6.2 Risk Analysis

Risk analysis looks at each risk root cause to determine:

- The probability it will occur;
- The consequence in terms of performance, schedule, and cost if it does; and
- Its relationships to other risk root causes.

Risk Analysis answers the question: "How big is the risk?"

- Includes both qualitative and quantitative methods.
- Assign a risk rating or level (e.g., high, medium, or low) based on the probability and consequence.
- Prioritize risks based on assigned ratings.

The Risk Management Plan should describe the methods to conduct risk analysis.

6.6.3 Risk Mitigation Planning

Risk mitigation planning includes identifying, evaluating and selecting options to set risk at acceptable levels given program constraints and objectives. Risk mitigation planning answers the question: "What is the program approach for addressing this potentially unfavorable consequence?" Includes specifics of: what should be done; when it should be accomplished; who is responsible for its accomplishment; and the funding required to implement the proposed responses.

There are four common risk mitigation strategies (one or more which may apply for a given risk):

1. **Controlling** the root cause or consequence;

2. **Avoiding** risk by eliminating the root cause and/or the consequence;

3. **Assuming** the level of risk and continuing with the current program plan; and /or

4. **Transferring** the risk.

Risk mitigation planning is the activity that identifies, evaluates, and selects options to set risk at acceptable levels given program constraints and objectives.

Risk mitigation planning involves an in-depth examination of possible strategies and methods to mitigate the potential risk causes (what), developing a schedule for accomplishing the risk mitigation tasks (when), identifying who is responsible for the risk area and its mitigation tasks (who), the funding required to implement the chosen risk mitigation strategy, and providing estimates of any cost and schedule impacts associated with mitigating the risk.

6.6.4 Risk Mitigation Plan Implementation

Risk mitigation plan implementation involves executing the planned risk mitigation efforts. Risk mitigation plan implementation answers the question: "How can the planned risk mitigation be implemented?"

- Determines what planning, budget, requirements and contract changes may be needed.
- Directs appropriate IPTs to execute the defined and approved risk mitigation plans.
- Outlines the risk reporting requirements for risk tracking.
- Documents change history.

6.6.5 Risk Tracking

Risk tracking provides feedback on the effectiveness of the risk mitigation execution. Risk tracking answers the question, "How are the planned mitigation efforts progressing?"

- Communicates risks to all affected stakeholders.
- Monitors risk mitigation plans.
- Reviews and updates risk status.
- Displays risk management dynamics by tracking risk status using a risk reporting matrix.
- Alerts management when to implement or adjust risk mitigation plans.

6.6.6 Manufacturing Risk

Assessing manufacturing risks is a DODI 5000.02 requirement, and it is required as early as pre-Milestone A where the Analysis of Alternatives (AoA) is required to assess the "manufacturing feasibility" of the proposed approach.

As a system progresses through its definition, design, development, testing and fielding, more information becomes available concerning the system's risk. If the risk management process is conducted continuously, then new information will lead to identifying and analyzing new risk root causes, and identifying and implementing mitigation plans for them. It will also lead to re-analyzing previously identified risk root causes, and re-evaluating and adjusting mitigation plans already in place. This continuous activity allows the PM to focus valuable program resources where they can be most effective, and shift resources as new future root causes are discovered and others are re-evaluated.

Manufacturing risk can come from many sources to include:

- Emerging critical technologies;
- Industrial base;
- Design (immature or not producible);
- Materials;
- Cost and Funding;
- Processes and process capabilities;
- Quality Management;

- Manufacturing Management;
- Facilities and equipment; and
- Personnel (skills, training and certification).

Iterative Systems Engineering process is the perfect vehicle for helping manufacturing managers to identify risk early through technical reviews and audits and to support the development of plans and mitigations to reduce those risks.

Critical success factors refer to identifying the factors that must be successfully mastered to execute a successful risk management program. Some examples of risk management critical success factors include:

- Clearly define and establish feasible, stable, and well-understood user requirements;
- Establish a close partnership with users, industry, and other key stakeholders;
- Comprehensively plan, formally document, and continuously apply the risk management process, and ensure it is integral to all program processes;
- Use continuous, event-driven technical reviews as part of the risk management process; and
- Clearly define criteria for assessing the effectiveness of implemented risk mitigation actions.

Risk is time phased and should be tied to appropriate maturity models such as the Technology Readiness Level (TRL), Manufacturing Readiness Level (MRL) and Sustainment Readiness Model (SRM) that are considered best practices. Other chapters will discuss these models. These models provide for an assessment of a technology, manufacturing process, logistics/sustainment considerations of a component, subsystem, or weapon system. These models have been structured to:

- Define the current level of maturity;
- Identify maturity shortfalls and associated cost and risk; and
- Provide a basis for investments to mature the component, subsystem, or weapon system and thereby manage risk.

6.7 Developing the Manufacturing Plan

The statement of work and the product design are the elements on which a program manufacturing plan is based. The manufacturing plan defines the required sequence of operations in engineering, purchasing, manufacturing, and product assurance prior to delivery. The plan contains the tasks to be performed by the contractor and the subcontractors, as appropriate, and the organizations delegated responsibility for carrying out these tasks. The plan can be a long term plan, perhaps an annual plan, that includes forecast and estimates of demand over a long period of time and requirements for investments. Or the Manufacturing Plan could be for a shorter period, say a month, that uses a 30-day forecast to define the Production Plan. Finally, the Manufacturing Plan could be for just that day's production run, or that batch's run.

There are numerous ways to depict the Manufacturing Plan. One way is to flow chart the various tasks and activities using classic flow charting techniques and symbols. Another way is to use a tool like MS Project and show the tasks in an order and with linkages indicating the dependencies. Another way to depict production flow is with a PERT or Gantt Chart, both involve the use of a critical path method. There are many software tools to assist the manufacturing manager in developing their manufacturing plans and for developing production simulations to exercise those plans.

One of the hardest activities in developing the manufacturing plan is estimating the resource requirements. Figure 6-5 below identifies some of the current estimating techniques in use today. Analogy is the correct estimating approach if the system being estimated is new and there is very little information and the detail is not very accurate. Analogy compares a new or proposed system with one that is similar (analogous) to the one proposed. This estimating technique has the highest risk factor for getting the estimate wrong and thus needs to have an "adjustment and or cost factor" to help cover any risk.

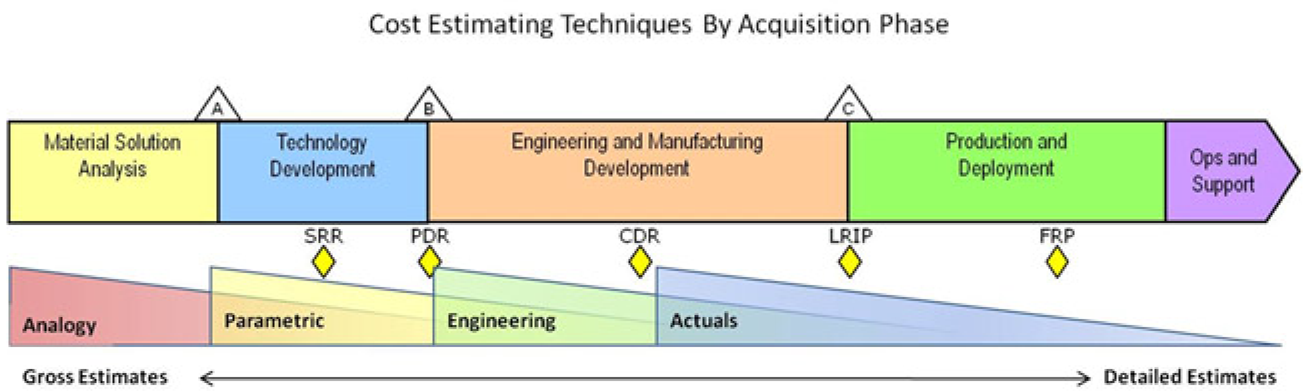

Figure 6-5 Cost Estimating Techniques

Parametric estimating uses regression analysis from a database of two or more similar systems to develop a cost estimating relationship (CER). Parametric estimating is often accomplished after a Milestone B decision and the system in question has been defined to a bit more detail. Key to parametric estimating is finding systems that are similar, the more similar the better the estimate.

An engineering estimate is a "bottoms-up" method of cost analysis based on a detailed build-up of labor, materials, and overhead cost for the proposed system. This type of estimating is especially useful after the critical design review (CDR) and the system is well defined.

The final estimating technique and most accurate is using "actual" cost experience based on knowledge gathered by building prototypes, and low rate initial production units. Estimates for full rate production can then proceed based on this knowledge; knowledge on the amount of touch labor; and learning curves.

In addition, today there are several estimating guides and estimating software tools that are available. For example, if you go to www.custompartnet.com you will find a software tool to estimate the production cost of many types of parts, from many types of materials, and for many different volumes and complexities.

Estimates of manufacturing resource requirements are used in conjunction with the work statement to develop a time-phased action plan. This plan displays the time flow of the manufacturing elements such as tooling, receipt of purchased parts and materials, fabrication, assembly, test, product assurance, and delivery. These plans are based on high level production plans which may be laid out for an entire program to support budget request. Figure 6-6 is a production plan for the Joint Strike Fighter (JSF).

	BLK 0.5		BLK 1	BLK 2	BLK 3									
	LRIP 1	LRIP 2	LRIP 3	LRIP 4	LRIP 5	LRIP 6	LRIP 7	LRIP 8	MY 1					MY 2
Buy Year	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Delivery Year	2010	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
USAF - CTOL	2	6	8	12	24	42	48	60	80	80	80	80	80	80
DoN - CV				4	6	15	17	20	19	50	50	50	50	50
DoN - STOVL		6	8	14	13	25	25	30	31					
UK - STOVL			2	1	0	6	1	8	11	12	13	12	12	7
IT - STOVL						4	3	3	3	3	14	14	12	1
IT - CTOL						2	3	11	11	11				11
AS - CTOL					4	8	15	15	15	15	15	13		
CA - CTOL								16	16	16	16	16		
DK - CTOL								8	8	8	8	8	8	
NL - CTOL			1	1		6	10	10	12	12	12	12	9	
NO - CTOL								8	12	12	12	4		
TR - CTOL						10	10	10	12	12	10	10	10	10
TOTAL	2	12	19	32	47	118	132	199	230	231	230	219	181	159

	MY 2				MY 3					MY 4					
Buy Year	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	
Delivery Year	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	TOTAL
USAF - CTOL	80	80	80	80	80	80	80	80	80	80	80	80	80	41	1763
DoN - CV	50	50	38	25	25	9									680
DoN - STOVL															
UK - STOVL	2	1	1	12	13	13	11								138
IT - STOVL															57
IT - CTOL	12	12	1												74
AS - CTOL															100
CA - CTOL															80
DK - CTOL															48
NL - CTOL															85
NO - CTOL															48
TR - CTOL	6														100
TOTAL	150	143	120	117	118	102	91	80	80	80	80	80	80	41	3173

Figure 6-6 JSF Production Schedule

In addition to a production schedule, the manufacturing resource estimates also looks at the manufacturing sequence flow (Figure 6-7) which gives an idea of how and when major subsystems are scheduled and where they fit in the workflow to complete the build. Figure 6-7 shows only one flow, but in reality there are often many branches off of the main flow with their own build sequence and schedule.

The longest cumulative flow in production, based on the critical path, determines the time at which design definition must be available from the engineering function so that production can begin. These flows are converted to manufacturing demand dates which are coordinated between engineering and manufacturing operations. The intent of the total process (engineering, supply chain management and production) is to ensure on time delivery of the product.

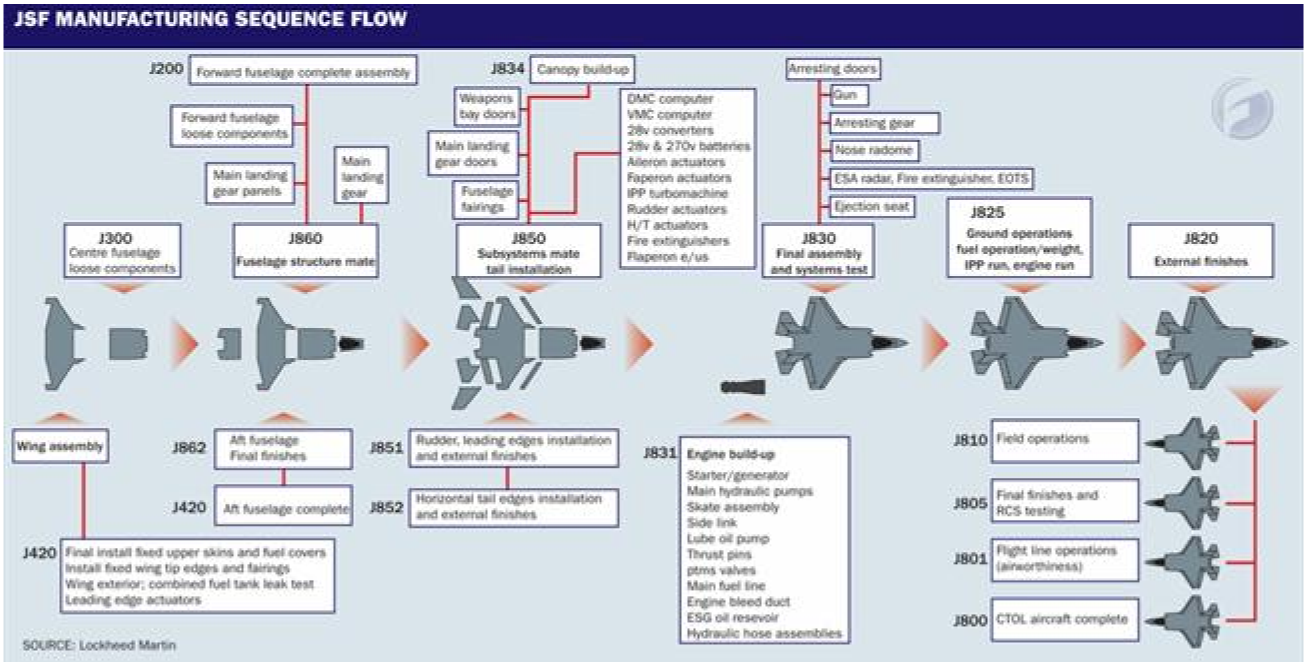

Figure 6-7 JSF Manufacturing Sequence Flow

Figure 6-8 provides an example of a detailed work flow for the fabrication of a printed circuit board (PCB). Note that this flow is linear, many products have a more complex flow with multiple paths. This is especially true for a build of a subsystem.

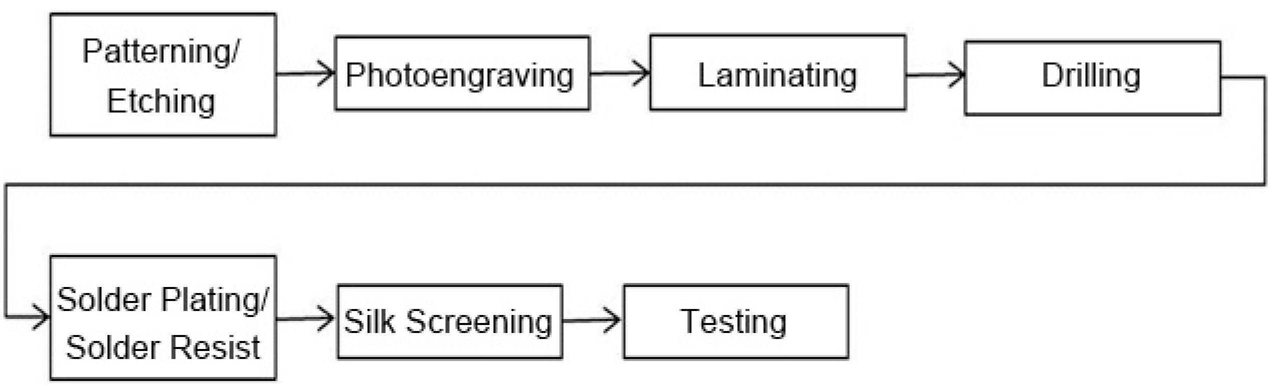

Figure 6-8 PCB Fabrication Process

6.7.1 Scheduling

One of the primary objectives of the contractor during the production phase is to produce and deliver a specified number of units of product to the user on the planned dates. In order to meet this objective, the contractor must schedule all of the steps in the process, from design to delivery, in a logical and economical pattern. The manufacturing plan and the schedule must be integrated since scheduling represents the ultimate application of time to the tasks to be performed. The plan emphasizes how and what to build. It determines when the resources are expended and must consider all active requirements. Scheduling ensures that resources are available when needed, no resources are overloaded or over expended during any of the manufacturing tasks, the most efficient application of resources is made, and customer delivery dates are satisfied.

The planning strategy must be communicated to scheduling, with all the supporting information on work package size selection, content, personnel loading, work center level loading. facilities occupancy determinations, timing of actual material needs, process options in the event that tools and equipment are unavailable or overloaded, and the many other considerations in the manufacturing plan. Since scheduling may be a function of several organizations or elements, this may be a formidable problem area.

A second problem area includes the need to accomplish the planned actions within the total resources available, without any discontinuities in the orderly and efficient performance of work. When discontinuities arise, scheduling often is compromised. Soon the carefully conceived manufacturing plan does not reflect the shop practice and the work is guided by a series of "work around" plans.

Information affecting scheduling must be available. It must be processed, sorted, and stored. Each contractor will have its own unique information system. The Program Manager Office (PMO) must be familiar with that system and its ability to recall quickly and accurately all those pieces of information impacting the execution of the manufacturing plan. Many companies use modeling and simulation tools to help them identify and remove bottlenecks in the production process and for improving quality.

A wide variety of schedules may be used by a contractor, some produced by the schedulers themselves. Some schedules cover the entire manufacturing effort and affect everyone. Others contain information of interest only to the group that produces them. To keep the many schedules from conflicting with each other, even though they may have been produced independently, a system of top-down scheduling is used. This means that a subordinate schedule must conform with the constraints of the parent schedule. A carefully disciplined one-way system keeps the more detailed, but smaller scope subordinate schedules, in harmony with the rest.

6.7.2 Master Phasing Schedules

The master phasing schedule establishes the basic relationship between the engineering release of the production design to the typical production flow process which consists of parts and material procurement, fabrication, assembly, installation, test, product assurance and delivery of the product. It summarizes the entire program in order to ensure compatibility of all subsequent planning and scheduling. The master phasing schedule is developed to reflect both the program requirements and contractor commitments. Completion milestone dates are normally displayed pictorially in a master-phasing chart, which visually depicts milestones for each major phase and planning element that must be completed. Figure 6-9 lists the major events for which relationships are required in a typical defense system production program. The master phasing schedule provides the basic schedule framework within which detailed schedule planning is accomplished. The master phasing schedule is used to develop the first unit flow chart, master schedules, and overall schedule direction for the various functional organizations.

Events	Schedule
Program Milestones: • Program Go-Ahead • Long-Lead Go-Ahead • Manufacturing Decision • Start Design Layouts • Engineering Drawing Release • Contract Delivery Schedules Fabrication, Assemble and Test: • Schedules and Events Operations Scheduling: • Issue Assembly Plan • Issue Final Tooling Plan • Issue Master Schedule Purchasing/Major Subcontracts: • Make/Buy Plan • Purchasing Order Awards • Major System Awards • Procure Long-Lead Material • Conduct PRRs for Critical Major Subcontractors Qualification Testing: • Components • Subsystems • System Manufacturing & Engineering: • Technology Development Plan • Subcontractor Data Packages • Manufacturing Tooling Policy • Manufacturing or Purchasing Plan • Producibility Studies	(Show appropriate start and completion dates by months or weeks in this section of the schedule)

• Identify Rate Tooling Tooling: • Fabricate Master Tooling • Fabricate Detailed Tooling • Fabricate Assembly Tooling • Design Tooling • Design Interface Tooling (Support of Subcontractors) Facilities: • Manufacturing Station Plan • Facility Layout • Facility Contracts Extensions • Design Contract, Prepare & Occupy Facilities • Set-up Assembly Areas for Manufacturing Manpower: • Develop Training/Certification Plans • Acquire Personnel • Train/Certify Personnel Management Systems: • Issue Material Requirements System • Issue Material Procurement & Inventory System • Issue Production Control System • Issue Work Measurement System • Issue OA System	

Figure 6-9 Master Phasing Chart for a Typical DOD Production Program

6.7.3 First-Unit Flow (FUF) Chart

The first-unit flow chart (Figure 6-10) is developed to define the schedules for the first unit of a new program or a model change. The first unit flow chart is developed by utilizing the schedule milestones found on the master phasing schedule and the assembly sequence, estimated labor hours, and most desirable crew size for each assembly or installation operation. The flow time for each of the assemblies is determined by utilizing the estimated labor hours, the most desirable crew size, and the number of shifts to be used. (This information is often estimated from past projects of similar nature and size.)

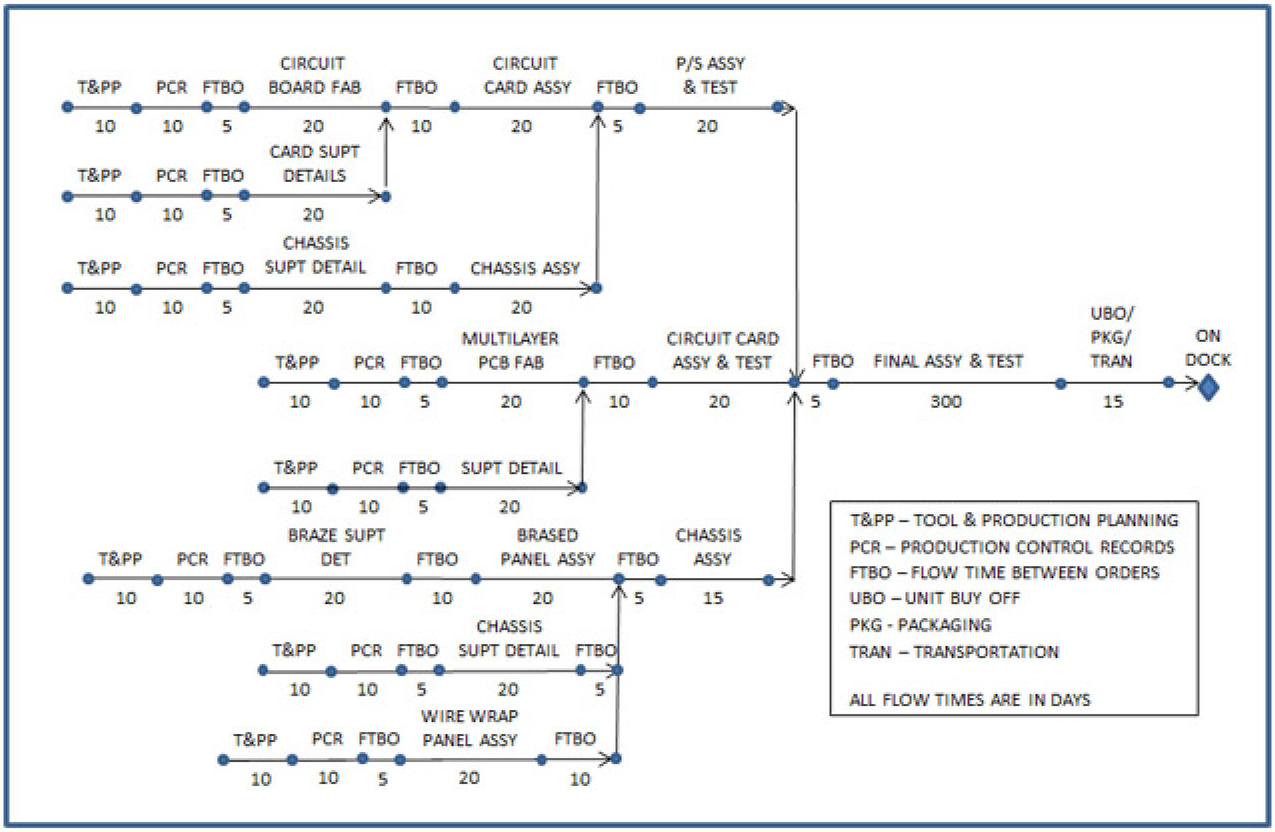

Figure 6-10 First Unit Flow

With the overall sequence of the major operations defined, all of the simultaneous activities and operations must be scheduled for completion to meet subsequent events which are dependent upon them. Correspondingly, start times for all the activities and operations being carried on simultaneously are determined in turn by individually working back through their required flow times.

In this manner, the entire schedule can be displayed on one chart for the first production unit. All organizations can determine at a glance when their responsibilities start, how long they have to carry them out, and when they must be completed. The first unit flow helps to establish your basis for cost estimating, work measurement and learning curves.

6.7.4 Integrated Master Schedules

The Intergrated Master Schedule (IMS) is an integrated, networked schedule containing all the detailed tasks necessary to support the events, accomplishments, and criteria of the IMP. The IMP events, accomplishments, and criteria are transferred into the IMS, and the criteria are then expanded by adding the detailed tasks necessary to complete each criterion. As a result, the IMS should include all the activities and elements associated with development, production, and/or modification and delivery of the total product and be directly traceable to the IMP. Durations are entered for each task, along with predecessor/successor relationships, and any constraints that control the start or finish of each task. It should be noted that although durations are only assigned at the task level, these durations will roll up to show the overall duration of any event, accomplishment, or criterion. The result is a fully networked schedule that includes a critical path and is capable of critical path analysis. Activities along the critical path define the sequence of discrete tasks in the network that have the longest total duration through the schedule. Therefore, when any critical path task slips, the program completion date slips.

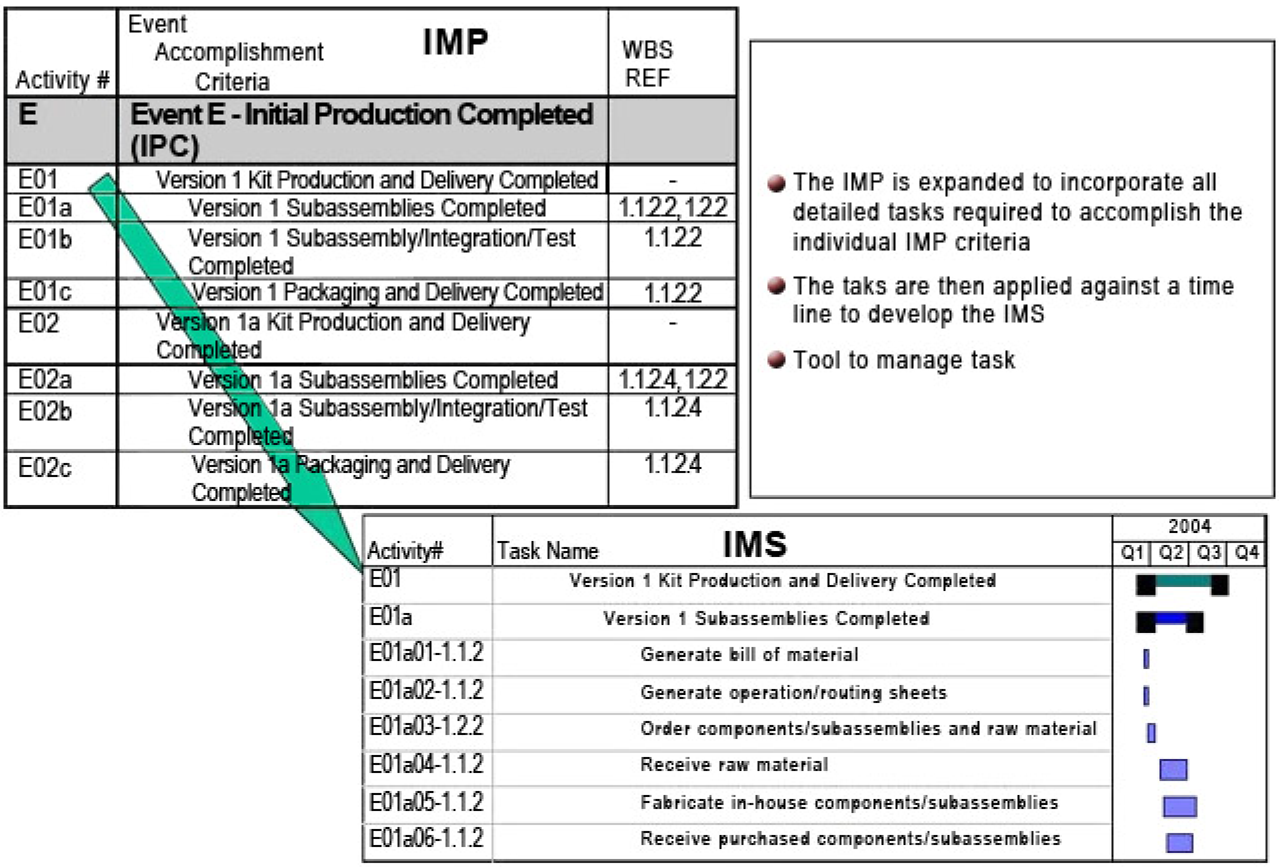

Figure 6-11 Integrated Master Plan (IMP) and Integrated Master Schedule (IMS)

6.7.5 Master Production Schedules

The Master Production Schedule (MPS) is a depiction of the demand, to include the backlog and forecast, the MPS, the estimated inventory at the time of production and the quantity to be produced. The MPS feeds into your Rough Cut Capacity Planning and your Material Requirements Planning. The MPS is developed in a manner similar to the first unit flow chart except that they show all the production components or units in sequence over a period of time instead of just the first unit. Master schedules are so called because they are the major source for controlling overall manufacturing operations. They are the basis for coordinating all supporting elements of the program from space and facilities requirements to tooling and equipment, vendor activity. labor, raw material preparation, detail parts fabrication, assembly and installation operations, functional testing, and finally delivery to the customer. Figure 6-11 shows a master schedule flowing from an Integrated Master Plan (IMP).

Inputs to the MPS include:

- Demand Forecast/Customer Orders;
- Inventory Cost and Levels;
- Production Cost;
- Lot Size and Quantity to be Produced;
- Production Lead Time;
- Capacity; and
- Staffing Levels.

Outputs of the MPS will support the following functions:

- Link strategic and business plans to production plans;
- Give marketing the information they need to make delivery commitments to customers; and
- Give purchasing and production managers the information they need to manage and control the production processes and help them improve efficiency.

6.7.6 Scheduling and Factory Loading

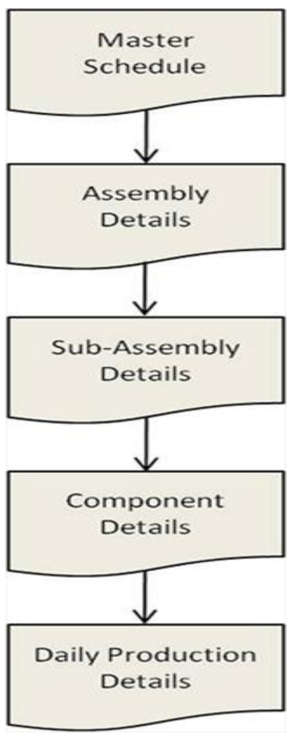

Figure 6-12 Hierarchy of Schedules

The goal of the scheduling effort is to optimize all of the manufacturing resources from program go-ahead through delivery of the product.

In general, the process involves analysis of the complete manufacturing operations down to detailed factory operations. The master schedule, discussed earlier, defines the framework of the starting and completion dates of the major manufacturing tasks to be accomplished in a defined period. The scheduling effort involves filling in this framework with the detailed manufacturing schedules of all components involved in the product. The first level down in this effort is to investigate all of the details for producing each major assembly and section into an overall time table in units of days or weeks. The second level schedule shows the sub-assembly sequence which ensures a smooth flow of work. It provides the schedule for completion of engineering, tooling, procurement, fabrication, assembly and checkout.

The third (next lower) level schedule, evolved from the master schedule, determines the day (or hour) each component is to be completed. This schedule is concerned with tooling, detail parts, subassemblies, and component fabrication.

The fourth level schedule is the most detailed. It includes the daily production activities of all the factory shops. Individual jobs are analyzed and sequenced and standards are applied to factory loading of materials, machines, and labor. Figure 6-12 shows the concept of the hierarchy of manufacturing schedules.

The initial effort in the production phase of a program often involves maximum personnel loadings to meet the schedule. The latter phases strive for optimum crew loading through refinement of the operating plan and supporting activities to achieve cost reduction. The objective of the manufacturing analysis during the EMD phase is to determine these optimum loadings, but normally the design changes which occur during initial production require revisions to the original concept. The contractor should have specific goals for each operating function, i.e., the facilities, material, and personnel required to perform the work. In order to achieve the manufacturing goals, the contractor should have a cost data collection and status reporting system to evaluate performance relative to the goals, determine performance trends, and make necessary adjustments.

There must be latitude available in all of the schedules. It follows, then, that the resulting schedules do not, indeed cannot, reflect the most streamlined and efficient way of doing the work, and the most cost-effective planning possible. Maximum effort is needed to carry out the work according to the lowest level manufacturing schedules so that the higher level schedule structure is satisfied. Otherwise, a major scheduling revision will be required that may impact other programs in the contractor facility along with the one in trouble.

The scheduling integration issues raised are applicable to all programs. While the manufacturing planning and scheduling techniques used to build defense systems - aircraft, ordnance, and space systems -will vary, the PM must be aware of the existence of this important aspect of manufacturing management in developing the manufacturing plan.

6.7.7 Inventory Control

Inventory control is aimed at minimizing the total cost of inventory. It is often concerned with minimizing the amount of inventory on-hand and with the loss of inventory. Manufacturing management is concerned with the integration of manpower, materials, measurement, machines, and manufacturing methods in the production of the end item. This requires determination of material requirements and components to support the manufacturing rate and determination of manufacturing lot quantities.

Manufacturing management is generally concerned with three types of material inventories. These are:

1. Raw Materials: Raw materials are the basic building blocks for the company. Often this is in the form of raw materials and components.

2. Work-in-Progress (WIP): WIP is made up of materials, components, sub-assemblies and assemblies that are in the process of being produced. That is they have been released from material stores and have not yet been through final inspection and acceptance.

3. Finished Goods: Finished goods have been inspected and accepted and are awaiting delivery to the customer.

Two other types of inventory are a sub set of WIP, these are buffer inventories and decoupler inventories. These inventories insulate a manufacturing process from the inherent variability of the processing stages in the manufacturing cycle. These inventories also provide protection against potential line stoppages. Buffer inventories are inventories that are carried as a safety valve or cushion against possible quality or vendor delivery problems. A decoupling inventory is inventory that exists due to the fact that all machines do not process parts and assemblies at the same speed and thus an inventory may build up in front of a slower machine. This may be a bottleneck in the production process.

Many companies use inventories to decouple successive stages of production. They view it as uneconomical to schedule parts through some systems due to the unbalanced nature of operation times in processes performed at the various machine stations and the tool changes required for each operation. The use of inventories to disengage successive stages allows each stage to operate more efficiently; the operation of a particular stage is not compromised by the demands of preceding and succeeding stages. Although inventories provide production benefits, they represent an investment that involves capital costs that needs to be balanced against the benefits obtained. Batch processing is a term often used to describe this type of manufacturing system. Batch size should reflect the most economical order quantity for the process, thus minimizing total cost of setup and processing.

6.7.8 Just-in-Time

Japanese manufacturers in the 1950's rejected many of the manufacturing approaches espoused by western companies, namely the techniques that were used for mass and craft production. In the 1970's the Japanese adopted Just-in-time (JIT) manufacturing control which came from Toyota's Production System developed by Taiichi Ohno. JIT is defined in the APICS dictionary as "a philosophy of manufacturing based on planned elimination of all waste and on continuous improvement of productivity."

JIT is an enterprise-wide operating control philosophy that has as its basic objective the elimination of waste. Under JIT, waste is considered anything other than the minimum amount of equipment, materials, parts, space, and worker's time that is absolutely essential to add value to a product. JIT strives to identify activities that do not add value and eliminate them and where there is variation in the process, eliminate that. JIT can be used by any manufacturer interested in eliminating waste and simplifying the workload.

In Japan where there is much less emphasis on staff specialists than in the United States, the workers and line manager are the focal points for implementing Just-In-Time technique.

Several experts have outlined the basic or key elements of a JIT system. Here are a few of those elements:

- Having a level production run and uniform Master Production Schedule;
- Building in small lots with quick setup and changeover times;
- Reduced cycle times and material movement;
- Having a "pull production system" or Kanban;
- Using standard components and work methods;
- Having flexible machines and workforce that can accomplish multiple tasks;
- Having consistent quality with a focus on continuous improvement;
- Having closer ties to your subcontractors with inspection at source;
- Good housekeeping discipline (5Ss); and
- A system of Total Preventive Maintenance.

Implementing JIT techniques is not just an inventory program for suppliers. In the right production environment with the right management, it can be a strategic tool for higher productivity, lower cost and, greater market penetration. However, for companies that practice JIT, you should have a back-up plan in case you have a significant production interruption like the 11 May 2011 tsunami that struck Japan and shut down much of its automotive industry.

6.7.9 Lead Time Evaluation

Contractors and the program office need to maintain visibility of their procurement and production schedules. This is especially important for items with long lead times and items on the critical path.

There are several definitions of "lead times." An initial estimate of the time required to procure the necessary components and to manufacture the item is defined as the "contract lead time." This lead time can be divided into its two primary components: manufacturing lead time and material lead time. Manufacturing lead time can be further sub-divided into inspection (also called dock time), fabrication, assembly and cheek-out. Material lead time can be defined in several ways. This is especially relevant when material or component lead times are experiencing large changes. There are three primary material/component lead times considered in this section; (1) First End Item Lead Time; (2) Material or Component Production Lead Time; and (3) Total Material and Component Lead Time. The time required to deliver the first end item (first end article lead time) may exceed the contract lead time when material and component lead times are extremely long.

6.7.10 Determinants Of Lead Time

The lead time for a particular material or component is not static. It varies with a number of economic or other type conditions. Some of the elements which affect lead times are:

- Number of industrial sources;
- Industrial source workload;
- Raw material availability;
- Raw material costs;
- Overall industry demand;
- Technology level of parts and materials;
- Cost of money;
- Escalation due to inflation; and
- De-escalation due to technology.

6.7.11 Lead Time Analysis

Production lead time is the time interval between when the item is put under contract and the initial delivery of the first unit(s). Defense systems typically exhibit lead time volatility due to the complexity of the product and complexity of the acquisition process. Lead time analysis begins with the customers' need date. The start date for contractor activity is normally based on a setback from the customers' need date. The setback is dictated by the operation flow times and the material, component and tooling lead times. Often these lead times can be very long (over a year) and may require long lead funding. Lead times may include the time it takes to place orders for long lead materials, components and tooling, transportation time for those items, receiving/inspection, fabrication, assembly, inspection and testing, packaging and shipping. It will also include the wait time in the systems as work-in-progress as the item sits in a cue waiting for the next operation. In a complex manufacturing/assembly process with several different production paths, the critical path will dictate the lead time, which will be the longest path.

When the lead time is in error, two possible problems exist. If the lead time estimate is excessive, the funds requirement will be established unnecessarily early. This may lead to an overstatement of the lead-time funding requirement and could result in funds being drawn unnecessarily from other areas of need. If the lead time estimate is understated, specific contractor activities could experience a start date that will not support the required delivery date without the expenditure of premium effort, resulting in higher than necessary program cost or even potential schedule slippage. The impact of lead time variations on a particular program can be minimized but requires management attention. Tools like JIT, Supplier Partnerships, Lean, Six Sigma and Theory of Constraints can be used to minimize the cycle time.

Figure 6-13 provides an overview of lead time and identifies the various elements that may impact lead time analysis.

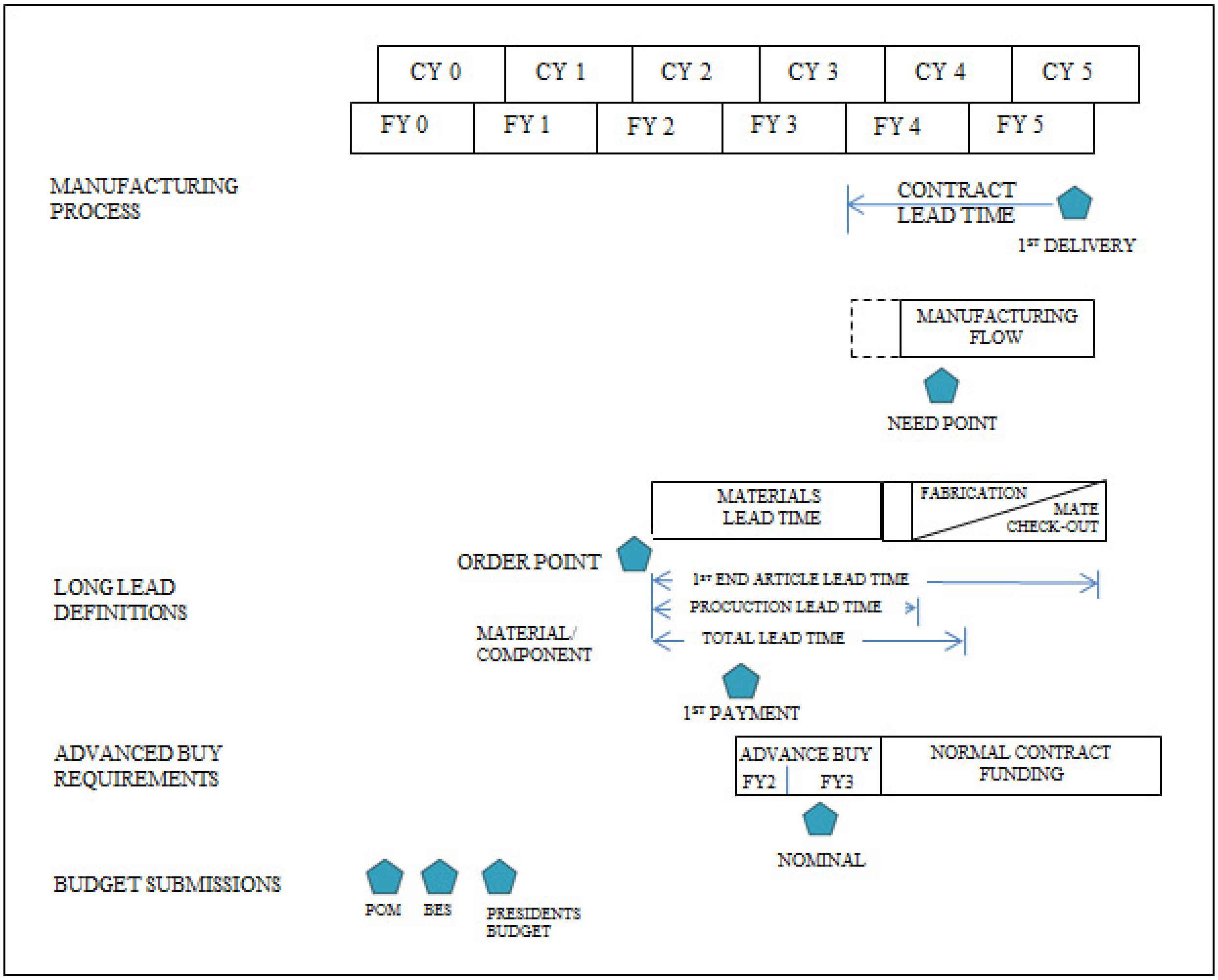

Figure 6-13 Lead Times

6.7.12 Personnel Planning

In developing a personnel plan, the contractor needs to consider the number of personnel needed, the specific skills of the personnel, the phasing of the requirements, and the ability of the organization to add personnel or move personnel. The ability to meet the personnel demands should be a function of the labor pool available within the contractor's organization and the ability of the local area to provide the quantity and types of people required which may include technical schools and other sources of trained personnel.

There also needs to be a clearly defined profile of the required workforce and a plan for the acquisition and training of new personnel. While on-the-job training (OJT) may be an effective mechanism for providing the required knowledge, its effectiveness is limited. Where the skills involved are relatively complex, there should be some form of formal training and/or certification requirements and a training program provided that manages the process and keeps track of these training and certification accomplishments.

The PMO should review the adequacy of the planned personnel loadings to ensure that adequate numbers of people with the required skills are made available. When a large personnel increase is planned, the sources of those personnel should be determined and evidence of their potential availability should be provided by the contractor.

6.7.13 Facility Planning

The facility includes the plant and productive equipment which is to be made available to accomplish the production task. In developing the facility plan, both the quantitative and qualitative demands of the product must be considered. The qualitative analysis determines the types of processes which will be required. The contractor then has the option of utilizing currently existing facilities, acquiring new facilities, requesting government-furnished facilities (must be requested in the proposal), or subcontracting a portion of the effort. The quantitative analysis will determine the size of the processing departments within the facility. This analysis should consider the number of units to be delivered, and the rate of delivery. The information collected in the analysis will provide a measure of the number of work stations and the floor space required.

After determination of the facility requirements, the next concern is plant layout and workflow planning. In most cases, the layout is constrained by the existing facility; however, it may be possible to revise the layout for a new program.

The planning for material flow within a manufacturing facility is of major importance. Some studies have indicated that, in the job shop environment (which is representative of much of the defense industry) parts are in transit, or waiting at work stations, as much as 95 percent of the time. In developing the flow pattern, the objective is to establish a pattern that allows constant progress from raw materials and purchased parts (or components) to the completed product.

In facility planning, the contractor should make a sufficient in-depth analysis of the demands on the facility to determine the most cost effective approach to production. This analysis should focus on the demands for services, and such things as power requirements, clean rooms, overhead clearance, as well as special requirements for handling explosives and other hazardous materials. The results of such an analysis and the plan to meet the demands on the facility are required data in some contracts. The requirement for such an analysis should be considered for inclusion in any contract where facility planning may have a major impact on program success. There are software and other tools available to assist contractors in assessing their requirements and in laying out the facility to optimize workflow.

6.8 Contractor Manufacturing Plan

6.8.1 Purpose

The purpose of the manufacturing plan prepared by the contractor for a specific program is to portray the method of employing facilities, machines and tooling, and the personnel resources of the contractor and selected subcontractors. The plan should reflect all time-phased actions which are required to produce, test and deliver acceptable systems on schedule and at minimum cost. The general structure of the plan should include, as a minimum, a description of the manufacturing organization, the make or buy plan, resources and manufacturing capability, and manufacturing planning data.

6.8.2 Manufacturing Organization

This section of the plan should address the contractor's organizational structure, i.e., the people responsible for the manufacturing task. It should include an organizational chart(s), identification of key individuals, and descriptions of the functional responsibilities of the key individuals. The government review of this section of the plan will focus on assuring that responsibilities are clearly defined and that all required tasks are assigned to the appropriate organizations. During the execution of the production phase of the program, this document should identify the points of contact for information and action.

6.8.3 Make or Buy

This section of the plan should describe the distribution of effort between the prime and subcontractor. Of specific interest during the evaluation of the plan is the impact of the in-plant loadings on the prime contractor's overhead rates. This is of great importance in the case of a facility which is involved with many programs, because the overhead rate to be applied to the program of interest can be greatly affected by the level of activity of the other programs planned for the facility. Specific attention should be given to the contractor's rationale for specific make or buy decisions because there may be differences between overall contractor goals in structuring make or buy decisions and the goal which a PM considers appropriate for his/her specific program. The contractor should review their Make or Buy Plans to identify sole source, single source, or foreign sourced items and make contingency plans for these items. In addition, the Make or Buy Plan should identify items that could become obsolete or a diminishing manufacturing source and make plans for these risks.

6.8.4 Resources and Manufacturing Capability

This section of the plan should describe the resources to be applied to the manufacturing task. The facilities to be used should be described in detail, and the division of the government-furnished and contractor furnished resources should be described, including the relationship to any Industrial Modernization Incentive Programs (IMIP) which are planned. If any improvement or rehabilitization of government-owned facilities is required, these should be described and justified.

The layout of the facilities to be utilized should be described along with the work flows through the facility. Where there are other programs in the facility, the integration of the work flow should be described. The key issue is to assure that there is a reasonable expectation that sufficient equipment and personnel exist in a form that will allow a manufacturing flow reflecting minimum cost and reasonable probability of schedule attainment.

The specific skills of the personnel required should be described in terms of time-phased requirements. Where personnel are not currently on-board, the contractor should describe how the required quantities and types of personnel will be acquired. The personnel requirements need to be analyzed in relation to the other programs within the facility and the local personnel market.

The contractor should describe the materials and components which will be utilized on the program. Where new materials or components which are in short supply are to be utilized, they should be justified. The relationship of material and component selection should be discussed in terms of the producibility studies which have been accomplished (or are planned). The contractor should provide a manufacturing breakdown - one that shows the relationship between manufacturing methods and materials, tooling concepts, and facilities. Also, the manufacturing risks on the program should be assessed.

The manufacturing breakdown should be supplemented with a discussion of the plan for tooling, including special tooling and special test equipment (as defined in the FAR). The contractor should describe the overall tooling concept and approach including the planning, design, fabrication, and control of tooling and test equipment. The mix of limited life (often described as "soft") and durable (often referred to as "hard") tooling should be described along with the rationale. The government interest in the tooling and test equipment is motivated by the cost and by the potential for cost reduction through investment in tooling or test equipment capability.

Where a requirement exists for surge or mobilization, the production plan should describe the facilities and other resources required and the method of accomplishing the required increase in manufacturing output.

6.8.5 Manufacturing Planning Data

This section of the plan should provide the detailed delivery schedules for the total program even though the specific contract may be for only a portion of the program. The schedule shows the lead times required for the major and critical elements of the program and the time phasing of the major milestones involved with attaining the schedule. Detailed schedule requirements for activities having potential impact on the end item delivery schedule such as engineering release, material procurement, tool fabrication, facility acquisition or improvement and government-furnished property should be provided. The (PM) should carefully analyze the details of the schedule to determine its attainability, the inherent risk, and the potential to use the Defense Materials System/Defense Priorities System. One of the more visible indicators of the program during the production phase is delivery performance. An unrealistic initial schedule can force the program into such things as high cost priority efforts to attain schedule and acceptance of equipment through waivers and deviations.

The success of the contractor in meeting the defined schedule can be affected by the quality of the manufacturing control system utilized. This control system should be described in the manufacturing plan so that the PMO can assess its adequacy for detailed shop release, manufacturing performance evaluation, and corrective action.

It is often beneficial to have the contractor include in the manufacturing plan a chart that portrays the details of the process of manufacture and assembly. These are often developed in formats such as tree charts or "goes-into" charts.

The productivity of the industrial organization can have a significant impact on the effectiveness and efficiency of the manufacturing activity. Where possible, the manufacturing plan should describe the measures planned to improve organizational productivity. These measures may be directed toward improvements in the effective utilization of personnel, equipment, or materials. Where these measures are described, the impact of their successful introduction on the overall manufacturing effort should be defined.

6.8.6 Planning for Spares

Spare parts production places an additional demand upon manufacturing resources. Determining the quantity of resources required must be based upon supporting both the deliverable system hardware and the required spares. Planning for spares procurement arises from two standpoints. The first is planning for those spare parts which must be produced concurrently in the weapon system production quantities. The second involves planning for the continuing availability of the spare parts during deployment. This requires establishing a way to acquire the needed spares on a competitive basis. Competition can be based on a performance specification or an acquisition data package with unlimited rights. If the latter approach is taken, it is necessary that the PM take action during the development phase to obtain a contractor commitment to deliver a full acquisition data package with unlimited rights.

6.9 Production Rate Discussion

One of the major issues to be addressed in the development of the manufacturing plan is determining the rate of production. When you have unstable production rates it is a significant factor in driving programs to be unaffordable. Conversely if you want to encourage or drive affordability then it is important to identify and maintain a stable production rate. The demands of the warfighter must be balanced against the capabilities of the industrial base to produce the items and affordability considerations.

Recently, OSD emphasis has been placed on determining and using more economical production rates. An economical production rate is a rate which makes effective and efficient utilization of existing manufacturing plant and facilities. Generally speaking, the higher the rate, the lower the unit production cost.

Economical production rates can be analyzed by plotting unit cost versus quantity (Figure 6-14). The maximum economical rate occurs just before the existing or planned plant capacity, (including tooling or test equipment) is exceeded; i.e., further increase in quantity incurs an increase in unit cost due to an inability to amortize further facilitization and rate tooling costs. The minimum economical rate occurs at the knee of the unit cost/quantity curve while still effectively utilizing existing manufacturing facilities or where further reduction in quantity causes an increase in unit cost with an unacceptable return on investment. Note that the cost is made up of fixed and variable cost.

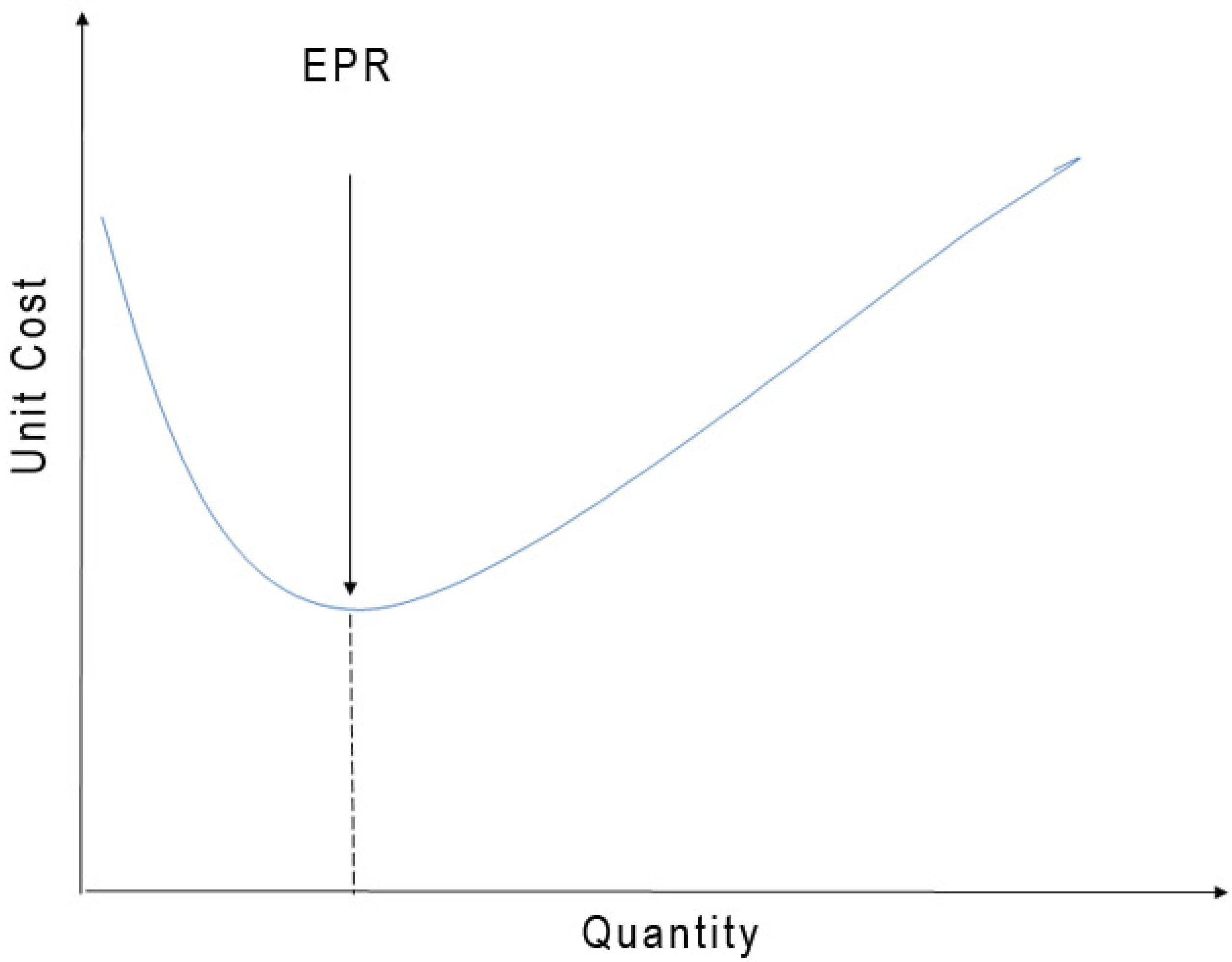

Figure 6-14 Economical Production Rates

An economical rate for many commodities is one at which the facility is operating nominally on a one-shift basis: however, programs can be structured to accommodate different bases (such as a two-shift operation). The availability of personnel in requisite numbers and skill levels, the existence of other plant loading (such as other systems produced at the same facility), and the capability of the industrial base including suppliers and vendors are other factors to be considered. Other assumptions may include:

- Producing only one item,
- Annual demand is known,
- Production rate is constant, and

- Lead time does not vary.

Planning for economical production rates (EPRs) must begin early enough in a program to influence contractor decisions. As early as the technology development phase, decisions on production quantities and production funds availability influence the EPR. During the production and deployment phase, the production rate should be maintained at the predetermined EPR in order to make the most efficient use of available industrial resources.

The production cost changes resulting from a change in production rate may be estimated either through direct discussion with the manufacturer, or through a modeling technique, or both. There are several models that can be used to predict the effect of a production rate change on unit cost. Unfortunately, many models require data that are very difficult to obtain, such as contractor variable and fixed costs.

The economical production and procurement rates represent goals. In practice, contractors usually produce, and program management offices usually procure, below the optimum rates. The prevalent reason for procuring (producing) a defense system below the EPR is the budget. Other reasons include keeping a "warm" production base, and not having an identified requirement for a follow-on defense system.

6.10 Manufacturing Planning and Control Systems

Manufacturing Planning and Control Systems (MPCS) are concerned with the planning, scheduling and control of all aspects of manufacturing to include manpower, machines, materials, methods and processes, quality, supply chain management, and other business and technical considerations. Most often today they are computer-based information systems, but do not have to be. The information system must take into account the various forms of production processes to include job shops, batch production, mass production and continuous flow production. Quite often the form of the production process will drive the form of the MPCS and they types of modules the information system will contain and the connectivity between modules. The more complex the manufacturing operation the more complex the MPCS. Most DOD prime contractors and their subcontractors have implemented one of several forms of MPCS, Material Requirements Planning (MRP), Manufacturing Resource Planning (MRP II), Enterprise Resource Planning (ERP), and/or JIT systems, to help them manage their manufacturing operations and inventory control. The PM should have an understanding of these systems and recognize that valuable information relative to program status can be obtained from these systems if the system has been properly planned for, implemented, and utilized.

The following is intended as a brief overview of MRR, MRP II and ER, which should provide a basic understanding of what each is, and what each can provide.

6.10.1 Material Requirements Planning (MRP)

Material Requirement Planning (MRP) is a production and inventory control software tool developed in the 1970's to assist in the management of manufacturing processes. Based on sales forecast and backlog, the MRP takes information from three sources to include the Master

Production Schedule (MPS), the bill-of-materials (BOM) and inventory status data as inputs to calculate the answer to these questions:

- What parts do we need to make or buy (Purchasing Plan)?
- How many of these parts do we need (Capacity Plan)?
- When must these parts be available (Detailed Manufacturing Schedule)?

Figure 6-15 indicates the information flow associated with an MRP system.

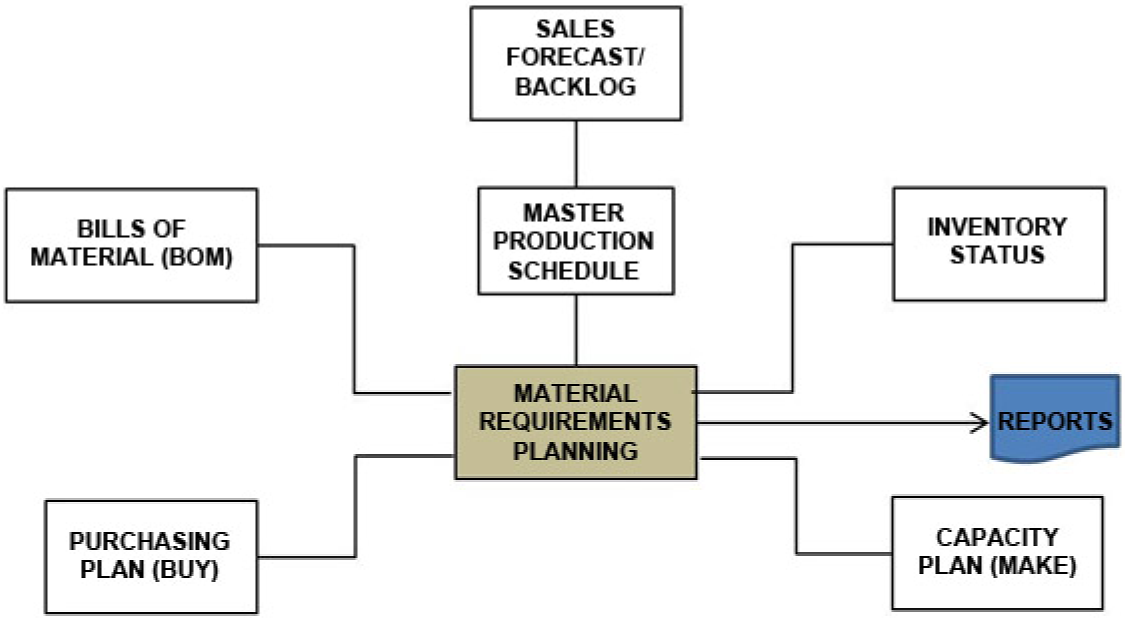

Figure 6-15 Material Requirements Planning (MRP) Information Flow

MRP systems generate two basic outputs, the Purchasing Plan and Schedule that lays out when the purchase orders (POs) should be released and when the purchased items should be received in order to support the production dates. The second output is the Capacity Plan or Production Schedule. The production schedule details the start and completion dates for steps in the production process (routing) to include how many items will be produced in each batch and what is required from the bill of materials to support the fabrication and assembly. A third output is the various reports that the MRP system can generate.

The MPS can be considered an agreement between marketing and manufacturing to support known demand (sales forecast) and backlog with product to be produced (by department) and furnished to stock for delivery to the customer. The BOM provides a product structure (tree) and list of what is needed for each component, sub-assembly and assembly. The inventory status should provide information on what is on hand and at what level (component, sub-assembly and assembly).

When properly planned for, implemented, and utilized MRP can reduce inventory because the contractor should only make or buy what is needed and when it is needed. MRP can help improve on-time delivery of end products because the MRP identifies which parts are needed (make or buy), and when they are needed to support the Master Production Schedule. MRP can also improve manpower and equipment utilization because it is possible to better plan and control the use of resources.

6.10.2 Material Resource Planning (MRP II)

Today's dynamic manufacturing environment generates information from many functional areas (sales, engineering, production, procurement, logistics and other support functions) that needs to be gathered, stored, and formatted for easy access by a large number of users. Manufacturing managers need to recognize the interdependent nature of functions, the need for interactive management information systems, the need for accurate, timely data reporting and storage for user friendly access, and the need to share common data in order to enhance day-to-day management decision-making. Current needs go beyond managing just inventory, purchasing, and production. Planning needs in all areas of the company must be integrated into a plan which provides feedback to keep the company game plan up-to-date and which answers "what-if" questions through computerized simulation.

Manufacturing Resources Planning (MRP II) was developed in the late 1970's as a 2nd generation MRP system. According to APICS, MRP II can be defined as "a method for the effective planning of all resources of a manufacturing company." MRP II systems are modular designs that facilitate implementation of a few modules at a time or many modules. MRP II systems can vary vendor by vendor, but in general the systems may contain the following modules:

Basic Modules	Auxiliary Modules	Ancillary Modules
• Master Production Schedule • Item Technical Data • Bill of materials (BOM) • Production Resources Data • Inventories and Orders • Purchasing Management • Material Requirements Planning (MRP) • Shop floor control (SFC) • Capacity Requirements Planning (CRP) • Standard Costing	• Business Planning • Lot Traceability • Contract Management • Tool Management • Engineering Change Control • Configuration Management • Shop Floor Data Collection • Sales Analysis and Forecasting • Finite Capacity Scheduling (FCS)	• General ledger • Accounts Payable • Accounts Receivable • Sales Order Management • Distribution Requirements Planning (DRP) • Automated Warehouse Management • Project Management • Technical Records • Estimating • Computer-Aided Design / Computer-Aided Manufacturing

• Cost Reporting / Management		

Table 6-1 Manufacturing Resource Planning II (MRP II) Modules

Because it draws together all departments, an MRP II system produces a company-wide game plan that allows everyone to work with the same numbers (see chart above). Employees can now draw on data, such as inventory levels, back orders, and unpaid bills, data that was once reserved for top executives. Moreover, the system can track each step of production, allowing managers throughout the company to consult other managers inventories, schedules, and plans. In addition, MRP II systems are capable of running simulations (models of possible operations systems) that enable managers to plan and test alternative strategies. The magnitude of the integration associated with an MRP II system is shown in Figure 6-16.

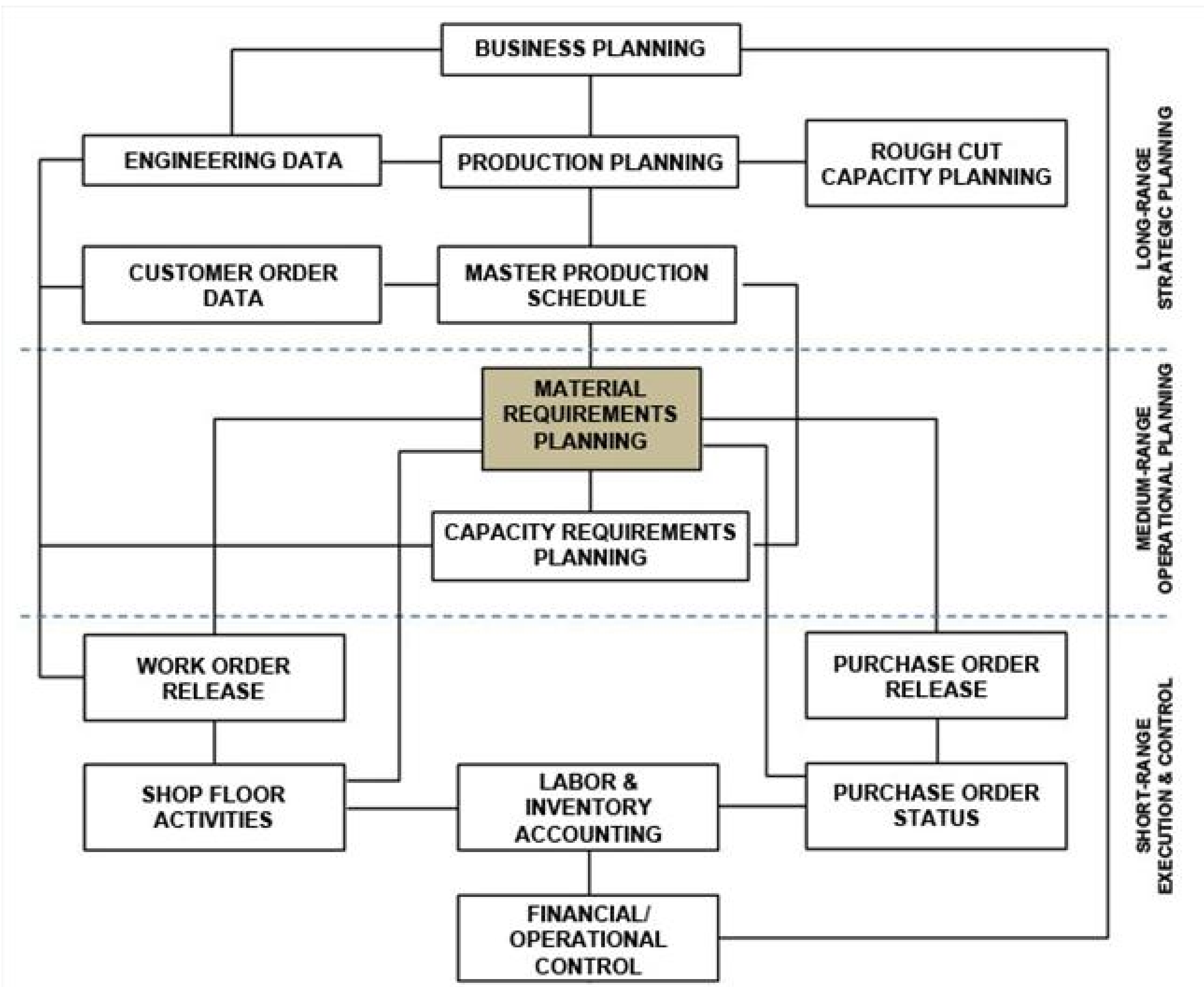

Figure 6-16 Manufacturing Resource Planning II (MRP II) Information Flow

Generally the modules have information at three levels:

1. Long-Range Strategic Planning Data;

2. Medium-Range Operational Planning Data; and

3. Short-Range Execution and Control Data.

Long-Range data could include things like capital investment strategies to support the building of a new facility needed to build a new product. That new product would be based on Strategic Business Plans and customer demand. The facility and equipment would need to have a project plan with build dates and receipt dates for new equipment, many that may be a long-lead item.

Medium-Range Panning includes Material Requirements Planning (MRP) and Capacity Requirements Planning (CRP). We have already discussed MRP so let's focus on CRP. CPR is a planning technique that provides businesses with a way to determine how large their future inventory capacity needs to be in order to meet customer demand. It also helps the company to determine how much space they will need in order to hold these materials in support of the production effort. This determination involves determining the 5Ms (manpower, materials, methods, measurement and machines) required for production.

Short-Range Planning is concerned with execution and control at a detailed level. It may look at job routings and operations, daily inventory levels, quality data (scrap, rework and repair cost), machine utilization, labor cost, machine set-up times, bottlenecks, and delivery schedules.

With proper understanding, commitment, and involvement of top management; the proper selection and implementation of hardware and software; adequate user education; training and discipline, an MRP II system can be very helpful to the PM. If any of the above data modules are missing on a program, the MRP II system as well as the program will be in trouble.

6.10.3 MRP-MRP II Problems

One of the major problems with any of the above information systems is the quality of the data, as the old saying goes "garbage in, garbage out." The following information sources could be incorrect causing errors in your MRP system:

- Master Production System (MPS);
- Bills of Material (BOM);
- Inventory and Inventory Status;
- Lead Times;
- Production Size;
- Production Schedule (working times);
- Quality Data (yield data, scrap, rework and repair, etc.);
- Safety Stock Levels and Times; and
- Work-in-Progress Data.

The Master Production Schedule is perhaps the most crucial information needed to support the effectiveness of MRP. If the Master Production Schedule does not accurately reflect the product, quantities, and required need dates that satisfy contractual requirements, MRP will generate invalid priorities for manufacturing and purchasing. Also, inventory records and bills-of-material must be highly accurate for MRP to generate valid priorities. The scheduling data needs to be accurate. If you have a lot of variability in your product, from a schedule or quality point of view, then there will be risks in the production plan and the assumption that you will meet your production dates. This variability extends down into your supply chain. All you need is one vendor delivering late parts or non-conforming parts to ruin your production efforts. Design changes that impact one product, but not another will make configuration control more challenging.

Even with a Master Production Schedule that identifies the correct mix of end products required, as well as the correct quantities and timing of availability for those products, MRP systems do not take into account capacity, that is the schedule can show that production can meet the customer dates, but in reality there probably are bottlenecks in your system (every system has them) that will prevent you from meeting your schedule unless you take management action to mitigate the bottleneck.

MRP II was supposed to solve many of the MRP problems but MRP II problems still mirror some of the MRP problems, mainly "garbage in, garbage out." If the underlying information is even slightly off (e.g. inventory) then you will have problems with your MRP II system. There can be many modules to an MRP II system, each of these modules needs to be fully understood by the implementers if you are to be successful. This means training all of the people on these modules. Insufficient training will give you very poor results. Management needs to understand the capabilities of these systems and use the information thoughtfully. There are both business (financial) and manufacturing aspects to these information systems, and management needs to understand how these information systems are mapped internally and each module to other modules.

6.10.4 MRP-MRP II Assessments

Quite a bit of publicity has been directed at MRP-MRP II and equivalent systems. Most of this publicity tends to lead the uninitiated to negative conclusions about MRP-MAP II in the government contracting environment.

The U.S. Marine Corps Maintenance Centers at Albany and Barstow have implemented MRP II systems to support their remanufacturing environment. The functionality that has been implemented includes demand planning, production planning, master scheduling, material planning, capacity planning, shop floor control, and performance measurement.

The Maintenance Center has also integrated Theory of Constraints (see Chapter 5) with their MRP II system. Production routes for the majority of the major end items have been matched to the "critical chain" and loaded into the production database, thereby ensuring that the refurbished material arrives from the back-shops in a timely manner to support the end item's delivery date to the warfighter.

The MRP II and TOC philosophies have complemented each other, and the integration of the two has resulted in a total system which has effectively reduced repair cycle time to the customer, improved inventory accuracy, and cut overall program costs.

Most of the perceived problems with MRP-MRP II are really only symptoms of the real problems. Symptoms which, when properly analyzed and studied, would lead us to a proper diagnosis of the real problems - the lack of up-front understanding of what it takes (or will take in the future) to operate a business from a total system standpoint and a lack of education and training about MRP/MRP II concepts and the inherent disciplines required to effectively implement such systems.

Every company needs to do a thorough "top down" analysis of how it is doing business (the "as-is" environment) and how will be doing business in the next three to ten years (the "to-be environment) before implementing MRP II. As part of the analysis each company needs to address, among other things, the adequacy of the current and planned material management and accounting system to ensure that it is in compliance with external regulations and standards as well as internal policies and procedures. If the "top down" analysis uncovers areas of noncompliance or other deficiencies in a current or future planned system, the deficiencies can be remedied in an effective, well-planned manner and all parties can become aware of the existing problems.

Each PM must understand the need to assess the effectiveness of contractor MRP-MRP II or an equivalent system. Just because a contractor has such a "state of the art" system in place does not assure that the program is under control and operating effectively. The contractor's attention to management of information that is in, or is an output from, such a system will ultimately determine the effectiveness of the system.

Today, hardware and software vendors can provide most of the functions required in the defense contracting environment. However, there will almost always be a need to either tailor some of a vendor's product to make it fit the contractor's business environment or, to tailor the way the contractor is doing business to fit the vendor's product. It is important to understand what and how much tailoring was done and how it impacts the ability of the government to obtain information needed to monitor contractor performance.

The PM must view the interface or interaction between the system and the people who must understand and utilize the information provided by the system as a critical element to be analyzed as part of any assessment of an MRP-MRP II system.

6.11 Summary

Manufacturing managers have always been responsible for the detailed planning that needs to occur if a contractor is to take a product design and produce it. For DOD and contractor manufacturing managers this planning begins very early in the acquisition process. In addition to needing attention early, manufacturing managers need to be able to utilize the emerging tools and processes as they are being developed and proven to assist them in this planning process.

6.12 Related Links and Resources

Numerous reference documents impact the manufacturing management function throughout the acquisition process. These documents originate from many sources and range across academic disciplines, functional activities, and job specialties.

The following is a reference list of DOD Directives (D), Instructions (I) Manuals (M), Pamphlets (P), Military Standards (MS), and other documents. The documents listed contain DOD policy guidance applicable to the manufacturing management function. They are listed as sources of DOD manufacturing management information.

Note: Many of the documents listed are no longer required (due to acquisition reform), but still contain some very valuable information.

Number	Title
	Manufacturing Resource Planning(MRP/MRP II)
	Production Scheduling
	Inventory Control
	Just-in-Time Manufacturing

7.1 Objective

According to DODD 5000.01, Knowledge-Based Acquisition, program managers (PMs) " *shall reduce manufacturing risk and demonstrate producibility prior to full-rate production* ." This chapter builds on a definition of producibility and its relationship to engineering design, factory floor processes, supportability and affordability. Approaches to the contractual implementation of producibility provide a basis for integrating Producibility Engineering and Planning (PEP) into the acquisition process. The chapter also provides a framework for evaluation of the prime contractor's producibility program and organization and a description of the Value Engineering process and its role in producibility.

7.2 Background

According to a 2008 GAO report (GAO-08-884R) about 75 percent of the casualties in combat operations in Iraq and Afghanistan were attributed to improvised explosive devices (IED). To mitigate the threat from these weapons, DOD initiated the Mine Resistant Ambush Protected (MRAP) vehicle program, which used a tailored acquisition approach to rapidly acquire and field the vehicles. In May 2007, the Secretary of Defense affirmed MRAP as DOD's single most important acquisition program. As of June 2008 more than $22 billion had been appropriated to acquire more than 15,000 MRAP vehicles, with over 9,100 of the vehicles delivered by May 2008. Necessity drove the need for rapid fielding and in order to achieve this capability quickly the acquisition focused on a simple, mature and producible design that could achieve performance goals. However, the MRAP was not without its problems. The use of multiple vendors and concurrent development/testing did accelerate delivery but at the same time increased maintenance and sustainability costs due to the different designs from different vendors requiring unique and specific operating and maintenance procedures. Figure 7-1 provides examples of commercial programs and weapon systems that are considered producible.

Item	Story
Model T	By 1918, half of all cars in the US were Model Ts. Ford produced over 15 million cars between 1917 and 1923 reaching a rate of 10,000 cars a day! Simple design, stable design, and a moving assembly line using expensive tooling with easy assembly
Liberty Ships	The first Liberty ships took 230 days to build, this was reduced to 42 days. Over 2,700 Liberties were build, assembly-line style from prefabricated sections. The design was modified to make construction quicker and cheaper
Higgins Boats	A WWII Landing Craft capable of landing 36 men and their equipment. Over 20,000 Higgins boats were produced. The Higgins landed more Allied troops during the war than all other types of landing craft combined. The Higgins had a simple design and were easy to produce.

Soviet AK-47	The AK-47 is well known for its rate of fire, ease of use, reliability and low production cost. The AK-47 has generous tolerances so it functions in a dirty environment with little maintenance. The Izhevsk factory could produce 24,000 rifles a day. Over 75 million units have been produced. More AK-47 (and derivatives) have been built than all other assault rifles combined.
Soviet T-34 Tank	Credited with being the most efficient and influential design of WWII. It was the most produced tank of WWII and the 2nd most produced tank ever. Over 84,000 tanks were produced between 1940 and 1958. Design changes were limited primarily for production improvements. Costs and time and time to produce were cut in half as a result of producibility improvements.
F-16	Over 4,400 F-16s have been produced. They were designed to be relatively inexpensive to build and maintain compared to previous fighter jest. 80% of the airframe is made of aviation grade aluminum alloys with only 1.5% of the airframe being titanium.

Figure 7-1 Producible Weapon Systems

7.3 Introduction

Producibility is an engineering function directed toward achieving a design which is compatible with the realities of the manufacturing capability of the defense industrial base. More specifically, producibility is a measure of the relative ease of producing a product at the desired rate and with acceptable yields, quality, reliability, cost and performance. Producibility is a coordinated effort by design engineering, manufacturing engineering, and other functional specialists to create a functional design that can be easily and economically manufactured. The product must be designed in such a manner that manufacturing methods and processes have flexibility in producing the product at the lowest cost without sacrificing function, performance, or quality.

The A-10 program office along with their contractor, Fairchild Republic, conducted producibility engineering activities (Figure 7-2) which resulted in:

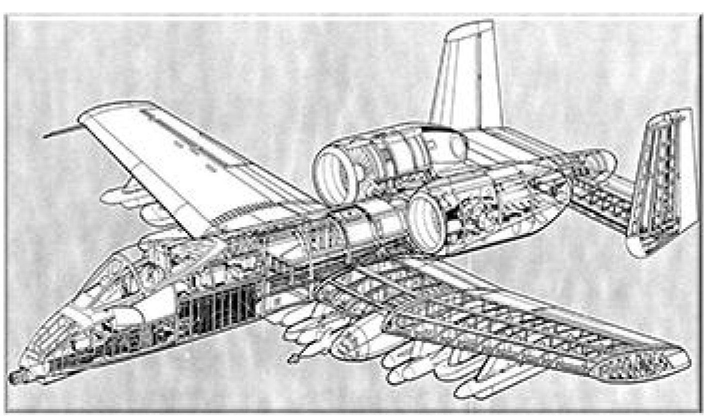

Figure 7-2 A-10 Aircraft

- An airframe that was 95 percent aluminum by weight;
- Rivets that were required to be flush on only the forward section of the aircraft;
- The only compound curvature was of the tub and nacelles;
- Landing gear pods that were external which simplified the load paths and internal structure;
- There was a heavy use of extruded parts which helped to minimize machining requirements;
- Empennage components were standardized so that there were no left-hand or right-hand parts

DOD policy on major system acquisitions makes producibility considerations a requirement prior to the start of Technology Development. The Alternative Systems Review should have included producibility assessments of the design concepts. Producibility assessments and engineering should be a part of the on-going systems engineering process. DODI 5000.02 states that "design for producibility" shall be a part of the Engineering and Manufacturing Development phase. DODD 5000.01 states that the PM shall "reduce manufacturing risk and demonstrate producibility" prior to full-rate production.

History has demonstrated that as the complexity of systems increases, so does the acquisition cost. Therefore, producibility programs are necessary as a management means for assuring that practicality is addressed and that the cost increases associated with the growing complexity of systems are minimized. It should be recognized that the producibility analysis accomplished by the program management office (PMO) must be performed by a team of specialists assembled from the program office: and supporting organizations. One functional organization cannot possibly accomplish the total producibility effort without assistance from other functional organizations. Consequently, the PMO approach to organizing for producibility is of prime importance to a successful defense system.

7.3.1 Defining Producibility

Producibility may be defined as the relative ease of production. It is relative because the system may be inherently complex (e.g. a submarine or spacecraft) or it may be difficult to produce because the designers may have little or no education on how to make systems producible. The intelligent government representative recognizes that the contractor may understand the definition of producibility but have no training. Most universities in the US offer little hands-on education with manufacturing processes. The best producibility engineers have "scar tissue" experience earned the hard way.

Producibility is the degree to which "Design for Manufacturing" concepts have been used to influence system and product design to facilitate timely, affordable, and optimum-quality manufacture, assembly, and delivery of system to the field. Producibility is closely linked to other elements of availability and to costs. Items that feature design for manufacturability are also normally easier to maintain, have better accessibility features, and have lower life cycle costs.

Manufacturability is the overall ability to consistently produce at the required level of cost and quality. Manufacturability focuses on process capabilities, machine or facility flexibility as considerations in the design cycle.

7.3.2 Causes of Poor Producibility

Causes of poor producibility can be classified as errors of either commission or omission. Errors of commission could include such elements as excessive complexity in the design, production restrictiveness, and conflicting direction. Errors of omission could include such elements as inadequate planning and direction, inadequate specification, and insufficient detail. Designers do not start out their day with the intent of producing a bad design or one that is less than optimal. Often the problem is that the designer lacks experience, that is you have a junior engineer assigned to a position that requires someone with more experience, or the program is on an aggressive schedule that provides little time for producibility engineering activities.

7.3.2.1 Excessive Complexity

Rube Goldberg was an American engineer and inventor but was most famous for his series of cartoons depicting complex devices that performed simple tasks (Figure 7-3). Most DOD weapon systems are inherently complex. As the design evolves and is iterated to achieve performance objectives, designers need to address the design's complexity, efficiency and producibility. Thus systems engineering needs to emphasize producibility engineering throughout the entire design process in order to achieve an efficient and optimized design. Program managers and engineers should understand that by the time a design is frozen a large percentage (about 80 percent) of the life-cycle cost are locked in. Early producibility will help to ensure that the product is producible, supportable and affordable. Design for Manufacturing and Assembly (DFMA) is one tool that design engineers can use to help simplify the design of their product and achieve higher design efficiency or optimization.

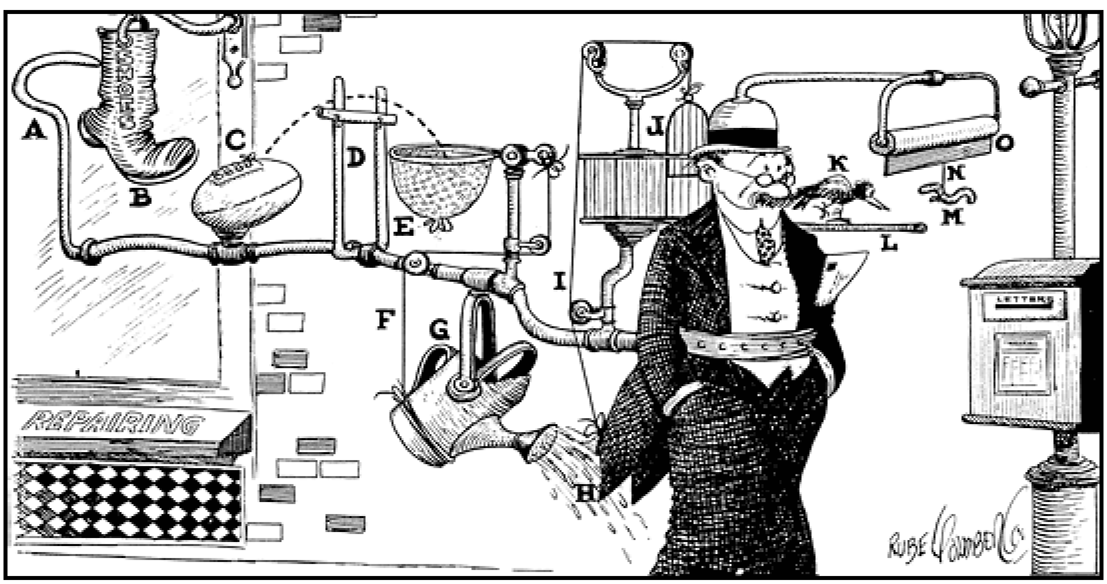

Figure 7- 3 Goldberg Device for Remembering to Mail a Letter

7.3.2.2 Production Restrictiveness

This occurs when items are designed with features that are difficult to manufacture and the design was achieved with little or no manufacturing input as to the producibility of the design. It is important that design and manufacturing engineers work together to understand current manufacturing process capabilities and designing to those capabilities where practical will help you to achieve a robust design.

7.3.2.3 Conflicting Direction

Often there are conflicting design goals. For example, the warfighter needs you something strong but at the same time needs to reduce the weight. Or the warfighter is operating in a corrosive environment but the product should not use material coatings that could harm the environment.

7.3.2.4 Inadequate Planning

Two common errors in planning is:

- Not allowing enough time after testing to redesign a product and retest, and
- Not have a truly integrated product team. It is a team on paper, but true interaction is not taking place at the necessary levels.

7.3.2.5 Inadequate Specification/Insufficient Detail

The writing of a well written specification is a serious undertaking. The specification must include enough detail to allow for the design and production of the product within cost, schedule and with the requisite quality levels. A poorly written specification for example may call for the cleaning of a part prior to painting. But if the specification does not define how "clean" is clean then you may end up with a process that down the road leads to products that rust early.

7.4 Integration of Design Considerations

During the creation of a design, the primary objective is to satisfy the specific functional and physical objectives established in the requirement documents. Coordination between design engineering and manufacturing engineering has proven to be effective in providing for flexibility in producing the product at the lowest cost without sacrificing performance or quality. The development of a successful producibility program is dependent upon the ability of the PMO to integrate the producibility task into the acquisition program.

The requirement documents establish what the system must accomplish in terms of performance objectives for the system. Subsequent statements in the requirements document describe the physical, functional, and support framework for the system. These statements operate as constraints on the design. The relationships between the performance objectives and the constraints establish the potential standards of producibility for the design. If the statements of constraints rigidly specify the system, subsystem, components, materials, and manufacturing processes, the producibility of the design is essentially determined (even though it may not have been a primary consideration in establishing the specification). The issue of design producibility and capabilities of the production system should be specifically considered when the PMO is tailoring the system specification and ether contractual requirements for the development contract.

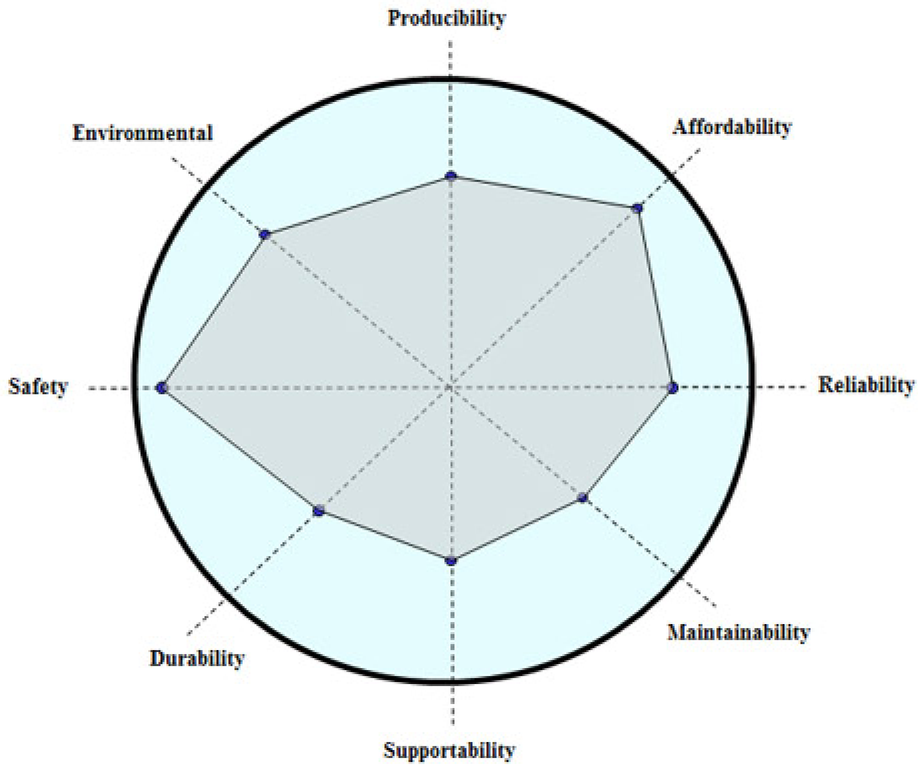

Figure 7-4 Spider Diagram

Figure 7-4 is a design spider diagram used to identify trade-off criteria. The diagram is a tool used to identify the relative importance of various factors that need to be considered during the design process (conceptual and detailed). The further away from the center of the diagram a factor is the more important that factor is. So as you can see from this diagram "safety and affordability" appear to be the two most important factors. In addition, the further away from the center a factor is indicates that the program may be willing to assign more resources (time and money) against achieving those factors.

Physical and functional characteristics place constraints upon the level of producibility that can be attained. By changing some of the requirements or constraints, the system might be more simply designed and more easily fabricated if the weight limitations could be increased by 5 percent. The objective of a balanced design is to create an item that will satisfy all of the specified performance and physical objectives and concurrently maximize producibility. Producibility engineering can make a substantial contribution to achieving program goals. Below are several design best practices:

1. Simplicity of Design: Eliminate components of an assembly by building their function into other components or into integral components through application of unique

manufacturing processes. In one case, the objective may involve working with the design engineer to identify and eliminate excess components. In another case, the focus may be on working with a manufacturing engineer to combine components.

2. Standardization of Materials and Components: A wide variety of off-the-shelf materials and components are available. When those items are incorporated in the design, cost is generally reduced and parts availability greatly increased.

3. Manufacturing Process Capability Analysis: Determinations of the available manufacturing capacity, and its capability to produce the desired end item without special controls, is a critical activity in the producibility analysis. This normally includes analysis of the degree of process variability, the causes of variability and the definition of methods to reduce it.

4. Design Flexibility: The design should offer a number of alternative materials and manufacturing processes to produce an acceptable end item. Unwarranted limitations of materials or processes seriously constrain the producibility analysis.

5. Modular Open Systems Approach (Figure 7-5): The design should utilize standardized units or dimensions, for easy assembly and repair or flexible arrangement and use. A modular design organizes a complex system (tank, aircraft, ship, electronic box) as a set of distinct components that can be developed independently and then plugged together.

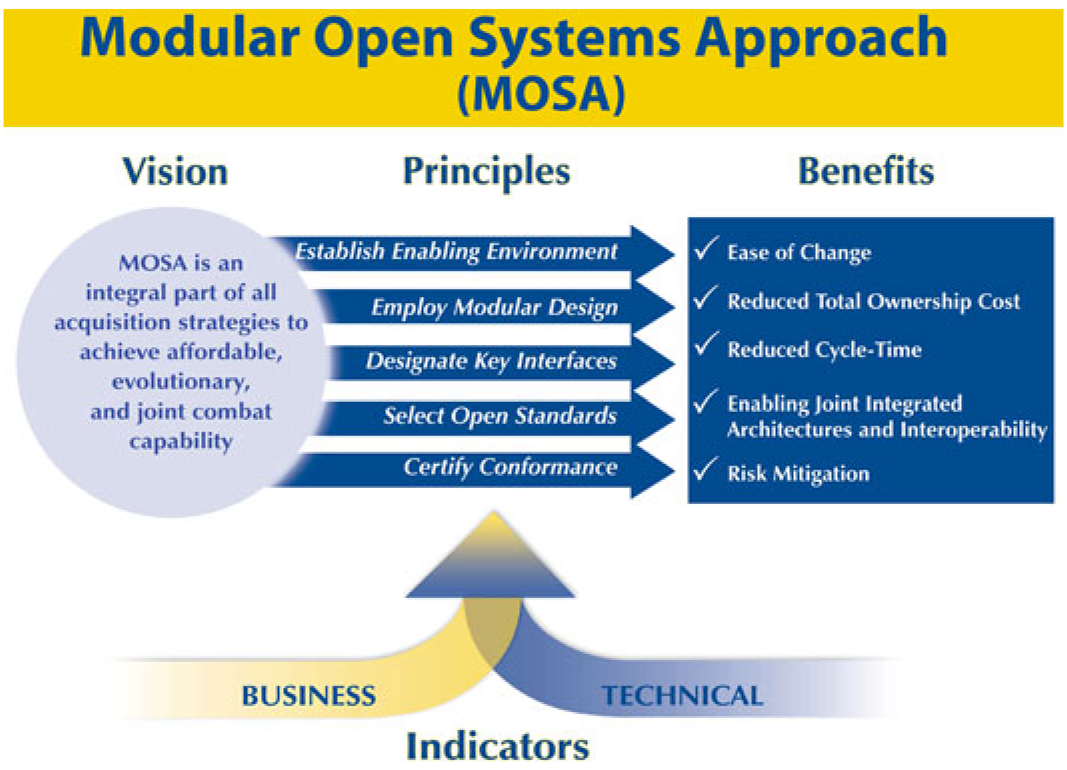

Figure 7-5 Modular Open Systems Approach

Modular designs are characterized by the following:

- Functionally partitioned into discrete scalable, reusable modules consisting of isolated, self-contained functional elements,
- Rigorous use of disciplined definition of modular interfaces, to include object oriented descriptions of module functionality, and
- Designed for ease of change to achieve technology transparency and makes use of commonly used industry standards for key interfaces.

7.4.1 Producibility in Conceptual Design

The key systems' producibility activity during conceptual design is the development of a producibility plan. System producibility design efforts generally are concerned with system-level tradeoffs. Alternative design approaches and concepts were analyzed for projected impact on manufacturability and affordability downstream in production. Customer interface and review of the producibility plans are also performed.

Emphasis on producibility can have a direct impact on RMS as well as life cycle cost. Many techniques are available to address manufacturability during design. Ease of manufacturing and repeatability in the process, along with concepts like process control and Six Sigma approaches, application of variability reduction analysis using Taguchi and Design for Experiments (DoE) techniques, as well as material characterization analysis and statistical process control, are essential elements to realizing affordable, reliable, and supportable design.

The Navy's Best Manufacturing Practices Center of Excellence (BMPCOE) conducted a benchmarking review of Northrop Grumman Electronic Systems (NGES) in Baltimore, MD and identified their Producibility Guidelines as a best practice. NGES personnel developed Producibility Guidelines that provide detailed manufacturing and production considerations to design teams. This process-specific information supports trade studies and preliminary design and establishes rules for validating manufacturability objectives during the detailed design phase. Northrop Grumman Electronic Systems has realized significant improvements in first-time-through-test yield, cycle times, touch labor requirements, and standardized part selection with the implementation of these guidelines.

Northrop Grumman Electronic Systems (NGES) defines producibility as "the capability to effectively produce a product at the target cost without additional process development beyond the release of a design to production." This approach uses simple, standardized manufacturing processes while providing the optimum compromise between cost and performance. The objective is achieved only when manufacturability factors such as material selection, yield, and process technology are considered during the design process and are included in alternative trade analyses.

NGES began a program in 2001 that has improved performance in this critical area through the development and distribution of Producibility Guidelines. These guidelines are established by manufacturing engineering for use by design engineering and exist for every manufacturing area within NGES. These documents contain key information impacting design choices that include:

- Material selection rules and implications;
- Detailed process capabilities and limitations;
- Established mechanisms for checking and verifying compliance with the guidelines; and
- Impact of design choices on manufacturing characteristics such as yield, cost, and non-recurring expenses.

Guidelines are used throughout the design and development cycle. During concept design, the guidelines support trade studies of competing designs and consider material selection, process technology, production cost, yield, and manufacturing cycle time. The preliminary design review is supported by information detailing parts selection, process capability/variation that impacts engineering analyses, and identification of cost drivers that support production cost estimation. During the detailed design phase, the guidelines provide "rules checking" to ensure that established production and manufacturing objectives are met by the final design.

Producibility Guidelines have been successful in positively impacting several manufacturing areas. In the manufacture of electronic modules, first-time-through-test yield (FTTTY) increased nominally by 2.1 percent, while touch labor was reduced by 15 percent. Standardization of part selection across electronic component assemblies reduced the number of line items needed to support production, improving kitting cycle time, throughput, setup time, and part restocking and changeout time. In the Surface Mount Technology (SMT) area, FTTTY has improved, with NGES achieving 100 percent yield in July 2005 for the first time. Cycle times are also consistently meeting or exceeding industrial engineering time standards, with this area seeing no design revision notices (RNs) in the past several years for parts influenced by the Producibility Guidelines.

7.4.2 Producibility in Detailed Design

Producibility must be addressed during every aspect of the design and development of a product in order to achieve the desired outcome of affordable products that meet the needs of the customer. During detailed design, it is crucial that the Integrated Product Team (IPT) responsible for the product continue to include a representative of manufacturing. As the product transitions to a final detailed design, the IPT must ensure that every aspect of producibility has been addressed. During this stage of the process, the IPT must continue to focus on the needs of the customer as stated in the product goals and on the product's key characteristics. As part of detailed design, product and process data are definitized through prototyping and testing of hardware and processes. The manufacturing plan gets fully developed during detailed design.

In this section, the three elements to address producibility during detailed design are presented. The three producibility system elements include the following:

1. Conduct Producibility Engineering Review;

2. Error-Proof the Design; and

3. Optimize Manufacturing.

7.4.2.1 Conduct Producibility Engineering Review

Engineering reviews using personnel who have not been involved in the product development are a traditional method for assessing the maturity of a design. In most cases, these reviews are conducted periodically during the design phases. With respect to producibility, a specific producibility engineering review (4.1) focused on the maturity of manufacturing processes is an essential step in achieving affordable products. Such a review should be accompanied by efforts to error-proof the design (4.2) and to optimize manufacturing (4.3). As described in this section, these three activities are inter-related. Although presented here as three separate elements, it is common practice to execute all three elements together, since they complement each other, to result in a final detailed design of a product that can be affordably manufactured.

The intent of a Producibility Engineering Review is to focus on manufacturability and not on the product's functionality. The goal is to identify manufacturing and assembly difficulties and potential problem areas. New process capabilities can then be traded off if the requirements exceed present capabilities.

As part of the Producibility Engineering Review, detailed attributes of the product under design are compared with documented process capabilities. This review is used as a checking mechanism to ensure that the product, as designed, can be produced with available manufacturing capabilities. This systematic, thorough evaluation is a necessary step in achieving enhanced producibility. The review can be conducted at one time or it can be done either continually or at pre-defined points in the design process.

The producibility engineering review is conducted in addition to normal and necessary design reviews. These latter reviews are conducted by the IPT throughout the design process and should be used to assess progress against the goals and metrics for the product. Since it is imperative that the IPT maintain a focus on producibility, the regular design reviews address many producibility issues. However, they are typically focused on individual processes and components and normally include tool, production, and facilities planning for those processes.

In contrast, the focus of the producibility engineering review expands to an evaluation of whether the entire product can be manufactured in the intended facility within the given schedule and budget. Internal experts who are not part of the product IPT nor involved in the product development are normally brought in to conduct this review.

7.4.2.2 Error-Proof the Design

Another key element to achieve enhancements in producibility is to error-proof the design. This oft-overlooked activity can have a remarkably big payoff in the reduction of manufacturing errors that can result in the need for rework and/or the production of scrap. The goal is to eliminate the causes for error, minimize the possibilities of error, and make errors that do occur more readily detectable. In simple terms, this goal is accomplished by designing products so that they can only be assembled the correct way and by using manufacturing processes that can only be implemented correctly. In reality, this goal may be unattainable for every product. However, by striving to identify opportunities to meet the goal, producibility will be enhanced.

An error-proof design is one in which the design team has considered ways to eliminate or reduce the occurrence of mistakes during manufacturing, assembly, and maintenance processes. A Failure Mode and Effects Analysis (FMEA) can assist in the identification of potential failure modes and in understanding the manufacturing process implications.

An example of eliminating an opportunity for errors is shown in Figure 7-6. In this redesign, a small lip was added to prevent installation of the bracket on the wrong side of the flange.

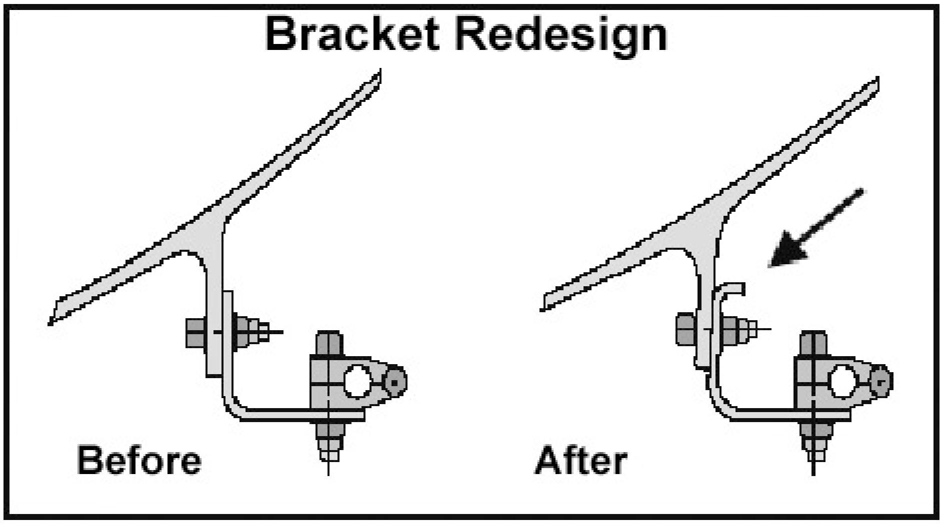

Figure 7-6 Error-Proofing Bracket Design

7.4.2.3 Optimize Manufacturing

This element involves the final tradeoffs of design details and manufacturing capabilities to arrive at a final detailed design configuration that will enable on-time, error-free, affordable production. As in error-proofing the design, optimizing manufacturing is a goal. The objective is to continuously improve both product design and process capabilities. During the detailed design phase, trade studies can assist in arriving at an optimum balance of quality, functionality, cost, performance, and producibility. Most of the techniques used to trade conceptual designs can now be used to assess detailed designs.

In this step, prototypes are manufactured or purchased, testing is conducted, and simulations of the planned manufacturing processes are evaluated. Virtual prototypes and the use of simulations can reveal changes required prior to any actual manufacturing. Physical prototypes can be tested extensively to provide data to support the achievement of the design goals as well as for process control variables. Process maturity, ease of assembly, and manufacturing risk continue to be key elements considered during these final trade studies. Prior to final design release, it is appropriate to review the manufacturing plan for the design to attempt to identify improvements. Prototyping of product and process, using either real mock-ups or computer simulations, can assist in identifying opportunities for improvement.

Factory floor, assembly, and process simulation tools can provide a cost-effective evaluation of the manufacturing plan before any product is manufactured. Manufacturing system simulation may be used to model the overall production process, material flow, and schedules, while process simulations help predict the outcome between individual processes and the product's characteristics.

Advances in solid modeling and improvements in computer performance make it possible to perform a comprehensive analysis of virtual parts and to assess the capability of processes before actual manufacturing begins. Tolerance analysis tools allow users to simulate different tolerance stack-up conditions that are likely to occur during a manufacturing process. Modeling software also allows designers to model the behavior of mechanical systems under real-world conditions.

7.4.3 Application to the Design Function

The classic systems engineering process is a top-down comprehensive, iterative and recursive problem solving process, applied sequentially through all stages of development. The SE process (Figure 7-7) is used to:

- Transform needs and requirements into a set of system product and process descriptions;
- Generate information for decision makers; and
- Provide input for the next level of development.

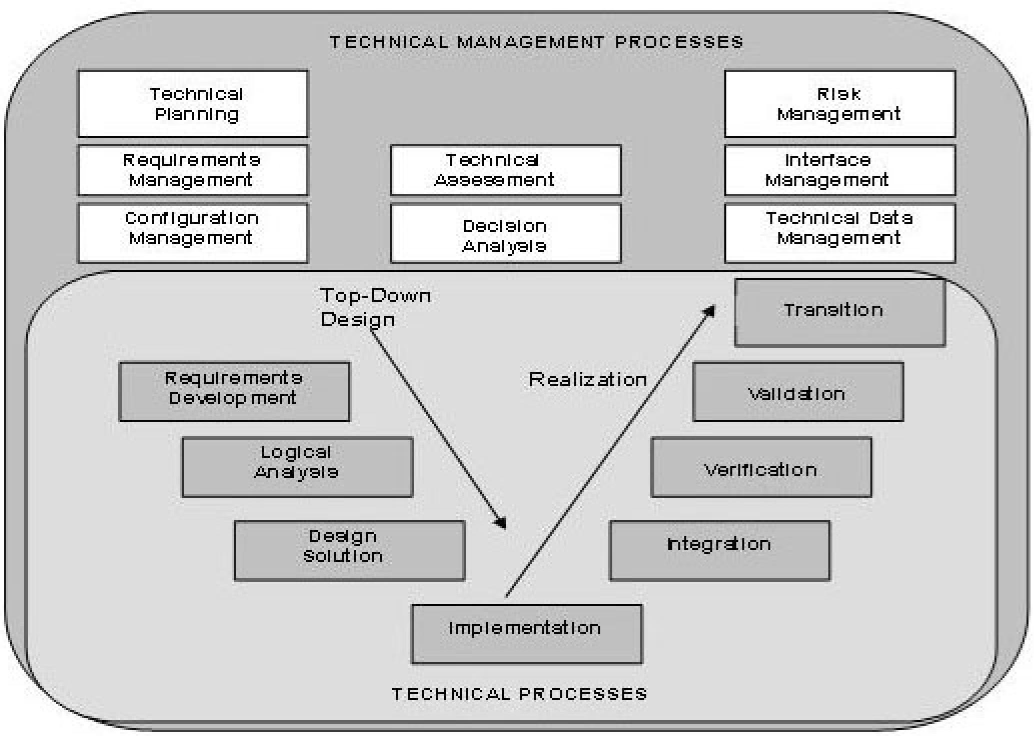

Figure 7-7 Systems Engineering Process Model (New)

The transformation process includes top-down design, design considerations and trade studies. Bottom-up realization includes the build of product for testing (validation and verification).

Manufacturing and production are one of the primary functions and manufacturing considerations should be included in the top-down design considerations and trade studies, and bottom-up realization for the fabrication of engineering test models and "brass boards," low rate initial production, full-rate production of systems and end items, or the construction of large or unique systems or subsystems.

7.4.4 Producibility Impact

The importance of addressing producibility early is illustrated in Figure 7-8. As a product concept matures, the ability to influence producibility and resulting product costs decreases. In contrast to the typical producibility activity profile shown on the figure, the goal is to reduce producibility activity during the production phase of a product and increase that activity during the initial concept and design phases. The producibility guidelines and tools presented in this document are focused on the consideration of manufacturing issues throughout the design and development of a product.

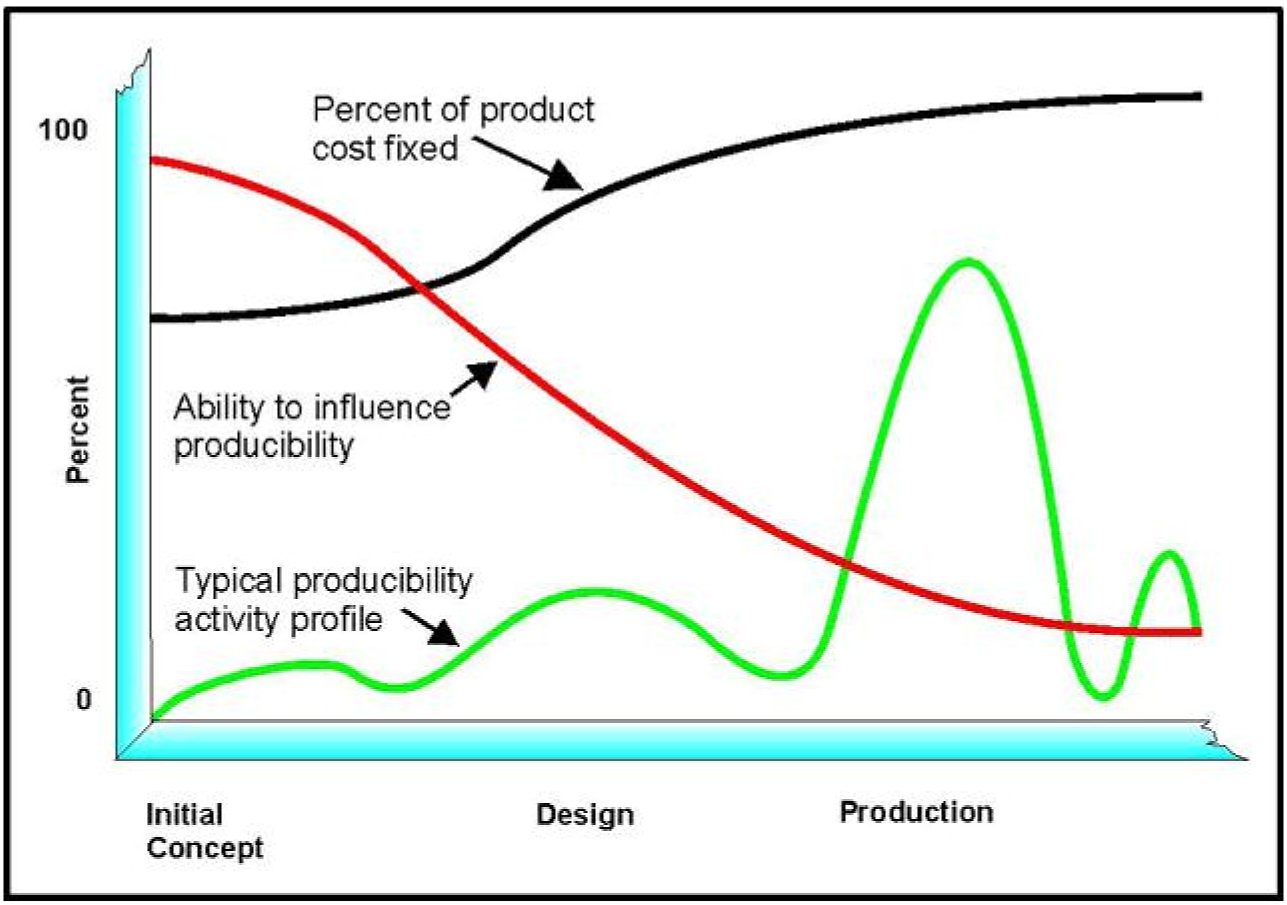

Figure 7-8 Producibility Impact

7.4.5 Producibility Tools

NAVSO P-3687, the Navy's Producibility System Guidelines, has identified several tools and techniques that can be used to support producibility efforts. Many of these tools are available as software tools, thus making the process that much easier to implement. Some of these tools, such as "benchmarking," can be used during all five of the Producibility Steps and Elements. Others, such as "statistical quality control," are applicable during only one of the steps (measurement). The following list identifies the tool and where in the Producibility Step and Element it is applicable. Those tools identified with an asterisk (*) have been discussed in other chapters of this guide. Most are in Chapter 5 on Continuous Process Improvement.

Producibility Tools and Techniques	Infrastructure	Process Capability	Conceptual Design	Final Design	Measurement
Benchmarking					
*Cost Tools (Discussed in Chapter 9)					
Database Management Systems					
Decision Support Tools					
Design for Manufacture / Assembly (DFMA)					
*Design of Experiments (DOE) (Discussed in Chapter 5)					
Failure Mode and Effects Analysis (FMEA)					
- Design Failure Mode and Effects Analysis (DFMEA)					
- Process Failure Mode and Effects Analysis (PFMEA)					
Integrated Product and Process Development (IPPD)					
Integrated Product Team (IPT)					
Knowledge-Based Systems					

*Manufacturing Planning Tools (Discussed in Chapter 4)					
*Manufacturing Simulations (Discussed in Chapter 14)					
*Modeling and Simulation (M&S) (Discussed in Chapter 14)					
Producibility Assessment Worksheet (PAW)					
Prototyping					
*Quality Function Deployment (QFD) (Discussed in Chapter 5)					
Rapid Prototyping					
Risk Management Tools					
Root Cause Analysis (RCA)					
*Six Sigma (Discussed in Chapter 5)					
*Statistical Process Control (SPC) (Discussed in Chapter 5)					
Statistical Quality Control (SQC)					
Tolerance Analysis					

Table 7-1 Producibility Tools and Techniques

7.4.5.1 Benchmarking

Benchmarking is the process of measuring one product or process against another similar product or process to identify best practices. It is a starting point for initiating change within a company or organization. The most common reasons an organization will benchmark are to determine where they stand amongst the competition and whether value can be added by incorporating the practices of others. Benchmarking can be used by organizations for comparison of internal operations, competitor-to-competitor products, industry standing, and generic business functions or processes. The goal of benchmarking is to identify the best practices of industry and to adapt and/or incorporate those practices that are beneficial to the organization.

7.4.5.2 Database Management Systems

A database management system is a computer application used to create, maintain, and provide controlled access to a database. A database is a shared collection of logically related data pertinent to an area of endeavor. A database management system is used to facilitate the collection, organization, and retrieval of data needed by the community of individuals involved in the endeavor. The system is used through the facilities of a "user interface" which provides the computer aided functions of data storage, retrieval, and modification.

7.4.5.3 Decision Support Tools

Decision support tools permit people to efficiently analyze and process large amounts of data required for decision making. Modern tools are computer based with interactive access to large database systems and allow for extracting, analyzing and presenting information from the databases in a useful format. Decision support tools are used as an aid to the decision makers by extending their intuitive capabilities; the tools are not meant to replace the decision-makers judgment or expertise.

7.4.5.4 Design for Manufacture / Assembly (DFMA)

DFMA is a systematic analysis of the design of an assembly or subassembly to reduce product cost by simplifying its design, assembly, and manufacturing without impacting performance. The analysis allows you to determine the theoretical minimum number of parts that must be in the design for the product to function as required. As you identify and eliminate unnecessary parts, you eliminate unnecessary manufacturing and assembly costs.

Figure 7-9 below is for an F-18 Oxygen Tank Bottle Holder. The original design was too complex, had too many parts, too many manufacturing operations and took too long to assemble. In addition, the complexity of the design provided more opportunities for parts failures and lower reliability. The improved design, as a result of producibility engineering, had 33 percent fewer parts, 38 percent fewer fasteners, 31 percent fewer operations and took 20 percent less time to assemble. The design was made more efficient and producible by using Design for Manufacturing and Assemble (DFMA).

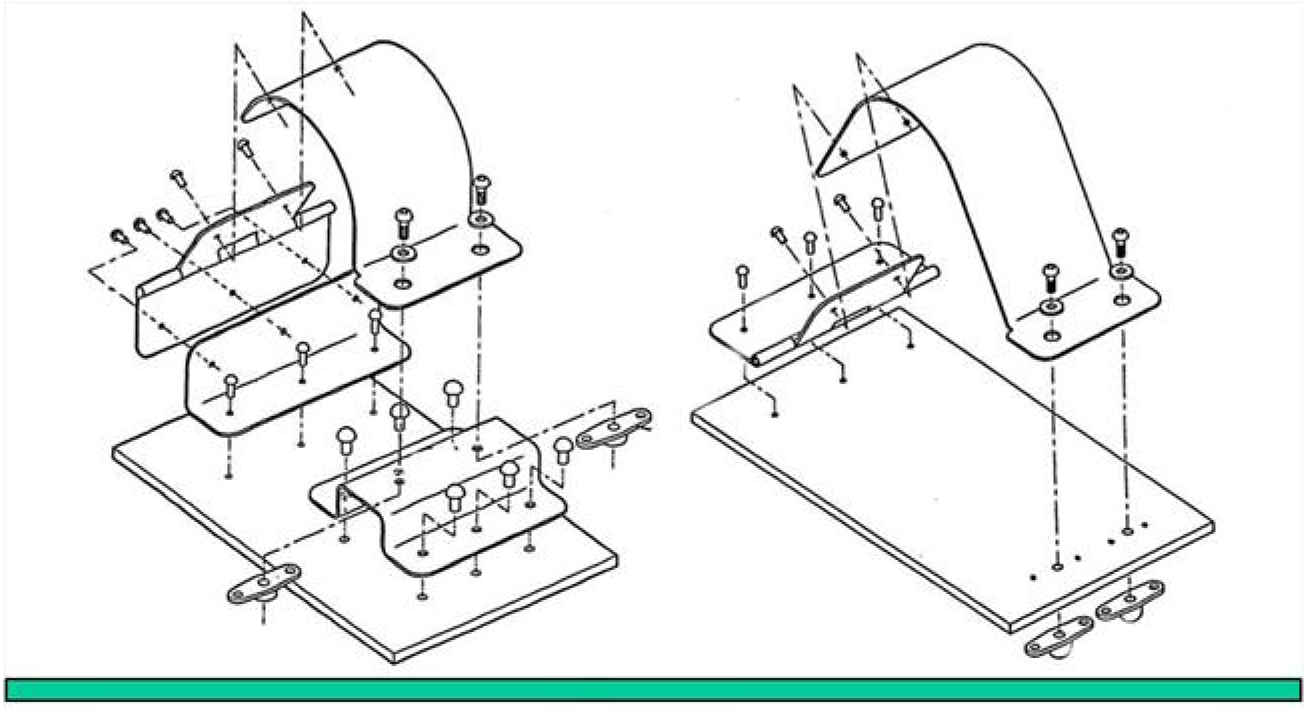

Figure 7-9 F-18 Oxygen Tank Bottle Holder

A technique developed by Boothroyd-Dewhurst measures a design's efficiency and has developed rules to assess a design to identify opportunities to improve the design, that is make the current design more producible, more efficient. Ask the following questions of the design on the right:

- During operation, does this part move relative to the part to which it is attached?
- Does this part need to be made of a different material than the part to which it is attached?
- Does this part need to be removable?

If the answer to all three questions is "no," then the part is a candidate for elimination or combination with other part(s). The redesigned oxygen tank bottle holder on the right is a result of producibility engineering.

7.4.5.5 Failure Mode and Effects Analysis (FMEA)

FMEA is a structured methodology for identifying failures, errors, and defects before they occur and prioritizing them for corrective action. There are two types of FMEA. Design Failure Mode and Effects Analysis (DFMEA) is a means of analyzing the part design for potential failures, errors, and defects prior to the first production run. Process Failure Mode and Effects Analysis (PFMEA) helps to analyze the parts manufacturing processes prior to production to identify possible process failures that can induce defects into the part. Both methodologies have the same goal, early identification of and reduction and/or elimination of failure mechanisms.

7.4.5.6 Integrated Product and Process Development (IPPD)/Integrated Product Teams (IPTs)

World-class companies have begun using integrated design and development concepts to improve their manufacturing processes, improve producibility and maintaining global competitiveness. Integrated Product and Process Development (IPPD) emerged from earlier integrated design practices, such as concurrent engineering. IPPD, also referred to as integrated product development, expands upon this concept by involving appropriate, multi-disciplinary teams in all phases of a product's development life-cycle. IPPD activities primarily focus on meeting the customer's needs, while simultaneously reducing costs, decreasing development times, and improving product performance and quality.

7.4.5.7 Knowledge-Based Systems

Knowledge-based systems are computer-based programs that incorporate human expertise and other documented knowledge with the facilities for applying that knowledge to real-world circumstances. Knowledge-based systems provide the benefit of and satisfy the requirement for documenting, developing, and dissemination rules, processes, and/or guidance related to a specific domain or problem area. Knowledge-based systems may be automated in embedded systems or employed through a user interface where questions can be presented in a manner similar to how they would be asked of a human consultant or expert.

7.4.5.8 Prototyping/Rapid Prototyping

Prototyping is a tool used for assessing form-fit-and-function of a product and for visualizing aesthetic quality. Prototyping techniques can also be used to create molds for full-scale production. Through use of a prototype, a designer can get feedback on design information and initial part acceptance for further use in optimizing the design and/or the manufacturing processes. Prototyping is used to check design features and complexity and is helpful in tradeoff studies. The use of prototyping begins in the preliminary design step and continues into the early stages of the final design step. The ability to quickly transform a design into a three-dimensional solid model or prototype can significantly streamline the design and product development process, while substantially reducing costs.

Product prototyping is an essential part of the product design cycle. It is a technique for design functionality and aesthetic quality assessment. Through use of a prototype, a designer can get feedback on design information and initial part acceptance for further use in the manufacturing process. Prototyping is used to check design features and identify complexity issues and is helpful in tradeoff studies. The use of prototyping begins in the preliminary design phase and can continue throughout the early stages of the detailed design. Prototyping can also be performed in production to test whether a new process can be used to produce a product that meets the customer's quality requirements. The ability to quickly transform a design into a three-dimensional solid model or prototype can significantly streamline the design and product development process, while substantially reducing costs.

7.4.5.9 Risk Management Tools

Risk is common to any product development effort. A risk is the potential inability of achieving product goals and is quantified by the probability of a failure and the consequences of that failure. Risk management includes risk identification and assessment, tracking of risks to determine how risks have changed, and mitigation/reduction of risk impact on the product.

Risk management activities begin at the outset of any product development effort and continue through all phases. They are important elements in achieving a producible design. Although the scope and method of implementation will vary with product scope and complexity, among other things, common threads of any risk reduction effort are:

- **Risk identification** : What process improvements are needed to ensure that producibility will be achieved? Do design analysis processes include a producibility assessment? Do trade study activities include producibility as a tradeoff criterion?
- **Risk assessment** : What consequences will result if identified areas of risk are not dealt with or are only partially addressed? Will the impact affect performance, cost, and/or schedule, and to what degree?
- **Risk tracking** : Is an unmitigated risk growing? By when must the risk be mitigated?
- **Risk mitigation/reduction** : What can be done to eliminate the source of the risk or reduce it to an acceptable level? Are funds available to develop and conduct the necessary risk mitigation efforts?

7.4.5.10 Root Cause Analysis (RCA)

Root Cause Analysis (RCA) is a method or series of actions taken to identify the reasons why a particular failure or problem exists and to highlight alternative solutions to eliminate the sources of those problems. An analysis of the comparative benefits and cost-effectiveness of the alternative solutions aids the decision maker in implementing the most beneficial course of action. RCA goes beyond identifying resolutions for the symptoms of a problem. It aims to provide solutions to eliminate the root cause of the problem to ensure that the problem can never occur or recur.

7.4.5.11 Statistical Quality Control (SQC)

Enterprises are placing a greater emphasis on improving the quality of products provided to the consumer as a means of improving and maintaining competitiveness within the global market. Many world-class organizations have adopted Statistical Quality Control (SQC) which involves using statistical tools and techniques, such as acceptance sampling, process capability analysis, and Statistical Process Control (SPC), to analyze, monitor, and control the efficiency and quality of its manufacturing processes. By improving the quality of the manufacturing processes used in production, the quality of the end-product increases, as does productivity and customer satisfaction.

7.4.5.12 Tolerance Analysis

Tolerance analysis looks at the relationship of design tolerance (requirement) and manufacturing variation (process capability) to define an optimal tolerance solution. The method of tolerance analysis will depend upon the method of manufacture and the tolerance range within which the parts may vary. The key concept of tolerance analysis is the interchangeability of parts. If two parts can be switched in an assembly, they are considered to be interchangeable. In terms of fit, these parts are considered to be the same. Tolerance analysis will determine the limit to which these parts can vary and still be considered interchangeable. As the tolerance range approaches zero, the cost of manufacturing the part increases greatly. Therefore, the goal of tolerance analysis is to generate parts with as loose a tolerance as possible to minimize the production cost while still meeting the conditions for interchangeability. From a producibility standpoint, maximizing design tolerances is a necessity for a robust design.

7.5 Producibility Goals and Objectives

Producibility is much more complex than is traditionally depicted. Producibility exists at the intersection of the design and the factory floor (see Figure 7-10). The factory floor consists of manpower, machines, methods (processes), material and measurement (inspection and testing). An in-depth analysis of the design and factory floor must be accomplished if you hope to achieve any measure of producibility.

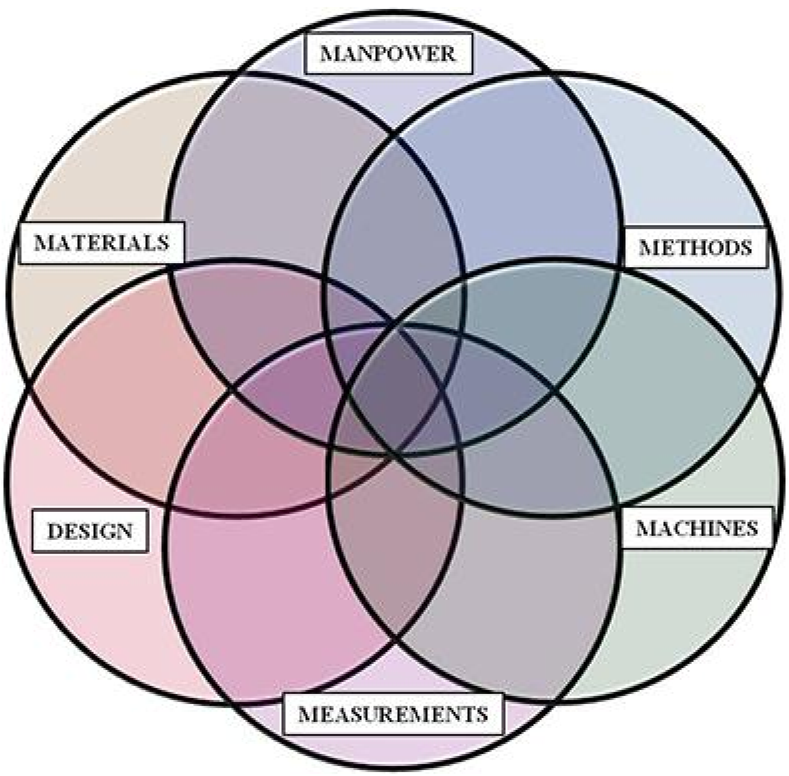

Figure 7-10 Producibility Intersection

7.5.1 Design Maturity Considerations

Below are some indicators of increasing maturity for several areas of producibility considerations.

7.5.1.1 Design Maturity

- State-of-the-Art product requiring significant research and breakthrough in technology;
- Technology approach has been formulated and studies (paper) are underway;
- Analytical and Lab studies are underway to physically validate predictions;
- Component/Breadboard studies have been validated (key characteristics have not been identified, other engineering functional specialists are being introduced into the project e.g. manufacturing and logistics engineers);
- System or subsystem prototypes have been developed and successfully tested in a lab environment;
- System/Subsystem prototypes have been successfully tested in an operational environment (key characteristics have been identified using experimental designs and other functional specialists are routinely involved in all design decisions); and
- System/Subsystem in its final form have been successfully tested in an operational environment.

7.5.1.2 Design Stability

- A significant number of design changes are continuously being introduced into the System/Subsystem or the changes are radical;
- Many changes are still being introduced into the System/Subsystem or the changes are significant;
- Some changes are being introduced into the System/Subsystem or the changes are moderate;
- Few changes are being introduced into the System/Subsystem and the changes are minor; and
- There are no design changes.

7.5.1.3 Schedule

- Timelines are stringent and you are betting on a miracle;
- Timelines are highly dependent of many factors and many of those have a high risk of failure;
- Timelines are dependent on several factors and some of those have moderate risks associated with their completion;
- Timelines are well known and have few risks associated with their completion; and
- Timelines are generous and there are no known risks.

7.5.1.4 Risk

- Risk is very high for the program and risk assessment has not been completed and there is no risk management plan;
- Risk is high and preliminary risk assessments are underway;
- Risk is moderate and risk assessments have been completed and a preliminary risk management plan is in development;
- Risk is low for the program, risk assessments and risk management plans have been completed; and
- Risk is very well understood and manageable.

7.5.1.5 Funding

- Funding is totally inadequate to complete the project;
- Funding is low given the complexity and risks, overruns are highly likely and the program faces low support;
- Funding is marginal, overruns of 25 percent or more are highly likely;
- Funding is adequate, overruns of more than 5 percent are highly unlikely; and
- Funding matches the projected budget and the project has a high probability of coming in on cost and schedule with the contracted for performance.

7.5.1.6 Manpower Maturity

- The manufacturing process utilizing manpower skills have not been developed and requires R&D;
- The manpower skills exists only in one place and by highly skilled personnel;
- The manpower skills exists in a few places and can be replicated with extensive training;
- The manpower skills exists in many places or requires only semi-skilled personnel with some training; and
- The manpower skills are readily available or requires little skills or training.

7.5.1.7 Materials Maturity

- Materials have not been invented and require R&D;
- Materials have been developed and tested in a lab environment, but are not available and/or have significant environmental impact that must be mediated;
- Materials are beginning to become commercially available, but have significant backlogs (12 months or more to deliver) or may have environmental concerns;
- Materials are easily available within a six months and/or have few environmental issues or those issues are easily mediated;
- Materials are available within 30 days and/or have no environmental concerns; and
- Materials can be delivered just-in-time, all of the time.

7.5 1.8 Methods/Process Maturity

- Process is new and requires R&D to understand;

- Process has been successfully applied in a lab environment;
- Process is available but has not been proven;
- Process is available from several sources and has been proven (some quality data is available and yields are known);
- Process has been proven, key process characteristics have been identified and are controllable to a three sigma level; and
- Process has been statistically proven, key characteristics are easily controllable to a six sigma level.

7.5.1.9 Machine Maturity

- Machines required in the manufacturing process have not been invented and need R&D to develop;
- Machines have been developed and are in testing;
- Machines have been used in an operational environment successfully;
- Machines are readily available from several sources, those sources have yield data available;
- Machines have been used with good statistical data (three sigma); and
- Machines have been used with excellent statistical data (six sigma yields).

7.5.1.10 Measurement/Test/Inspection Maturity

- No measurement/test method has been identified and requires R&D to develop;
- Inspection/Test equipment has been developed and tested in a lab environment;
- Inspection/Test equipment has been developed and tested in an operational environment;
- Several sources for inspection and test exist;
- Inspection and test equipment and methods provide good quality data (three sigma); and
- Inspection and test equipment and methods provide excellent quality data (six sigma).

7.5.1.11 Tooling

- Manufacturing requires a dedicated fixture that has not been built yet;
- Manufacturing requires a dedicated fixture that has been built and proven;
- Manufacturing requires a significant investment in fixturing that must be proven;
- Manufacturing fixtures exists and are proven;
- Manufacturing requires a moderate amount of fixturing that must be proven;
- Manufacturing requires minor fixturing; and
- Manufacturing can be accomplished without fixturing.

7.5.1.12 Key Characteristics

- Have not been identified;
- Non-key characteristics have been identified and are being used to control quality;
- Key characteristics have been identified but are not yet capable or in control;
- Key characteristics have been identified and are capable and in control; and
- Key characteristics have been identified and are capable and in control to six sigma.

7.5.2 Things to Maximize/Things to Minimize

Figure 7-11 below identifies several producibility and manufacturing considerations that should be either maximized or minimized.

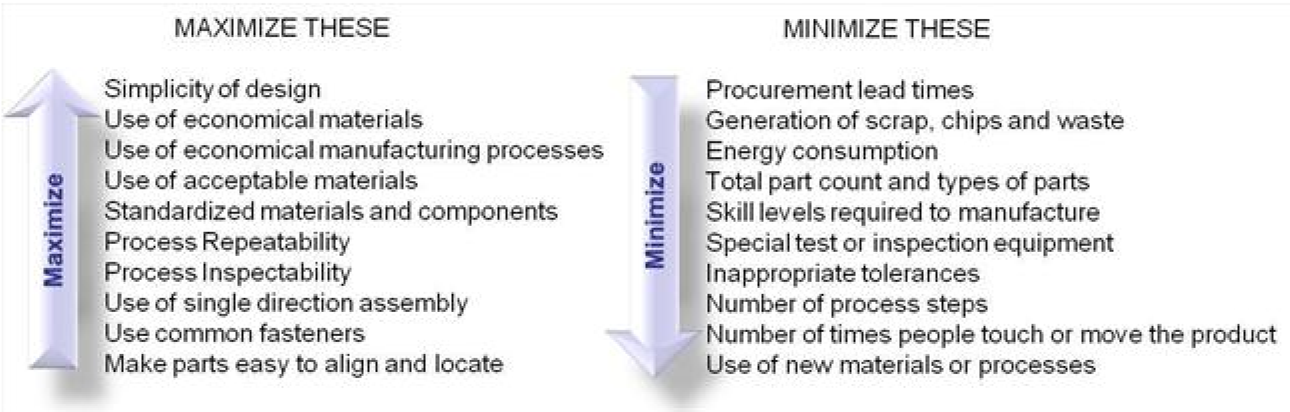

Figure 7-11 Maximize and Minimize

Two good examples of ways to improve producibility and reliability are:

- Reduce the number of interfaces. An interface is a particular location where energy, forces, materials or information is transferred; more interfaces mean more opportunities more manufacturing errors and increases the need for interface management (e.g., welds, joints, hose and cable connections, hardware to software),
- Reduce the number of components, especially components that move.

7.6 Producibility Engineering and Planning

The primary purpose of producibility engineering and planning (PEP) is to ensure a smooth transition from development to production. To accomplish this objective, the PEP effort must be an explicit part of the developmental activity and encompass those tasks necessary to assure weapon system or element producibility prior to quality production.

Five steps (Figure 7-12) have been identified as building blocks in the development and deployment of a producibility program. The five steps are based on criteria from numerous successful producibility programs and provide the foundation for this revised guidelines document. Although they may be examined independently, the five producibility steps are interdependent, each building on the preceding step.

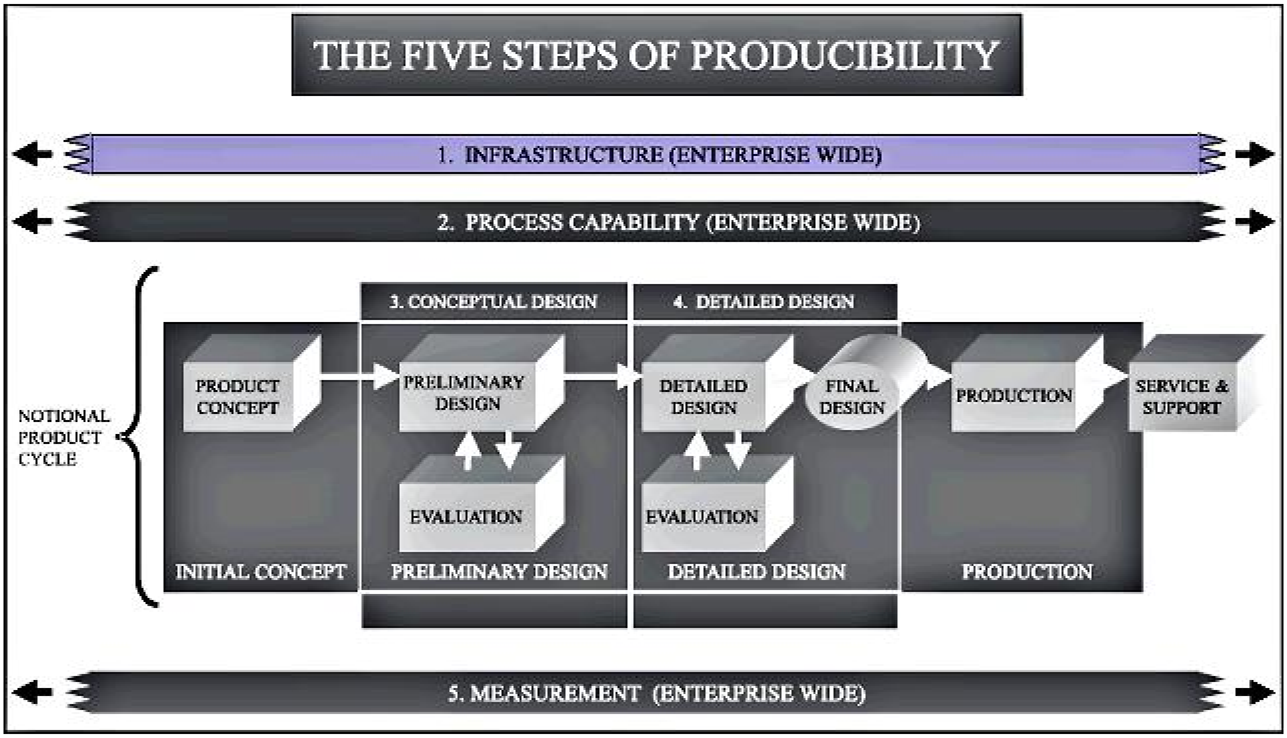

Figure 7-12 The Five Steps of Producibility

7.6.1 Establish a Producibility Infrastructure

The success of an enterprise's producibility system is directly related to the commitment of the enterprise to the producibility elements presented in this document and the ability of the organization to implement them effectively. In order to accomplish this step you need to:

- Recognize the need for management commitment;
- Organize for producibility;
- Implement a risk management plan;
- Incorporate producibility into new product introduction strategy;
- Employ producibility guidelines; and
- Instill a commercial best practice philosophy.

Management must initiate the process, communicate expectations, set goals, empower teams, remain visible, provide managerial inputs, and commit to implementation of the results. Strong commitment and effective leadership generate success in a producibility system which, in turn, produces higher-quality, lower-cost designs for products that can be repeatedly manufactured with high yields. An effective producibility environment should permeate all infrastructure elements.

The establishment of a seamless, information-rich environment is a crucial part of the commitment. It is important that all members of the IPT have ready access to all relevant information. Furthermore, it is essential that management is committed to understanding the capabilities of its organization and its processes. In this regard, measurement of all elements of product and process is critical. Management must foster an environment that requires measured data for decision making. Finally, it must be clear to all that management believes that the ability to affordably manufacture and support the product is as important as product performance. The organization must maintain a focus on the customer - delivering what the customer wants, when it is wanted, and at the price the customer is willing to pay.

7.6.2 Determine Process Capability

A thorough knowledge of an enterprise and its suppliers' process capabilities is critical to implementing a successful producibility system. Process capability must be understood, measured, controlled, and documented, and process capability information must be updated at periodic intervals. Information must be focused on what can be successfully manufactured accurately and repeatedly under various conditions and not what can be manufactured once under the best possible circumstances.

It is essential to fully understand present and future process capabilities to ensure that, as new or improved processes mature, they can be readily introduced into manufacturing with no detrimental effects to producibility. Predicting future capabilities is especially important in markets like the electronics industry where product or process obsolescence forces the rapid development and use of new technology. Future process capabilities in this context means more than advanced, new processing techniques. It also means being cognizant of processes used by competitors or manufacturers in different industries and adapting those processes if, and when, it is appropriate.

7.6.3 Address Producibility During Conceptual Design

Producibility must be addressed during every aspect of design and development in order to achieve the desired outcome of affordable products that meet the needs of the customer. During conceptual design, it is crucial that the IPT responsible for the product include a representative of manufacturing. It is also crucial that the IPT ensure that manufacturing issues are considered in every stage of the process. The development of a design concept is conducted by identifying possible alternatives and prioritizing them according to their ability to satisfy the goals of the product. By addressing manufacturing considerations early, the IPT ensures that the maturity of manufacturing processes is considered during the assessment of various design options. While a design and associated processes might be selected for which a particular process is technologically immature, the IPT must understand the implications of that choice and the investment needed to mature the process before production at the prime contractor and critical subcontractors/vendors.

Producibility activities to be conducted during the preliminary design phase include:

- Identify critical design parameters;
- Fabricate product model;
- Develop manufacturing process plan;
- Develop product test strategy;

- Identify parts and materials;
- Perform initial Sigma analysis;
- Perform initial Design for Manufacturing and Assembly (DFMA) analysis;
- Establish Defects per Unit (DPU) goal;
- Update Design to Cost (DTC) goals;
- Perform trade studies;
- Perform preliminary producibility analysis;
- Generate design documentation;
- Hold supplier producibility reviews; and
- Hold Preliminary Design Review (PDR).

Exit criteria: The customer agrees with the qualification plan and the preliminary analysis indicates that the product requirements, cost, and schedule can be met.

7.6.4 Address Producibility During Detailed Design

During detailed design, it is crucial that the IPT responsible for the product continue to include a representative of manufacturing. As the product transitions to a final detailed design, the IPT must ensure that every aspect of producibility has been addressed. During this stage of the process, the IPT must continue to focus on the needs of the customer as stated in the product goals and on the product's key characteristics. As part of detailed design, product and process data are definitized through prototyping and testing of hardware and processes. The manufacturing plan is created during detailed design.

Producibility activities to be conducted during the critical design phase include:

- Build engineering prototype;
- Verify performance to customer requirements;
- Verify parametric Sigma performance;
- Verify process Sigma to goals;
- Verify DTC to goal;
- Verify DPU to goal;
- Final production layout defined;
- Release formal design documentation;
- Update DFA analysis;
- Update producibility analysis;
- Hold supplier producibility reviews; and
- Hold Critical Design Review (CDR).

Exit criteria: The engineering prototype has demonstrated functional compliance to customer requirements and manufacturing targets. Final configuration has been documented.

7.6.5 Measure Producibility

Effective measurement is critical to an accurate assessment of producibility. It is the key to understanding an organization's capability to produce a product and the accuracy of the product produced. It is a tool for evaluating the effectiveness of producibility performance and for determining the degree to which improvements need to be made to ensure that future products are producible.

Producibility assessments are conducted on a product level, both the product and its manufacturing processes must be measured. Processes must be monitored and controlled, through measurement, to ensure that they can repeatedly produce accurate, high-quality products. The goal of process monitoring and control is to limit process variability to a tolerable range. Process variability results in product variability, and product variability, when outside of design limits, means unacceptable quality. As a general rule, reducing process variability improves product quality and, therefore, producibility.

In general, to assess producibility on an enterprise level, an organization must first evaluate its producibility performance on a product-by-product basis. Analysis of producibility on a per-product basis allows the organization to better understand the strengths and weaknesses of its producibility system or enterprise-wide producibility approach, so that enhancements can be identified.

Fundamental to measurement of any kind is the setting of measurable goals and metrics. Metrics, in this case, are an objective means of measuring producibility performance as well as overall producibility system effectiveness. Establishing goals and applicable metrics forces the organization to focus in on those measurements critical to ensuring or enhancing producibility. Care should be taken to measure only what is important to measure and what will provide the organization critical information on which to base decisions regarding future actions.

7.6.5.1 Producibility Assessment Worksheet (PAW)

The Navy's' Best Manufacturing Practices Center of Excellence (BMPCOE) has developed a series of Producibility Assessment Worksheets (PAW) for assessing the producibility of a product or process. PAWs are used to determine the best means of production for components and the overall item. The worksheets use numeric values to determine the ease of producibility for the elements that make up the process which when averaged produce a measure of the probability of successful production, i.e., producibility.

The PAWs are designed to open communications between management and the functional disciplines involved in product development and manufacture. A producibility engineer, manufacturing engineer, or another appropriate individual is chosen to evaluate the producibility of an assembly. After reviewing the preliminary drawings with design engineering, the appropriate PAW is chosen for the evaluation.

After reviewing the design, cost goals, schedule, and quantities, the evaluator selects three possible production methods for the assembly (Figure 7-13 is a PAW for a missile power supply):

1. Assemble parts from sheet metal with nuts and bolts;

2. Sand casting with some secondary machining operations; and

3. Investment casting - near net shape, minor drilling and tapping.

The evaluator assesses each production method against the criteria in the PAW. In each instance the evaluator examines the design and selects one of the five values in each section for each of the methods, entering that value in the appropriate column.

The effort involved in determining the values for each section of the PAW will depend on the complexity of what is being evaluated and the background of the evaluator. Ideally, completion of the worksheet will not be done in isolation, either in terms of one individual in a particular functional discipline such as design, manufacturing, etc., nor should inputs be limited to the collective work of any one functional discipline. Consultations and exchanges of information between individuals in a given functional discipline and in different disciplines are vital to achieving the best assessment possible.

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Producibility Assessment Worksheet

Assessment Candidate Power Supply Assembly

Production Method (PM)

1. Sheet Metal with nuts and bolts
2. Sand casting with some secondary machine operations
3. Investment casting - near net shape, minor drilling and tapping
4.

	Method	PM #1	PM #2	PM #3	PM #4
A1 Design					
.9 Existing / simple design					
.7 Minor redesign / increase in complexity					
.5 Minor redesign / moderate increase complexity					
.3 Tech. avail. complex design / significant increase					
.1 State-of-the-art research req. / highly complex					
A2 Process					
.9 Process is proven and technology exists					
.7 Previous experience with process					
.5 Process experience available					
.3 Process is available, but not proven yet					
1. No experience with process, needs r&d					
A3 Materials (availability/machinability)					
.9 Readily available/aluminum alloys					
.7 1-3 month order/ferrous alloys					
.5 3-9 month order/stainless steels					
.3 9-18 month order/non-metallic (smc, etc.)					
.1 18-36 month order/nre r&d material					
A4 Design to cost (DTC)					
.9 Budget not exceeded					
.7 Exceeds 1-5% in DTC					
.5 Exceeds 5-20% in DTC					
.3 Exceeds 20-50% in DTC					
.1 Cost DTC goods cannot be achieved >50%					
A5 Schedule compliance					
.9 Negligable impact on program					
.7 Minor slip (<1 mo.)					
.5 Moderate slip (1-3 mo.)					
.3 Significant slip (3-5 mo.)					
.1 Major slip (>5 mo.)					

Producibility Assessment Ratings **PM #1**_____ **PM #2**_____ **PM #3**_____ **PM #4**_____

For each Method $\frac{(A1 + A2 + A3 + A4 + A5)}{5}$ **= Producibility Assessment Rating for that method**

Figure 7-13 Producibility Assessment Worksheet (PAW)

7.7 Contractor Producibility Efforts

The importance of the program plan as a contractual clause cannot be overemphasized. The contractor's producibility program plan details the organizational structure, authority, and responsibilities of the personnel that will be utilized to monitor producibility and perform the required analyses. Many manufacturers classify their manufacturing process information as proprietary and it is advisable to clarify this point with a contract clause on the predetermination of rights. It will frequently be necessary to purchase producibility engineering as a data item under a research and development contract for an end item. To assist the program office in the preparation of the data item description, the information in the following paragraphs may be helpful.

7.7.1 Organizing for Producibility

Concern for producibility must be exercised at the start of the concept exploration phase and will influence the entire design effort from that point on in every item of the life cycle. Inherent producibility limitations must be recognized and addressed at each stage of the life cycle process. Broad producibility considerations might include the selection of materials and manufacturing processes. The iterative design process is filled with decision points, each of which permits a potential trade-off against some other requirement. However, all demands upon the system such as reliability, availability, maintainability, safety, or producibility heavily interact with each other throughout the design process, creating the need for trade-offs.

There are a number of alternatives for the contractor when organizing to achieve producibility. Four approaches often used are:

1. Assign responsibility for the achievement of producibility to those personnel in the various existing functions as a part of their basic work tasking.

2. Assign responsibility for producibility engineering to an existing product or design engineering function. They already have responsibility for product design and consequently are in the best position to ensure producibility in the design.

3. Assign responsibility for producibility to the production or manufacturing engineering function. They are already in the best position to understand the production processes and their effect on producibility.

4. Establish a new function of producibility engineering and staff it with personnel of product engineering and manufacturing engineering background with emphasis on the latter.

7.7.2 Contracting for Producibility

The contract should include specific requirements for the integration of producibility considerations into the design process. During each stage of development, an organized and systematic pattern of events must take place if a design is to fully meet all of its objectives. Implicit in these objectives is the requirement that a design achieve the highest possible degree of producibility. However, producibility goals are rarely defined in documents describing the end item.

The focus of the PEP effort is evaluation of the system's design as it evolves to identify potential manufacturing problems and to suggest design trade-offs which would facilitate the manufacturing process. In order to ensure contractor availability of the necessary disciplines, such as those required to develop data packages, design special purpose production equipment and perform computer modeling or simulation of the manufacturing process from a producibility assessment standpoint, a Statement of Work (SOW) must be developed to establish both general and specific requirements.

The objectives of PEP can be segregated between producibility engineering design criteria described above, and the producibility planning data requirements. With approximately 60 percent of weapons system acquisition dollars expended in the production phase, it is important that the Request for Proposal or earlier program phases clearly identify the government's PEP needs. This is especially important because contractor PEP efforts will be dependent on the level of funding provided by the government in this area. Thus, the early identification of design criteria and date requirement objectives, along with the corresponding funding, will be instrumental in achieving meaningful results. Clearly, the requirements govern the level of contractor effort.

7.7.2.1 Contract Functions

The PM should ensure that PEP objectives are identified early in the development cycle and that corresponding levels of funding will be available. The SOW items establishing the PEP effort may involve many specialized contract functions and monitoring organizations. For example, in designing to meet prototype fabrication and low rate initial production schedules, special hard and soft production tooling and special test equipment requirements will normally be generated, requiring the use of attendant government property clause. These clauses differ as a function of contract type (cost or fixed-price), degree of competition (sole-source or competitive), and category of government property. Because contractors may be influenced by factors such as desire to use contractor-peculiar capabilities and proprietary process/equipment, or to maintain a certain work force skill mix, the government's program management organization must include the flexibility to ensure focus on program goals. Government production engineers must be continuously involved with contractor design engineering in order to evaluate design proposals (such as specifications, trade-off studies and producibility analyses), configuration management, and production plans.

7.7.2.2 Data Item: Producibility Program Plan

The producibility program plan permits the determination of the manufacturer's ability to maximize the system, subsystem, and/or component producibility through the utilization of an effective organization to identify, establish, and accomplish specific producibility tests and responsibilities. This data item description is applied when the producibility task has been included in the contract statement of work.

The contractor's producibility program, which is documented in the producibility program plan, should contain (but not be limited to) these items:

- A detailed listing of tasks and procedures used to conduct the producibility program.
- A description of each task.
- An identification of the unit or persons having the task assignment and their responsibility and authority.

- An assessment of known or potential problem areas and their impact on the progress of the program.
- A milestone planning chart or other graphic portrayal of scheduled events.
- The plan shall provide for and schedule producibility analyses to be conducted on each design concept being considered.
- Alternate approaches will be reported.
- Detailed procedures and checklists for accomplishing the producibility analyses prepared for design reviews.

7.7.2.3 Data Item: Producibility Analysis

The producibility analysis plan permits the evaluation of manufacturer's methods of conducting the analysis to determine the most effective manufacturing methods of the end product. This data item description can be applied throughout the acquisition cycle of any program whose end result is a production program. The purpose is to assure that the systems, subsystems, and component designs meet the standards of producibility. In establishing a requirement for producibility analyses, the PM may require the contractor to develop an appropriate set of checklists applicable throughout all the program phases. The checklists in Figure 7-7 should aid manufacturers in performing productivity analysis.

7.7.2.4 Producibility Funding

PEP efforts are funded early enough to be essentially complete by the end of the full-scale development phase of a program. PEP should be started early in the acquisition cycle to preclude reiteration of designs resulting from changes brought about by producibility analyses. The efforts accomplished during the full-scale development phase will primarily address producibility of critical components, and extend sufficiently into the low rate initial production phase to ensure producibility analysis of the total end item. Simultaneously, it will assure the adequacy of the technical data package. This includes changes resulting from low rate initial production.

PEP should be treated as a separate task in a research, development test and evaluation project and should have complete visibility and traceability during the project. To ensure this visibility, the subject of producibility should be an agenda item at all program reviews and production readiness reviews.

7.8 Value Engineering (VE)

The DOD Value Engineering program reduces cost, increases quality, and improves mission capabilities. VE employs a simple yet flexible and structured set of tools, techniques and procedures to promote innovation and creativity. Furthermore, it incentivizes government participants and their industry partners to increase their joint value proposition in achieving best value solutions as part of a successful business relationship. VE can be defined as " *an organized effort directed at analyzing the functions of systems, equipment, facilities, services, and supplies for the purpose of achieving the essential functions at the lowest life-cycle cost consistent with required performance, reliability, quality, and safety* ."

7.8.1 DOD Policy

DOD policy has always been to encourage value engineering because it saves money, increasing emphasis in the 1980's led to Congressional interest in 1987 and the OMB Circular A-131 in January, 1988, Policy has shifted from DOD encouragement to OMB directed use of Value Engineering Program Requirements Clauses for contracts in initial production or research and development unless a waiver is justified. Agencies are now required to "actively elicit" Value Engineering Chance Proposals (VECP's) from contractors and are to emphasize VE to government and contractor personnel.

7.8.2 Types of Value Engineering

Within the defense environment there are two acronyms used for the recommendations resulting from VE efforts. They are:

1. Value Engineering Proposal (VEP). A VE recommendation originating and implemented solely within the Government, one which was originated by a contractor and may be implemented as a unilateral contractor action (i.e., a Class II change), or one which was originated by a contractor hired solely for the purpose of doing VE and implemented by the Government.

2. Value Engineering Change Proposal (VECP). A formal recommendation by a contractor requiring Government approval and which will require a change to the contract, specifications, purchase description, statement of work, etc., and result in a decrease in the overall cost to the Government. VECPS may be submitted by contractors having a VE clause included in their contract in accordance with the applicable acquisition regulation. Subcontractors may also submit VECPS to prime contractors in accordance with the terms of their contract. The current acquisition regulation directs contractors to include VE provisions in subcontracts (with certain limited exceptions) of $100,000 or more. Spares contracts and subcontracts of $25,000 or more must include a VE incentive clause.

7.8.3 Contracting for Value Engineering

The objective of VE in defense contracts is to reduce the cost of acquisition and/or ownership to the government, In addition VE is also used to enhance the effectiveness of the system. Special contract clauses can be utilized (FAR 48.2) to either allow or require contractors to initiate, develop and submit cost reduction proposals during the performance of the contract. Through the VE clause, the contractor is offered the opportunity to share the attained savings with the DOD.

<u>Value Engineering Incentive Clause</u> : The objective of this clause is to encourage contractors to develop and submit VECPs by providing for the sharing of any savings, although the contractor are not required to do VE. The clause merely describes the sharing that will take place should the contractor submit a VECP which the government accepts. Entirely permissive in intent, it allows the contractor to ignore this provision and still otherwise perform under his contract.

Value Engineering Program Requirement Clause : The objective of the VE program requirement clause is to reduce development, production, or use costs by requiring the contractor to establish a VE program. This clause should be used when a sustained VE effort at a predetermined level is desired. The VE program requirement is a separately priced line item in the contract and may apply to all or to selected phases of contract performance.

7.8.4 Value Engineering Savings

There are two basic types of savings that can be shared when a VECP is approved and implemented. They are acquisition and collateral savings.

Acquisition savings may include savings from the instant contract, concurrent contracts, and future contracts. The VECP is submitted under the instant contract. If the VECP is accepted and implemented on items delivered on the instant contract, the contractor receives a percentage of the net savings that accrue as a result of the VECP. In calculating these savings, contractor costs of developing and implementing the VECP and the Government's cost of implementation are all subtracted from the gross saving before sharing begins. Therefore, it is important that the contractor identify and record (for audit purposes) the costs incurred in developing and implementing the VECP. Development costs are expenses incurred after it has been determined that a VECP will be prepared and before the Government accepts the VECP. Implementation costs are expenses that will be incurred to implement the change after the VECP has been approved. All development and implementation costs must be offset before any sharing of acquisition savings may occur.

Collateral savings are measurable net reductions in costs of operation, maintenance, logistics and support alternatives, shipping costs, stock levels, or GFP when these savings are a result of an accepted VECP. In some cases, a VECP may increase the acquisition cost of an item but result in larger collateral savings. For collateral savings, the contractor is entitled to 20 percent of the net savings that the purchasing office estimates will be realized during an average 1-year period. However, the contractor's share cannot exceed $100,000 or the contract's firm-fixed-price, target price, target cost, or estimated cost at the time the VECP is accepted, whichever is greater. The amount of collateral savings is determined by the purchasing activity, and its determination is not subject to the "disputes" clause of the contract. Collateral savings provisions are included in contracts whenever an opportunity may exist for savings. They are intended to focus the contractor's attention on savings benefits other than acquisition savings. However, because the savings share is not intended as a partial replacement for a reduction in the contractor's current or future billings, the contractor's share of collateral savings, although substantial, is nonetheless smaller than its share of acquisition savings.

7.9 Summary

Producibility is an engineering function directed toward achieving a design which is compatible with the realities of the manufacturing capability of the defense industrial base. More specifically, producibility is a measure of the relative ease of producing a product at the desired rate and with acceptable yields, quality, reliability, cost and performance. Producibility is a coordinated effort by design engineering, manufacturing engineering, and other functional specialists to create a functional design that can be easily and economically manufactured. The product must be designed in such a manner that manufacturing methods and processes have flexibility in producing the product at the lowest cost without sacrificing function, performance, or quality.

7.10 Related Links and Resources

Numerous reference documents impact the manufacturing management function throughout the acquisition process. These documents originate from many sources and range across academic disciplines, functional activities, and job specialties.

The following is a reference list of DOD Directives (D), Instructions (I) Manuals (M), Pamphlets (P), Military Standards (MS), and other documents. The documents listed contain DOD policy guidance applicable to the manufacturing management function. They are listed as sources of DOD manufacturing management information.

Note: Many of the documents listed are no longer required (due to acquisition reform), but still contain some very valuable information.

Number	Title
	Air Force Aerospace Producibility Guide
AMCP 706-100	Engineering Design Handbook: Design Guidance for Producibility
VAVSO P-3687	Producibility System Guidelines (Navy)
	Missile Defense Agency Producibility Guide

Chapter 8 - Technology Development and Investments

8.1 Objective

This chapter describes the role and impact of technology development on the systems acquisition process in support of the warfighter, and how technology development and investments must be planned for and managed. It describes programs that have been developed that facilitate the development, maturation and transition of technologies and discusses how program offices need to create an infrastructure that will enable technology development and most importantly, the transition of technology to the warfighter.

8.2 Background

The Battle of the Atlantic was waged for six years (1939-1945), pitting German U-boats and other warships against the convoys and warships of the Allies. Grand Admiral Karl Donitz, Commander of the German U-Boats, predicted that Great Britain could be brought to its knees by the German blockade. Donitz's prediction almost became a reality and the cost to the Allies was tremendous. Over 3,500 merchant ships were along with 175 warships were destroyed. So what changed the battle in favor of the Allies?

One answer was the development of the radar. Britain realized early in the war that the future of radar development depended on the use of higher frequencies (advanced technology) and on the ability to develop and produce these advanced radar. But England was not in a position to allocate resources for these technological innovations or production and was forced to provide their advanced research to the United States in order to gain our productive capacity. The radars developed by the U.S. allowed the Allies to find and destroy U-boats that were previously almost invisible. The Germans had no answer for this new technology and over 780 U-boats were sunk leaving the Battle for the Atlantic an Allied victory.

8.3 Introduction

Superior technology has been, and continues to be, a cornerstone of the U.S. military's strategic posture. This was true during the Cold War, when technology provided superior conventional weapons for U.S. and allied forces. The same is true in today's Information Age which involves significant activity in the cyber domain. DOD Research and Engineering (R&E) programs are needed need to create, demonstrate, and partner in the transition to operational use of affordable technologies that can provide a decisive military superiority to defeat any adversary on any battlefield. Just as the past superior technologies have enabled an operational advantage for U.S. forces, continued technology development should enable future military superiority. The operational capability advantage enabled by technology used in previous conflicts did not occur instantaneously, but was the result of long-term, sustained, and balanced DOD research and development planning and management. Today, the wide availability of technology and the agility of our adversaries demand that the DOD R&E program be executed with urgency, agility, and creativity.

A 2005 GAO Report (GAO-05-480), *Defense Technology Development: Management Process Can Be Strengthened for New Technology Transition Programs* , noted that the DOD relies on its laboratories and test facilities as well as industry and academia to develop new technologies and systems that improve and enhance military operations and ensure technological superiority over adversaries. Yet, historically, DOD has experienced problems in bringing technologies out of the lab environment and into real use. At times, technologies do not leave the lab because their potential has not been adequately demonstrated, matured or recognized. In other cases, acquisition programs-which receive the bulk of DOD's funding in research, development, testing and evaluation of technology-are simply unwilling to fund final stages of the development of a promising technology that will enable the technology to transition into a weapon system, preferring to invest in other aspects of the program that are viewed as more vital to success. Other times, they choose to develop the technologies themselves, rather than rely on DOD labs to do so-a practice that brings cost and schedule risk since programs may well find themselves addressing problems related to technology immaturity that hamper other aspects of the acquisition process. And often, DOD's budgeting process, which requires investments to be targeted at least two years in advance of their activation, makes it difficult for DOD to seize opportunities to introduce technological advances into acquisition programs. In addition, it is challenging just to identify and pursue technologies that could be used to enhance military operations given the very wide range of organizations inside and outside of DOD that are focused on technology development and the wide range of capabilities that DOD is interested in advancing.

8.3.1 Defining Technology Development and Technology Transition

Research and Development (R&D) is the discovery of new knowledge about products and processes and then applying that knowledge in the development of new and/or improved products and processes to fill a market need or in the case of the DOD, to meet a warfighter need. While there is no official definition of *technology development* , it can be thought of as a continuous process of discovery and advancement of knowledge that involves a close collaboration between the S&T community, the acquisition community (system developers), and the users.

Technology transition takes the technology that has been developed and applies or transitions it to military systems to create effective weapons and support systems - in the quantity and quality needed by the warfighter to carry out assigned missions at the " *best value* " as measured by the warfighter. *Best value* refers to increased performance as well as reduced cost for developing, producing, acquiring, and operating systems throughout their life cycles.

Performance, timeliness and affordability are all important, even critical. Our warfighters must maintain a technological advantage over their adversaries. This requires compressed development and acquisition cycles for rapidly advancing technologies. In addition to compressing development and acquisition times, PMs must at the same time compress the weapon system cost, acquisition costs and support costs.

One of the major objectives of Technology Transition is to meet the warfighter's requirements at the lowest possible Total Ownership Cost (TOC) in addition to compressing the schedule and improving performance. To this end, the goals of technology transition are to use available resources to:

- Leverage the best technology available from both government and commercial sources;
- Rapidly transition the technology into new weapons and other military systems;
- Refresh the technology, as needed, to maintain the advantages that our warfighters need throughout the life of a system; and
- Protect sensitive leading-edge research and technology against unauthorized or inadvertent loss or disclosure.

Technology transitions can occur during the development of systems, or even after a system has been in the field for a number of years. The ability to transition technology smoothly and efficiently is a critical enabler for evolutionary acquisition. In addition, technology transitions can occur between government organizations, such as when a government laboratory transitions a technology to a government Research and Development (R&D) organization for use in a specific system. Or industry and academia can transition technology to government for further development or transition into a weapon system, and vice versa.

8.3.2 RDT&E budget activities

RDT&E is one of the five major appropriations used by the Department of Defense. RDT&E appropriations finance research, development, test and evaluation efforts performed by contractors and government installations to develop equipment, material, or computer application software; its Development Test and Evaluation (DT&E); and its Initial Operational Test and Evaluation (IOT&E). These efforts may include purchases of end items, weapons, equipment, components, and materials as well as performance of services whatever is necessary to develop and test the system. RDT&E funds are used for both investment-type costs (e.g., sophisticated laboratory test equipment) and expense-type costs (*e.g.* , salaries of employees at R&D-dedicated facilities). There is an RDT&E appropriation for each service as well as one to cover other Defense agencies. RDT&E funds are budgeted using the incremental funding policy and are normally available for obligations for two years. The RDT&E budget activities are broad categories reflecting different types of RDT&E efforts. Each RDT&E appropriation is subdivided into seven budget activities (BAs). The definitions for each BA is provided below.

8.3.2.1 Budget Activity 1, Basic Research

Basic research is systematic study directed toward greater knowledge or understanding of the fundamental aspects of phenomena and of observable facts without specific applications towards a processes or products. Basic research is farsighted high payoff research that may lead to: a.) subsequent applied research and advanced technology developments in Defense-related technologies, and b.) new and improved military functional capabilities in areas such as communications, detection, tracking, surveillance, propulsion, guidance and control, navigation, materials, and structures.

8.3.2.2 Budget Activity 2, Applied Research

Applied research is systematic application of knowledge to develop useful materials, devices, and systems or methods. Applied research translates promising basic research into solutions for broadly defined military needs, short of system development. It may include design, development, and improvement of prototypes and new processes to meet general mission area requirements. The dominant characteristic is that applied research is directed toward general military needs with a view toward developing and evaluating the feasibility and practicality of proposed solutions and determining their parameters.

8.3.2.3 Budget Activity 3, Advanced Technology Development (ATD)

This budget activity includes development of subsystems, components, and models and the efforts to integrate these into system prototypes for field experiments and/or tests in a simulated environment. The subsystems, components, and models may be form, fit and function prototypes or scaled models that serve the same demonstration purpose. The results of this type of effort are proof of technological feasibility and assessment of subsystem and component operability and producibility rather than the development of hardware for service use. ATD demonstrates the general military utility or cost reduction potential of technology when applied to different types of military equipment or techniques.

8.3.2.4 Budget Activity 4, Advanced Component Development and Prototypes (ACD&P)

This budget activity includes efforts necessary to evaluate integrated technologies, representative models or prototype systems in a high fidelity and realistic operating environment. The ACD&P budgets includes system specific efforts that help expedite technology transition from the laboratory to operational use. Emphasis is on proving component and subsystem maturity prior to integration in major and complex systems and may involve risk reduction initiatives.

8.3.2.5 Budget Activity 5, System Development and Demonstration (SDD)

This budget activity includes programs that have passed Milestone B approval and are conducting engineering and manufacturing development tasks aimed at meeting validated requirements prior to full-rate production. This budget activity is characterized by major line item projects and program control is exercised by review of individual programs and projects. Prototype performance is near or at planned operational system levels.

8.3.2.6 Budget Activity 6, RDT&E Management Support

This budget activity includes research, development, test and evaluation efforts and funds to sustain and/or modernize the installations or operations required for general research, development, test and evaluation. Test ranges, military construction, maintenance support of laboratories, operation and maintenance of test aircraft and ships, and studies and analyses in support of the RDT&E program are funded in this budget activity.

8.3.2.7 Budget Activity 7, Operational System Development

This budget activity includes development efforts to upgrade systems that have been fielded or have received approval for full rate production and anticipate production funding in the current or subsequent fiscal year. All items are major line item projects that appear as RDT&E Costs of Weapon System Elements in other programs.

8.4 Technology Development in OSD

There is no single priority, principle, capability, or technology that constitutes a successful DOD research and engineering (R&E) program. OSD and the services each have identified but a number of priorities and a portfolio of technologies that support the National Security Strategy and the Quadrennial Defense Review (QDR). These R&E strategic plan identifies these higher-valued principles, capabilities, and technologies that are used to guide the investment and management of the DOD and service R&E programs. The result is a proactive R&E program that:

- Generates new scientists and engineers for the national security program;
- Develops new and enhanced operational capability options for our warfighters and strategic decision makers;
- Transitions technologies to acquisition programs and the warfighters;
- Reduces risk for acquisition programs;
- Enhances the affordability of DOD systems and capabilities;
- Enhances sustainment and upgrade of existing weapon systems;
- Forges partnerships with other government agencies, industry, academia, and international allies;
- Shares information across multiple components through proactive collaboration;
- Minimizes the probability of technology surprise against U.S. capability advantage;
- Values technical competency and integrity; and
- Provides maximum value for the taxpayer.

Unfortunately, much of what technology developers produce ends up in the proverbial " *Valley of Death* ." The *Valley of Death* is a 2-5 year funding gap between the time a capability gets developed and the time that capability gets funded as part of an acquisition program. It is often the result of the lack of a coordinated plan between S&T and acquisition managers and the lack of funding for transition by acquisition managers.

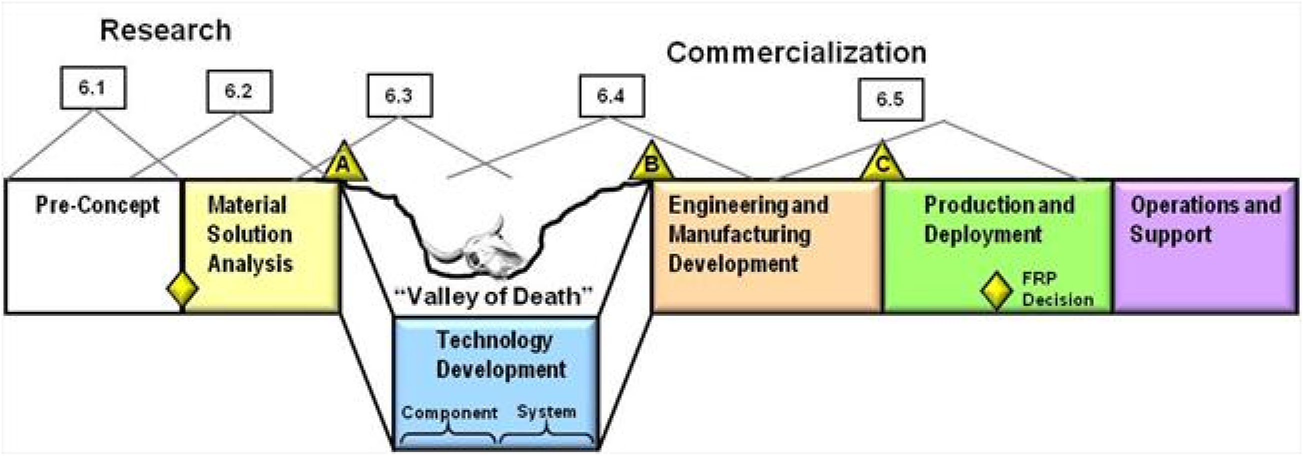

Figure 8-1 Valley of Death

Technology Transition Best Practices includes the following:

- Strong strategic planning to prioritize technology needs and a structured technology development process as a precursor to transition.
- Merge technology development and product development activities prior to product launch.
- Use the following tools to support technology transition activities:
    - Relationship managers,
    - Technology Transition Agreements, and
    - Metrics.

8.4.1 Organizing for Technology Development

Organizing for successful technology development requires innovative players who understand their roles and responsibilities in the process. The following Government and industry players play important roles and should have high levels of interaction in the technology development and transition process:

- Requirements community,
- S&T community,
- R&D community,
- Acquisition community,
- Financial community,
- T&E community,
- Manufacturing/QA community,
- Software community,
- Sustainment community,
- Security community,
- Industry, and
- Academic community.

8.4.2 Technology Strategy and Roadmaps

Sun Tzu, in the Art of War, noted that " *The general who wins a battle makes many calculations in his temple before the battle is fought. The general who loses a battle makes but few calculations beforehand. Thus do many calculations lead to victory, and few calculations to defeat; how much more no calculation at all! It is by attention to this point that I can foresee who is likely to win or lose* ." Strategic Planning is a key factor in any technology development and transition program. Strategic Plans or Technology Roadmaps provide for investment and management priorities for R&D programs.

The Department's S&T Components each play an important role in the development of a comprehensive DOD R&D Program. The Services provide the stable long-term part of the program, focused on their services' needs and responsibilities. The Service S&T communities constantly look for opportunities to achieve revolutionary breakthroughs while maintaining a range of core competencies and supporting the acquisition and logistics systems that produce and maintain military equipment. Each Service has a vision of future capabilities required to support the core competencies they are uniquely responsible for maintaining. The Defense Advanced Research Projects Agency (DARPA) focuses its S&T program on high-risk, high-payoff technology development efforts. The Defense Threat Reduction Agency (DTRA) focuses its R&E investment on protecting the nation and our armed forces from present and future WMDs, while the Missile Defense Agency (MDA) develops technology to protect the nation and our armed forces from present and future missile threats. These strategic plans or roadmaps provide a basis for the development of R&D budgets and the allocation of investment dollars once the funding has been authorized and appropriated by Congress.

8.4.3 Technology Investment Areas

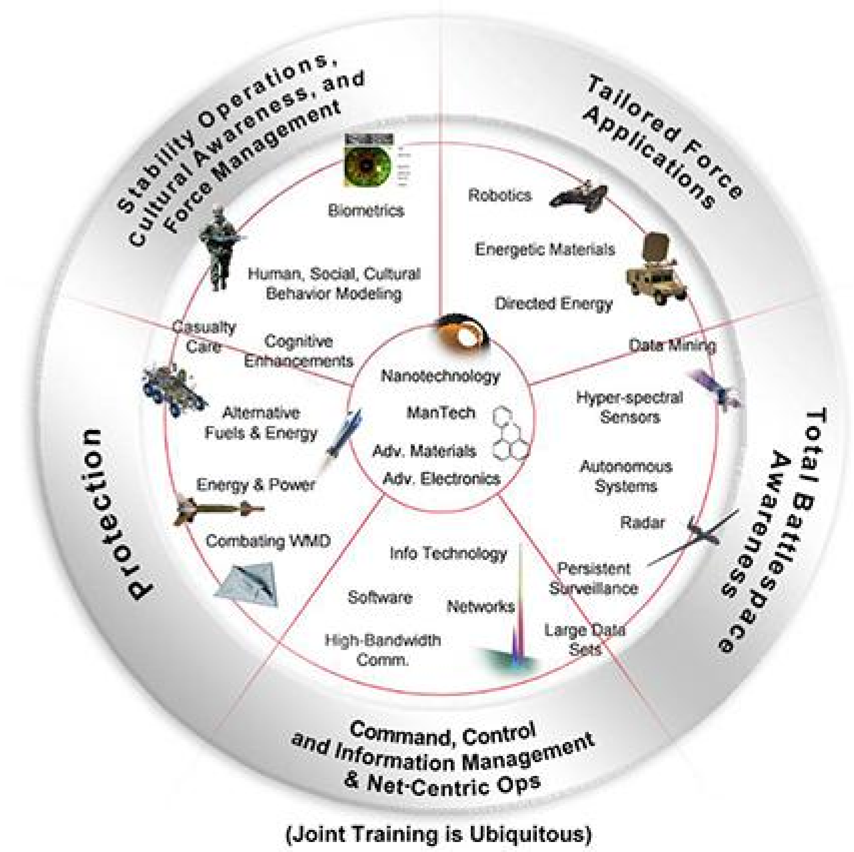

Figure 8-2 S&T Technology Investment Areas

DOD's R&E program typically focuses on delivering the capabilities outlined in the Quadrennial Defense Review (QDR) and other high-level guidance to the warfighters. Each of these capability sets are supported by a large number of enabling technologies that provide S&T focus areas (Figure 8-2). Taken as a whole these capabilities and enabling technologies drive the S&T priorities needed to achieve the desired strategic outcomes. S&T priorities represent the most important S&T investment areas, and are organized into three broad categories depending upon technology maturity:

1. Desired Capabilities to Support Strategic Outcomes,
2. Enabling Technologies, and
3. Basic Research.

These investment areas focus on developing and delivering capabilities (demonstrations and prototypes) that support achievement of the desired strategic outcomes. The capabilities can be aggregated into a few high-level mission areas that include:

- Total Battlespace Awareness;

- Stability Operations, Cultural Awareness, and Force Management;
- Command, Control and Information Management; and
- Net-Centric Operations; Protection; Joint Training; and Tailored Force Application.

Enabling Technology Investment Areas : These investments focus on developing and maturing broad technology areas, leading to mature technologies that are ready to be integrated into demonstrations. Enabling technologies support multiple types of systems and platforms, all capable of providing the above listed capabilities. Technology enablers also capture the S&T response to non-traditional and disruptive technology threats and serve to preclude technology surprise. The specific enabling technologies are:

- Biometrics & Bio-inspired Technologies;
- Nanotechnology;
- Information Technologies;
- Persistent Surveillance Technologies;
- Networks & Communications;
- Software Research;
- Organization, Fusion, & Mining Data;
- Human, Social, Cultural, & Behavioral Modeling;
- Cognitive Enhancements;
- Casualty Care & Human Performance Optimization;
- Advanced Materials;
- Advanced Electronics;
- Energy & Power Technologies;
- Alternative Fuels & Energy Sources;
- Energetic Materials, Rocket Propellants, and Explosives;
- Directed Energy Technologies;
- Hyperspectral Sensors;
- Radar;
- Autonomous Systems Technologies;
- Robotics;
- Manufacturing Technologies;
    - Affordability & Producibility,
    - Agile Fabrication,
- Combating Weapons of Mass Destruction Technologies; and
- Large Data Set Analysis Tools.

8.4.4 Maturity Measures

The U.S. military's dominant operational capabilities were largely due to the continued development and delivery of superior technology. The goal of R&D is to create, demonstrate, prototype, and deliver capabilities that enables affordable and decisive military superiority to defeat any adversary on any battlefield. Pursuing the R&D requires attention to identification and development of new technological opportunities, insertion of those technologies into warfighting systems and operations, and management and evaluation of the effectiveness of technology programs.

Technology maturity is a major concern and component of the development and delivery of capabilities. At program initiation, technology maturity is a measure of acquisition program risk and a predictor of program success. Technology Readiness Levels (TRLs) provide a "yardsticks" for evaluating technological maturity. However, TRLs alone do not give a complete picture of the state of a technology, or of the risks in adopting a particular technology to the needs of a given acquisition program. Manufacturing Readiness Levels (MRLs) and Sustainment Maturity Levels (SMLs) are additional maturity models that can be used to assess risk and assist in the development and delivery of affordable capabilities.

8.4.4.1 Technology Readiness Levels

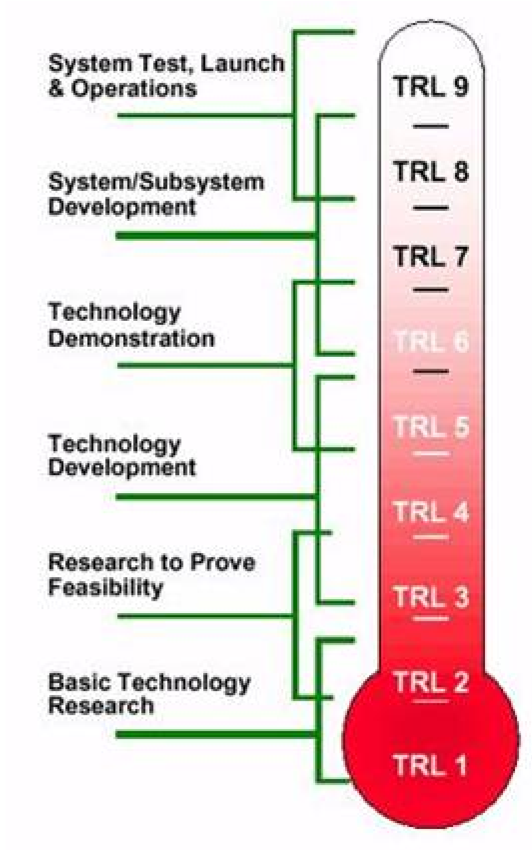

Figure 8-3 Technology Readiness Levels

Technology Readiness Levels (TRLs) provide a systematic metric/measurement system to assess the maturity of a particular technology. TRLs enable a consistent comparison of maturity between different types of technology. The TRL approach has been used for many years in the National Aeronautics and Space Administration (NASA) and is the technology maturity measurement approach for all new DOD programs. TRLs have been primarily used as a tool to assist in tracking technologies in development and their transition into production. The nine hardware TRLs (Figure 8-3) are defined as follows:

- TRL 1: Basic principles observed and reported.
- TRL 2: Technology concept or application formulated.

- TRL 3: Experimental and analytical critical function and characteristic proof of concept.
- TRL 4: Component or breadboard validation in a laboratory environment.
- TRL 5: Component or breadboard validation in a relevant environment.
- TRL 6: System or subsystem model or prototype demonstrated in a relevant environment.
- TRL 7: System prototype demonstration in an operational environment.
- TRL 8: Actual system completed and "flight qualified" through test and demonstration.
- TRL 9: Actual system "flight proven" through successful mission operations.

TRLs provide a common language and widely-understood standard for:

- Assessing the performance maturity of a technology and plans for its future maturation; and
- Understanding the level of performance risk in trying to transition the technology into a weapon system application.

8.4.4.2 Manufacturing Readiness Levels

Manufacturing Readiness Levels (MRLs) were designed to be measures used to assess the maturity of a given technology, component or system from a manufacturing prospective. The purpose of MRLs is to provide decision makers (at all levels) with a common understanding of the relative maturity (and attendant risks) associated with manufacturing technologies, products, and processes being considered. Manufacturing risk identification and management must begin at the earliest stages of technology development, and continue vigorously throughout each stage of a program's life-cycles.

MRL	Definition
1	Basic manufacturing implications identified
2	Manufacturing concepts identified
3	Manufacturing proof of concept developed
4	Capability to produce technology in a laboratory environment
5	Capability to produce prototype components in a production relevant environment
6	Capability to produce prototype system or subsystem in a production relevant environment
7	Capability to produce systems, subsystems, or components in a production representative environment
8	Pilot line capability demonstrated and ready to begin Low Rate Production
9	Low Rate Production demonstrated and capability in place to begin Full Rate Production
10	Full Rate Production demonstrated and lean production practices in place

Table 8-1 MRL Definitions

Manufacturing readiness and technology readiness go hand-in-hand. MRLs, in conjunction with TRLs, are key measures that can be use do identify and define risk when a technology or process is being matured and/or transitioned to a system.

It is quite common for manufacturing readiness to be paced by technology readiness or design stability. Manufacturing processes will not be able to mature until the product technology and product design are stable. MRLs can also be used to define manufacturing readiness and risk at the system or subsystem level. For those reasons, the MRL definitions were designed to include a nominal level of technology readiness as a prerequisite for each level of manufacturing readiness.

MRLs were developed by a joint Government/Industry working group under the auspices of the Joint Defense Manufacturing Technology Panel (JDMTP).

8.4.4.3 Sustainment Maturity Levels (SMLs)

The Sustainment Maturity Level (SML) concept was established to help the Product Support Manager (PSM) identify the appropriate level of maturity the support plan should achieve at each milestone and the extent to which a program's product support implementation efforts are likely to result in the timely delivery of a level of capability to the Warfighter. Achieving the appropriate maturity levels will help the PSM evolve the program's product support approach to achieve the best value support solution. The SMLs provide a uniform metric to measure and communicate the expected life cycle sustainment maturity as well as provide the basis for root cause analysis when risks are identified and support OSD's governance responsibilities during MDAP program reviews. Focus is on assessing the sustainment strategy development and implementation status towards achieving Full Operational Capability and, where applicable, determining the risk associated with achieving the sustainment KPP.

SMLs were crafted to address the full range of support options, from traditional organic based to full commercial based product support. They provide a standard way of documenting the product support implementation status that can be traced back to life cycle product support policy and guidance without prescribing a specific solution. SMLs provide the PSM a disciplined structure and rigor for assessing program performance based product support implementation status and is compatible with the design evolution of the system being supported.

Level	Sustainment Maturity Level (SML) Overview
1	Supportability and sustainment options identified.
2	Notional product support and maintenance concept identified
3	Notional product support, sustainment, and supportability requirements defined and the documented to support the notional concept. (Occurs in the AoA)
4	Supportability objectives and KPP/KSA requirements defined. New or better technology required for system or supply chain identified. (Occurs at ASR).
5	Supportability design features required to achieve KPP/KSA incorporated in Design Requirements. (Occurs at SRR)
6	Maintenance concepts and sustainment strategy complete. Life Cycle Sustainment Plan

	approved. (Occurs at PDR)
7	Supportability features embedded in design. Supportability and Subsystem Maintenance Task Analysis complete. (Occurs at CDR)
8	Product Support capabilities demonstrated and supply chain management approach validated.
9	Product Support Package demonstrated in operational environment. (Occurs at IOT&E)
10	Initial Product Support Package fielded at operational sites. Performance measured against availability, reliability and cost metrics. (Occurs at IOC)
11	Sustainment performance measured against operational needs. Product support improved through continual process improvement.
12	Product Support Package fully in place including depot repair capability. (Occurs at FOC)

Table 8-2 Sustainment Maturity Levels (SMLs)

8.5 Programs That Facilitate Manufacturing/Technology Readiness

Recent studies and reports on the acquisition process have stated that ensuring sufficient technology maturity levels, supported by adequate test and evaluation and manufacturing assessments, is an excellent way to avoid cost overruns in acquisition programs. In conjunction with DDR&E representatives, Component S&T Executives are responsible for ensuring that the technologies are mature. In addition, the R&E community, working with all representatives of the defense enterprise, must ensure that necessary S&T investments are made to deliver the appropriate product at the appropriate maturity level at each development phase, allowing successful progression through milestones. One of the primary tools available for reducing risk in acquisition programs is the effective use of prototyping using one of several technology programs. Enhanced prototyping benefits the DOD by serving as a tool to recruit capable scientists and engineers, to develop system engineering and program management skills, to successfully transition technology, and to advance the development of concepts of operation.

Transitioning technology so that it facilitates both technology readiness and manufacturing readiness does not come naturally and can be very difficult to accomplish. To transition technology and mature manufacturing processes successfully requires positive actions by people interacting throughout the system. A marketplace for the technology and manufacturing processes and appropriate applications for those technologies and processes is a necessary ingredient to draw interest in investing in technology and manufacturing transition programs. Figure 8-4 identifies several programs that are designed to assist the community with developing new technologies and maturing the manufacturing processes (these programs are shown identifying their relative position in the acquisition framework). In some cases, the programs offer another source of funds that could be used to support technology and manufacturing readiness.

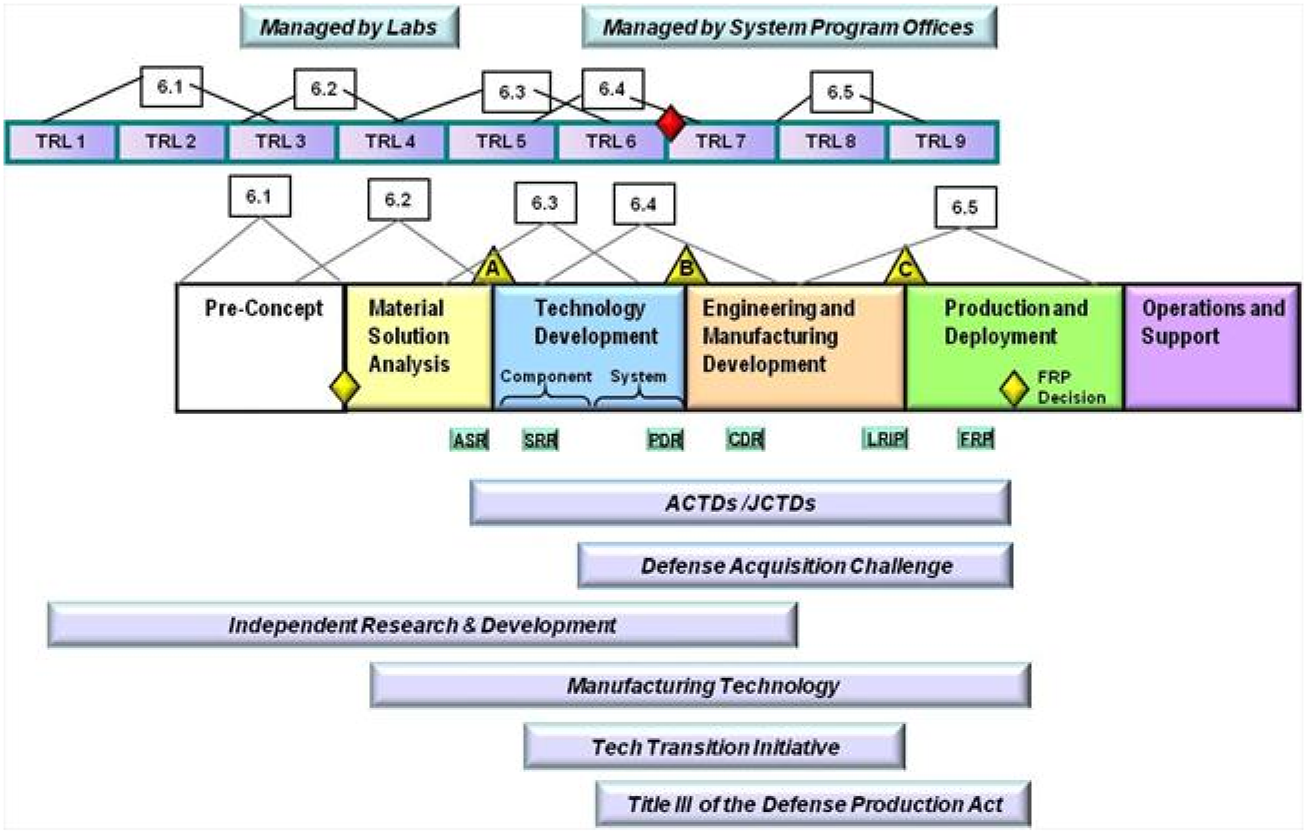

Figure 8-4 Technology Programs

These following programs will be discussed in greater detail:

- Advanced Technology Demonstrations (ATDs);
- Advanced Concept Technology Demonstration Program (ACTDs);
- Defense Acquisition Challenge Program (DACP);
- Defense Production Act Title III Program (Title III);
- Dual-Use Science and Technology Program (DUST);
- Joint Experimentation Program (JE);
- Manufacturing Technology Program (ManTech);
- Quick Reaction Special Projects ;
- Small Business Innovation Research Program (SBIR);
- Small Business Technology Transfer Program (STTR);
- Technology Transition Initiative (TTI);
- Industrial Modernization Incentive Program (IMIP)/Industrial Base Innovation Fund (IBIF);
- Rapid Technology Transition Program (RTT);
- Warfighter Rapid Acquisition Programs (WRAP);
- Commercial Operations and Support Savings Initiative (COSSI); and
- North American Technology and Industrial Base Organization (NATIBO).

8.5.1 Advanced Technology Demonstration (ATD)

Advanced Technology Demonstration (ATD) is a process for managing selected high-priority S&T programs. ATDs are reviewed and approved by the services, and funded with service S&T funds. ATDs are intended to evolve and demonstrate new technologies. Technology development benefits when the communities work as a team, beginning early in the process. This could include the S&T, Acquisition and Operations communities. ATDs are a process for managing S&T programs that brings the team together early, and demonstrates a military capability in either:

- Joint warfighting experiment,
- Battle lab experiment,
- Demonstration, and
- Field test, or simulation.

ATDs are used to accelerate the maturation of technology needed by warfighters for either next-generation systems or upgrades to existing legacy systems. ATDs use the IPPD process to ensure collaboration between the communities - S&T, requirements/warfighter, R&D, Test and Evaluation (T&E), sustainment, and industry resulting in early interaction and exchange between the communities, permit experimenting with technology-driven operational issues, weed out unattainable technologies as early as possible, and result in more focused requirements and capability documents.

ATDs require planning, review, and approval at the service or agency level. ATDs have a finite program duration, agreed-upon exit criteria, and typically require transition plans. Accordingly, ATDs require technologies and manufacturing processes that are mature enough to provide a capability that can be used or demonstrated during the demonstration period. Services and agencies must provide full funding for ATDs because no source of external funding exists for this process. Most ATDs are funded with 6.3 funds, respond to high-priority user needs, and have a funded target program. ATDs also are reviewed to ensure that they do not duplicate other programs.

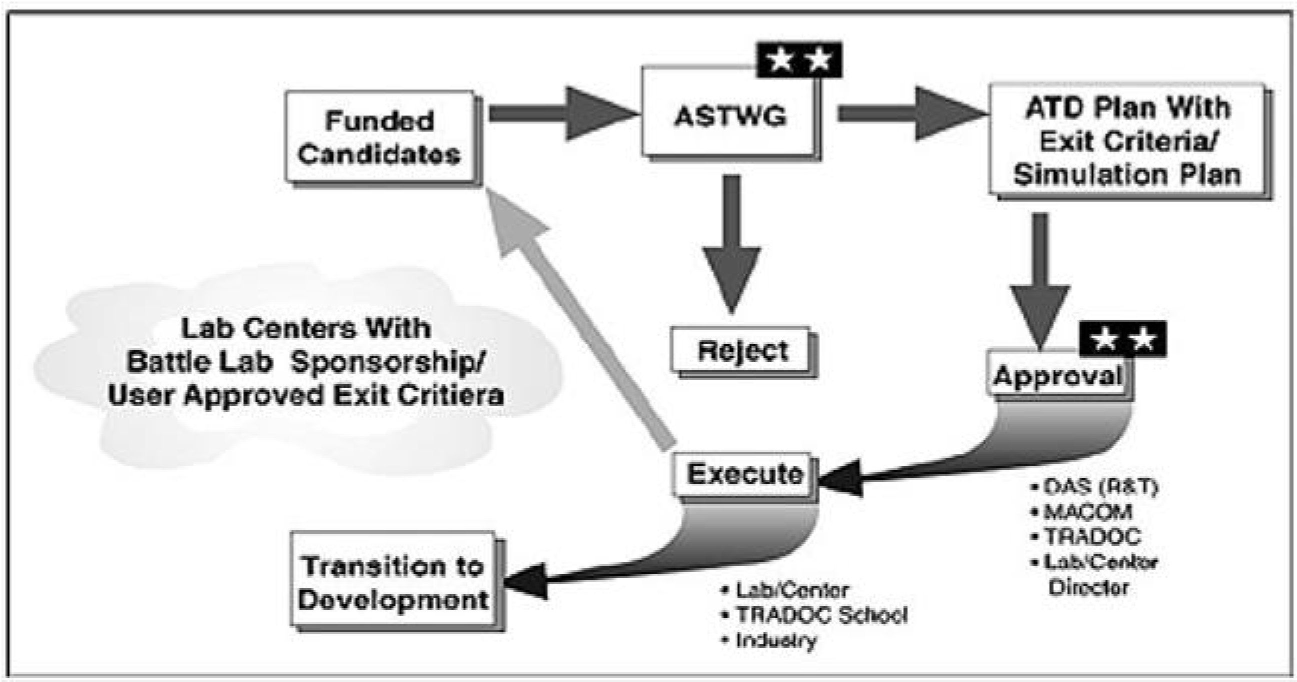

Figure 8-5 ATD Process

The ATD team evaluates technical feasibility, affordability, and compliance with operational and technical architectures, operation and support issues, and user needs as early as possible. This fully integrated approach and focus on operationally-sound capabilities ensures that militarily significant capabilities can be developed, evaluated, and transitioned to the warfighter rapidly.

Services and agencies have processes for nominating and approving ATDs (Army process in Figure 8-5) and have plans for managing ATDs. In general, the senior research and technology manager in the organization manages ATDs. Typical requirements for participating in the program are the following:

- A concept that addresses established S&T objectives, and could provide a significant new or enhanced military capability or more cost-effective approach to providing the capability.
- A fully planned and funded program which has a limited duration (usually less than five years, with shorter durations being better).
- Exit criteria and a transition plan that is supported by the user representative and the systems developer.

8.5.2 Advanced Concept Technology Demonstration (ACTD)

A program designed to help expedite the transition of mature or nearly mature technologies from the developers to the users. The ACTD program was developed to help adapt the DOD acquisition process to today's economic and threat environments. ACTDs emphasize assessing, maturing, and integrating technology rather than developing it. The goal is to give the warfighter a prototype capability and to support the warfighter in evaluating the capability. These capabilities must be affordable, interoperable, sustainable, and capable of being evolved as the technologies and threats change. The evolutionary acquisition approach is an integral part of the ACTD concept. The warfighters evaluate the capabilities in real military exercises and at a scale sufficient to fully assess military usefulness.

ACTDs are designed to enable users to understand the proposed new capabilities for which there is no user experience by giving the warfighter opportunities to:

- Develop and refine the warfighter's concept of operations to fully exploit the capability of the technology being evaluated.
- Evolve the warfighter's operational requirements as the warfighter gains experience and understanding of the capability.
- Operate militarily useful quantities of prototype systems in realistic military demonstrations and, on that basis, assess the military usefulness of the proposed capability.

There are three possible outcomes. (1) the user sponsor may recommend acquiring the technology and fielding the residual capability that remains after the demonstration phase of the ACTD to provide an interim and limited operational capability; (2) the project is terminated or returned to the technology base if the capability or system does not demonstrate military usefulness; (3) the user's need is fully satisfied by fielding the capability that remains when the ACTD is concluded, and no additional units need to be acquired.

There are several major differences between ACTDs and ATDs. ACTDs are programs, usually employing multiple technologies, which are reviewed by Office of the Secretary of Defense (OSD) and the Joint Requirements Oversight Council (JROC), and funded (in part) with OSD ACTD funds. An ATD is actually a process for managing selected high-priority S&T programs. ATDs are reviewed and approved by the services, and funded with service S&T funds.

ACTDs should work with relatively mature technologies to improve the probability of success and the likelihood of transitioning the technology into programs. A recent GAO report addresses this and other factors affecting ACTDs' success. This GAO report concludes that the OSD can improve ACTD outcomes, while noting that the majority of the ACTDs examined did transition some technologies to the user. The GAO found that:

- Some technology was too immature to be effectively demonstrated in the hands of the warfighter, leading to cancellations of demonstrations.
- Services did not provide follow-on funding for some successful ACTD technologies.
- Military utility assessments required in ACTDs have not been conducted consistently.

ACTDs should consider manufacturing and sustainment issues as a part of their program. Historically, manufacturing and sustainment issues have not received a high priority in ACTDs. The long-term success of ACTD initiatives can be improved by considering all of the manufacturing, sustainment, and operational and support issues.

The Deputy Under Secretary of Defense for Advanced Systems and Concepts is responsible for selecting and approving ACTDs. Ideally, a user-developer team, having combined a critical operational need with maturing technology, will develop an ACTD candidate for consideration. The Advanced Systems and Concepts (AS&C) staff is available to assist the team with developing and refining the concept and clarifying the ACTD's basic criteria and attributes. When the details of the concept are defined, a briefing is presented to the DUSD (AS&C). If accepted, a briefing is presented to an advisory group of senior acquisition and operational executives, for their review and assessment. The candidate ACTDs then are presented to the Joint Staff, through the Joint Warfare Capabilities Assessment and the Joint Requirements Oversight Council, for their review and recommended priority.

8.5.3 Defense Acquisition Challenge Program

The Defense Acquisition Challenge (DAC) Program is authorized by Title 10, United States Code, Section 2359b and the 2003 Defense Authorization Act, DACP is administered by the Deputy Under Secretary of Defense (Advanced Systems & Concepts) and provides opportunities for both innovators and the Department of Defense (DOD). For innovators, it means faster entry to the defense acquisition system. For the DOD Program Manager (PM), it means increased technology insertions to improve systems.

Technological developments and operational needs are emerging faster than ever before. Yet the defense programming and budgeting process cannot always keep up. On the supply side, many of America's companies generating technological innovations have found it difficult to break into the defense market, especially those classified as small and medium-sized U.S. businesses. In an effort to remedy the technology-to-programming lag and overcome the "valley of death," the Defense Acquisition Challenge Program, authorized by Title 10, USC, Sec 2359b and the 2003 Defense Authorization Act, provides opportunities for the increased introduction of innovative and cost-saving commercial technologies or products into existing DOD acquisition programs. Furthermore, the DACP is especially designed to give small and medium-sized companies the opportunity to introduce new technologies and inject innovation into current DOD Programs. To do so, the DACP provides any person or activity within or outside the DOD the opportunity to propose alternatives, known as Challenge Proposals, to existing DOD programs that could result in improvements in performance, affordability, manufacturability, or operational capability of the systems acquired by that program. As a result of selecting, testing, and inserting the best of these production-ready technologies, the DACP ultimately expands the opportunities for emerging defense suppliers, widens the U.S. defense industrial base, and leverages unique innovations for the benefit of the warfighter.

The Defense Acquisition Challenge Program legislated process is outlined below in Figure 8-6.

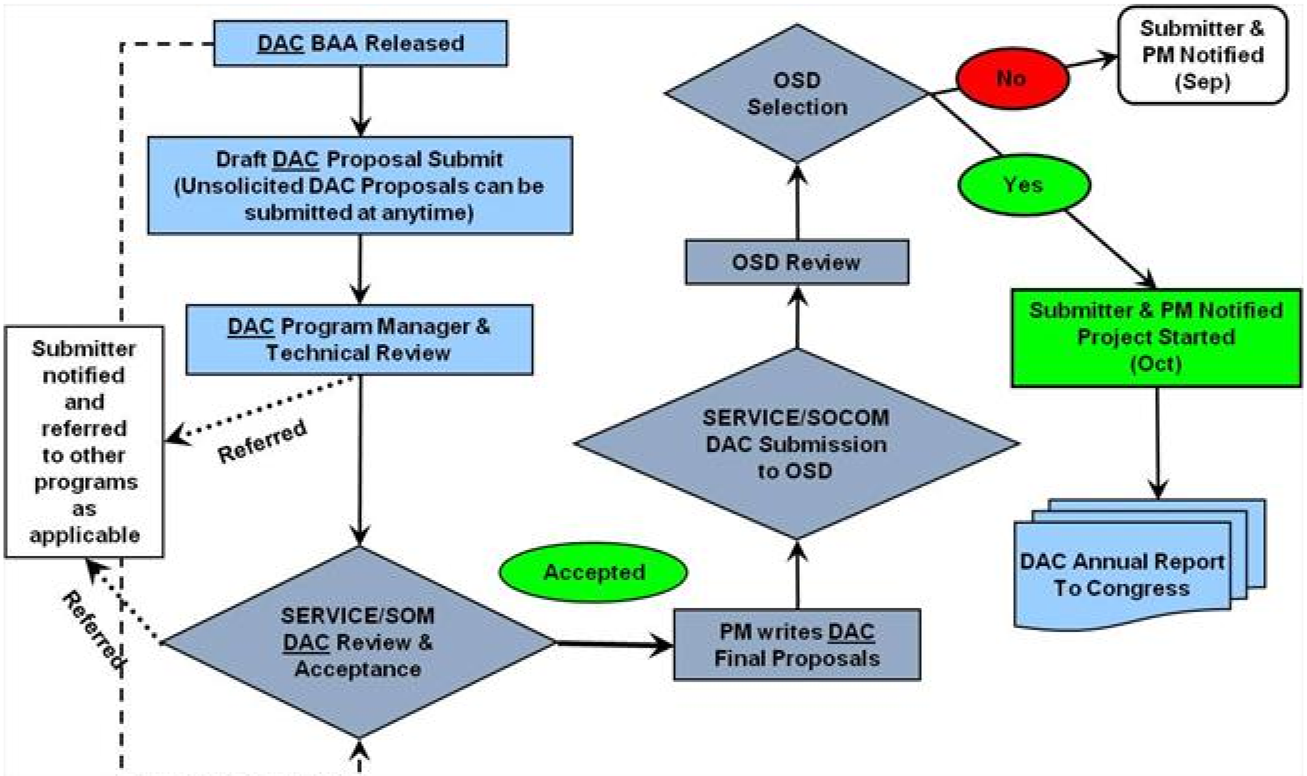

Figure 8-6 Defense Acquisition Challenge Program Legislated Process

The Defense Acquisition Challenge Program's objectives are to improve the U.S. warfighter's capabilities and reduce expenditures through:

- Rapidly fielding quality military equipment;
- Eliminating unnecessary duplication of research, development, test, and evaluation;
- Reducing life cycle or procurement costs;
- Enhancing standardization and interoperability;
- Promoting competition by qualifying alternative sources; and
- Improving the U.S. military industrial base.

8.5.4 Defense Production Act Title III Program

The mission of the Defense Production Act Title III Program (Title III) is to create assured, affordable, and commercially viable production capabilities and capacities for items that are essential to the national defense. By stimulating private investment in key production resources, Title III helps to:

- Increase the supply, improve the quality, and reduce the cost of advanced materials and technologies needed for the national defense.
- Reduce U.S. dependence on foreign sources of supply for critical materials and technologies.

- Strengthen the economic and technological competitiveness of the U.S. defense industrial base.

Title III activities lower defense acquisition and life-cycle costs and increase defense system readiness and performance by using higher quality, lower cost, and technologically superior materials and technologies.

Title III authority can be used to address the following:

- Technological obsolescence, i.e., when a newer technology replaces an older one and the capability to produce the older technology falls into disuse and is gradually lost. By using Title III authority, flexible manufacturing capabilities can be created to produce aging technologies efficiently and affordably. Alternatively, the authority can be used to consolidate and maintain production capabilities that otherwise would be lost because of changing market conditions, even though such capabilities are still needed for defense and still can be operated efficiently and profitably.
- Low or irregular demand (i.e., when the demand for an item is inadequate to support continuous production), so the delivery of the item is delayed because of the time needed to obtain materials for producing the item or for the time needed by the production queuing. Title III purchase commitments can be made to consolidate and level demand for key production capabilities, which gives suppliers incentives to maintaining and upgrade these capabilities, and to respond to defense acquisition needs in time. Purchase commitments can also be used to reserve production time to ensure timely access to production resources for fabricating critical defense items.
- Producers exiting the business, *i.e.* , when companies go out of business or drop product lines that no longer fit their business plans. Title III authority can be used to support transferring production capabilities to new sources.

Virtually all Title III projects promote integrating commercial and military production to lower defense costs and enable earlier defense access to, and use of, emerging technologies. The production for both military and civilian markets represents a new thrust for the Title III program, and is referred to as "dual produce." A governmentindustry working group identifies dual-produce projects, develops a list of general project areas, and publishes a Broad Area Announcement (BAA) based on the list to solicit proposals from industry and DOD organizations. Projects are selected according to potential cost savings - both direct savings from the projects themselves and indirect savings from the broader application of demonstrated capabilities to other defense items.

The Title III program is a DOD -wide initiative under the Director, Defense Research and Engineering (DDR&E). Management responsibilities include program oversight and guidance, strategic planning and legislative proposals, approval of new projects, and liaison with other federal agencies and Congress.

The Air Force is the executive agent for the program in DOD. The Title III program office, at Wright-Patterson Air Force Base, Ohio, is a component of the Manufacturing Technology Division of the Air Force Research Lab. The program office identifies and evaluates prospective

Title III projects, submits projects for DDR&E's approval, structures approved projects, implements contracting and other business actions for the projects, oversees active projects, provides for selling and using materials acquired through Title III contracts, and does the planning and programming support for DDR&E.

8.5.5 Dual-Use Science and Technology Program (DUST)

A *dual-use technology* is one that has both military utility and sufficient commercial potential to support a viable industrial base. Funding for this program has shifted from OSD to the services. The government's objectives of the Dual-Use Science and Technology (DUST) program are the following:

- Partnering with industry to jointly fund the development of dual-use technologies needed to maintain DOD's technological superiority on the battle-field and industry's competitiveness in the marketplace.
- Making the dual-use development of technologies with industry a normal way of doing business in the services.

These objectives are met by using streamlined contracting procedures and cost sharing between OSD, the services, and industry.

The industry objective for the program is to achieve the following benefits:

- Leverage scarce S&T funding.
- Be a vehicle for forming beneficial partnerships with other firms, defense labs, or universities.
- Gain access to advanced technology.
- Increase the potential for transitioning technologies

8.5.6 Joint Experimentation Program (JE)

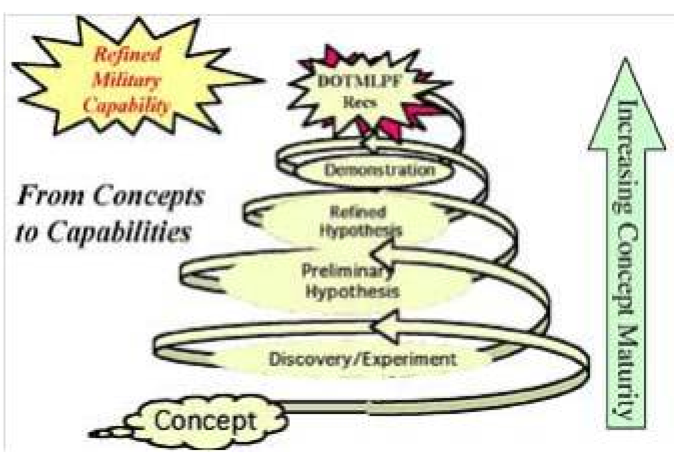

Figure 8-7 Joint Experimentation Program

Joint experimentation is defined as the application of scientific experimentation procedures to assess the effectiveness of proposed (hypothesized) joint warfighting concept elements to ascertain if elements of a joint warfighting concept change military effectiveness. The U.S. Joint Forces Command (USJFCOM) leads the Joint Experimentation program, with support from the Joint Staff, other combatant commands, services, and defense agencies. The Joint Experimentation program examines new warfighting concepts and techniques, either by modeling and simulation or through exercises with actual forces. The results of the experiments are used to shape the concepts, doctrine, and materiel systems requirements for the future joint force. One of the focus areas is joint interoperability to ensure that our service capabilities operate as one unified force during future conflicts. Selected high-payoff technologies may be examined during the joint experimentation. This program works closely with the ACTD program, assisting with improving and demonstrating ACTD products.

The Joint Experimentation Program is one of the key ingredients for the Joint Integration role of USJFCOM. The joint concepts being developed and explored by the Joint Experimentation Program offer the potential to significantly transform the way future U.S. forces accomplish their missions.

The Joint Experimentation program has limited funding. The majority of the funding is used to get the military units involved to participate and support the events. In general, candidate technologies must address major future joint force capability shortfalls. The technology must be sufficiently mature to demonstrate in an actual exercise. In certain cases, surrogate capabilities may be used, or the system may be represented in computer simulations. Entry is easiest for contractors that submit a fully-funded proposal.

The J-9 (Joint Experimentation) staff at USJFCOM, Norfolk, Virginia, has more information about opportunities and needed capabilities. Each service has its own experimentation programs and participates in the Joint Experimentation program. The relevant service experimentation point of contact (e.g., U.S. Army Training and Doctrine Command) can provide information about opportunities.

8.5.7 Manufacturing Technology Program (ManTech)

Figure 8-8 DoD Mantech Thrust

The DOD Manufacturing Technology (ManTech) program focuses on the need of weapons system programs for affordable, low-risk development and production. The mission to anticipate and close gaps in defense manufacturing capabilities makes the program a crucial link between technology invention and industrial applications from system development through sustainment.

The program is the crucial link between technology invention and development, and industrial applications. The program matures and validates emerging manufacturing technologies to support low-risk implementation in industry and DOD facilities, e.g., depots and shipyards. The program addresses production issues, beginning during the development of the technology. The program continues to support the system during the transition into its production and sustainment phases. By identifying production issues early and providing timely solutions, the ManTech program reduces risk and improves affordability by addressing potential manufacturing problems before they occur. The program vision is to realize a responsive, world-class manufacturing capability to affordably meet the warfighters' needs throughout the defense system life cycle.

ManTech has developed a strategy that balances its traditional emphasis on processing and fabrication technology solutions with active support for broader defense manufacturing needs. Strategic Thrust 1 is committed to manage and deliver processing and fabrication solutions in an area predominantly within ManTech's span of control. Thrusts 2, 3, and 4 commit active support for enterprise level solutions, manufacturability and process maturity, and manufacturing infrastructure and workforce, respectively, and recognize it is beyond the program's charter and resources to fully satisfy these thrusts. Goals are defined in all four strategic thrusts with sufficient description to enable focused action.

8.5.8 Quick Reaction Special Projects

The USD (AT&L), established a team of highly qualified acquisition professionals to advise the Under Secretary on actions that can be taken to expedite the acquisition of needed systems. This requirement was addressed in Conference Re-port 107-772, House Report 107-436, and in H.R. 4546 House Bill, Sec. 809. Quick-Reaction Special Projects Acquisition Team. The duties of the team shall include advice on:

- Industrial base issues, including the limited availability of suppliers;
- Technology development and technology transition issues;
- Issues of acquisition policy, including the length of the acquisition cycle;
- Issues of testing policy and ensuring that weapons systems perform properly in combat situations;
- Issues of procurement policy, including the impact of socio-economic requirements; and
- Issues relating to compliance with environmental requirements.

Quick Reaction Special Projects provides flexibility to respond to emergent DOD needs within budget cycle. It takes advantage of technology breakthroughs in rapidly evolving technologies. Completion of projects is to be within six to twelve months.

8.5.9 Small Business Inovation Research Program (SBIR)

Congress created the SBIR program in 1982 to help small businesses participate more in federal R&D. Each year, federal departments and agencies are required to reserve part of their R&D funds for awarding to small businesses under the SBIR program. DOD's SBIR program funds early-stage R&D projects at small technology companies - projects that serve a DOD need and could be commercialized in the private-sector or military markets.

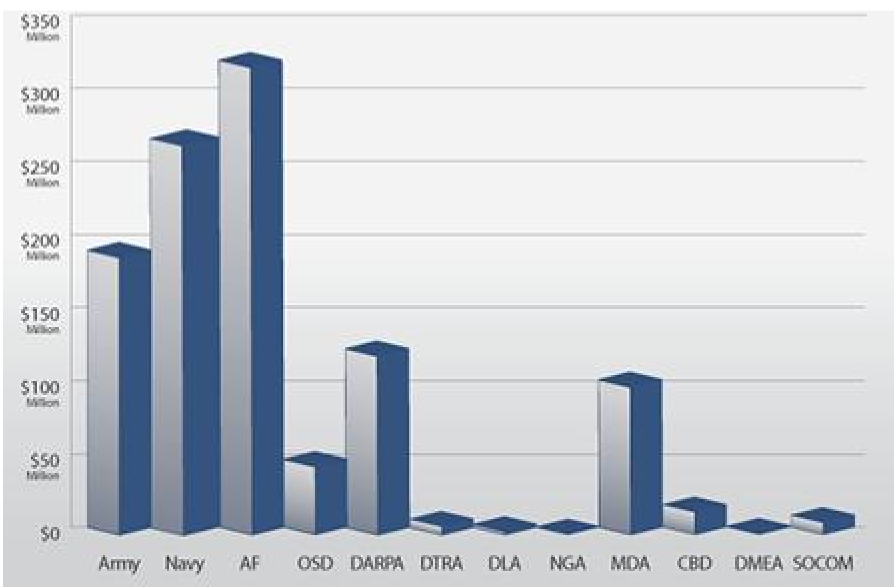

Figure 8-9 DoD Small Business Innovation Research Program

The DOD SBIR program, funded at over one billion dollars annually, is made up of 12 participating components: Army, Navy, Air Force, the Office of the Secretary of Defense (OSD), Defense Advanced Research Projects Agency (DARPA), Defense Threat Reduction Agency (DTRA), Defense Logistics Agency (DLA), National Geospatial-Intelligence Agency (NGA), Missile Defense Agency (MDA), Chemical Biological Defense (CBD), Defense Microelectronics Activity (DMEA), and Special Operations Command (SOCOM).

The Small Business Innovation Research program funds early-stage R&D at small technology companies and is designed to:

- Stimulate technological innovation;
- Increase private sector commercialization of federal R&D;
- Increase small business participation in federally funded R&D; and
- Foster participation by minority and disadvantaged firms in technological innovation.

To participate in the SBIR program:

- A firm must be a U.S. for-profit small business of 500 or fewer employees;
- Work must be performed in the United States;
- During Phase I, a minimum of 2/3 of the effort must be performed by the proposing firm; a minimum of 1/2 of the effort in Phase II; and
- The Principal Investigator must spend more than 1/2 of the time employed by the proposing firm.

8.5.10 Small Business Technology Transfer Program (STTR)

The Small Business Technology Transfer (STTR) program is a small business program that expands funding opportunities for federal innovation R&D. Central to the program is the expansion of the public- and private-sector partnership, including joint venture opportunities for small businesses and the nation's premier nonprofit research institutions. The program's most important role is to foster the innovation necessary to meet the nation's S&T challenges.

The DOD STTR program, funded at over one hundred million dollars annually, is made up of six participating components: Army, Navy, Air Force, Missile Defense Agency (MDA), Defense Advanced Research Projects Agency (DARPA), and Defense Research & Engineering (DDR&E).

In 1992, Congress established the STTR pilot program. STTR is similar in structure to SBIR but funds *cooperative* R&D projects involving a small business and a research institution (i.e., university, federally-funded R&D center, or nonprofit research institution). The purpose of STTR is to create, for the first time, an effective vehicle for moving ideas from our nation's research institutions to the market, where they can benefit both private sector and military customers.

To participate in the STTR program:

- A firm must be a U.S. for-profit small business of 500 or fewer employees; there is no size limit on the research institution;
- Research institution must be a U.S. college or university, FFRDC or non-profit research institution;
- Work must be performed in the United States;
- The small business must perform a minimum of 40 percent of the work and the research institution a minimum of 30 percent of the work in both Phase I and Phase II;
- The small business must manage and control the STTR funding agreement; and
- The principal investigator may be employed at the small business or research institution.

8.5.11 Technology Transition Initiative (TTI)

The Technology Transition Initiative (TTI) was called for in the FY 2003 National Defense Authorization Act, which provided limited funding for selected technology transition projects. The objectives of the (TTI) are to accelerate the transition of new technologies into operational capabilities within the armed forces; and to successfully demonstrate new technologies in relevant environments.

Once a decision is made to move a technology from the S&T program into acquisition, it often takes 2-3 years to obtain procurement funding to buy the product. During that time, many technology projects either become obsolete or are cancelled due to a lack of funding. To help address this need, Congress established the TTI in 2002 to bridge the gap between demonstration and production of Science and Technology (S&T) funded technology.

Key provisions of the code include:

- TTI is intended to accelerate the introduction of new technologies into operational capabilities for the armed forces.
- TTI can successfully demonstrate new technologies in relevant environments.
- The science and technology and acquisition executives of each military department and each appropriate Defense Agency and the commanders of the unified and specified combatant commands nominate projects to be funded.
- The TTI Program Manager identifies promising projects that meet DOD technology goals and requirements in consultation with the Technology Transition Council.
- The TTI Program Manager and the appropriate acquisition executive can share the transition cost. Service/Agency contribution can be up to 50 percent of the total project cost. A project cannot be funded for more than four years.

8.5.12 Industrial Base Innovation Fund Program (IBIF)

Numerous Defense Authorization Acts have provided the ManTech program with funds to ensure that investments are made to address defense industrial base shortfalls especially related to surge production requirements and diminishing sources of defense material. This program is a sub-set of DOD ManTech to ensure that investments are made to address shortfalls in manufacturing processes and technologies in support of DOD long-term and short-term needs. Current (2011) IBIF technical interest areas include:

- Adaptive Machining,
- Automation of Non-Destructive E analysis,
- Electro-Optical Targeting System Producibility,
- Low Observable Technologies,
- Metal Direct Digital Manufacturing,
- Optical Windows, and
- Technical Data Packages for the Digital Enterprise.

8.5.13 Rapid Technology Transition (RTT)

The mission of the Rapid Technology Transition (RTT) program is to increase the rate that new, innovative, and potentially disruptive technologies are inserted into DOD acquisition programs and into the hands of the warfighter. The RTT program is structured to bring transition efforts to closure quickly, and to provide execution year funding for a rapid start, bridging the gap until the program of record can fund the completion of the technology insertion.

Rapid transition opportunities occur when a sufficiently mature technology is identified that can meet a particular need on a timetable which matches that of an acquisition program, and is supported by a business case which justifies the associated cost and schedule risk. RTT is designed to be pro-active in identifying opportunities and to work with resource sponsors, warfighters, acquisition sponsors (PEOs), and Program Managers (PM) in constructing viable technology transition efforts.

To be considered for RTT funding a proposal must meet the following criteria:

- Proposed technology can transition to acquisition in 24 months or less.
- Proposed technology has Program & Fiscal Support:
    - Requires no more than $2 million in RTT funding,
      Purchase/POM Commitment,
    - Supportable Funding Profile,
    - Requirement/Resource Sponsor (OPNAV & USMC P&R),
    - Acquisition Sponsor (PEO/DRPM), and
    - Fleet Sponsorship (USFFC or USMC).
- Proposed technology is feasible:
    - Technology Readiness Level (TRL) 6 or higher,
    - Navy/USMC Infrastructure, Policy, and CONOP support, and
    - Supportable Business Case (Return on Investment, Improved Capability, Reduced Total Ownership Cost, Urgent Need, Accelerated Capability Introduction).

8.5.14 Warfighter Rapid Acquisition Program (WRAP)

The Army established the WRAP to address the gap in funding that exists because of the time required to plan, program, budget, and receive appropriations for procuring a new technology. WRAP was designed to shorten the acquisition cycle and be a bridge between experimentation and systems acquisition. The goal was to put new weapons in the hands of soldiers faster and cheaper. Candidates for the WRAP were selected according to urgency of need, technical maturity, affordability, and effectiveness. To promote program stability, candidates received funding for the first two years, which allowed time to build them into the overall budget.

The Army used WRAP for several programs: the Stryker, its new lightweight combat vehicle; the lightweight laser designator rangefinder, used to determine the range of a target and relay that information back to tanks, artillery, or aircraft; and radio frequency tags, a computer tracking system used to pinpoint equipment quickly and easily. The Army is no longer funding WRAP, but is developing other initiatives to rapidly transition technology to warfighters.

The Air Force Warfighter Rapid Acquisition Process (AF WRAP), which is an ongoing program, is a rigorous process that speeds the initial acquisition decision and allocation of funds for a small number of competitively selected projects that either increase warfighter capability or significantly reduce costs. AF WRAP can accelerate implementing and fielding of projects meeting the immediate needs of the warfighter. AF WRAP quickly makes available newly matured, often pivotal technology. The AF WRAP candidate review ensures the smooth transition of selected candidates to operational capabilities that are acquired and sustained as part of the baseline Air Force program.

WRAP funding is allocated in the execution year to support selected projects for as long as two years. Major commands selected to receive FY02 WRAP funds have committed to funding, developing, procuring, and sustaining their selected project.

AF WRAP candidates approved in FY02 include the Panoramic Night Vision Goggles (PNVG), increasing night vision goggle field of view from 40 to 100 degrees; the remote casualty locator and assessment device, a low-cost, hand-held, battery-powered device that enables the user to "see" through walls, rubble, wood, and earth to locate and assess the condition of casualties; and the Information For Global Reach - Aerovac, which provides continuous, seamless exchange of mobility- and medical-related C2 and patient health information among fixed, airborne, deploying, and deployed mobility and medical elements.

8.5.15 Commercial Operations and Support Savings Initiative (COSSI)

Many DOD systems require maintenance long beyond the useful life initially anticipated. Extending the service life of military systems increases the costs of ownership. For the purposes of COSSI, O&S costs are the costs of owning and operating a military system, including the costs of personnel, consumables, goods and services, and sustaining the support and investment associated with the peacetime operation of a weapon system. One way to reduce O&S costs is to take advantage of the commercial sector's technological innovations by inserting commercial technology into fielded weapon systems. The Commercial Operations and Support Savings Initiative (COSSI) was initiated under 10 U.S. Code 2511 to develop and test methods for reducing DOD Operations and Support (O&S) cost by inserting commercial items into fielded military systems. COSSI is a two-stage process:

1. In stage I of each selected project, COSSI and the chosen proposer will share the costs of developing and testing the kit. (There is no minimum cost share required); and

2. If Stage I is successful, the Military Customer may then purchase reasonable production quantities of the kit in Stage II

8.5.16 North American Technology and Industrial Base Organization (NATIBO)

The North American Technology and Industrial Base Organization (NATIBO) is not a program but rather another resource available to American and Canadian program managers. NATIBO was chartered to promote a cost effective, healthy technology and industrial base that is responsive to the national and economic security needs of the United States and Canada. Current policy calls for a national defense force that derives its strength and technical superiority from a unified commercial/military industrial base. NATIBO can provide access to a broader national manufacturing and technology base especially where defense downsizing could jeopardize basic national security goals. NATIBO can help unify the industrial base by applying the most modern industrial products, processes, practices, and standards of management and manufacturing.

The NATIBO can address the challenges of advancing and maintaining technological superiority in light of reduced government research and development funding by providing funding for industrial base projects that involve Canadian companies. The criteria used for selecting technologies to study through this program are:

- The candidate is a key technology area of high interest;
- The candidate has potential for broad military and commercial application;
- Development and/or production exists in both the U.S. and Canada; and
- There is a good window of opportunity for investment and application.

In summary, NATIBO's primary purpose is to identify and analyze key industrial sectors that are critical to defense, assess the viability of these sectors, identify issues and barriers related to sector viability, and develop strategies to enhance and sustain the health of the marketplace.

8.6 Technology Development Challenges and Considerations

Keeping pace with technology and maintaining a technological advantage over our adversaries will be challenging in the 21st century because of the following factors:

- *Technology is changing rapidly in many key areas* . The advance of technology has accelerated. Yesterday's technology may not be good enough on tomorrow's battlefield. Critical enabling technologies may become obsolescent quickly, or countermeasures may be developed.
- *Critical commercial technology will be widely available* . The lead for developing many critical technologies has shifted from the defense industry to commercial industry.
- *Our adversaries may have access to our defense technology* . Adversarial activity has extended from the battlefield into the international marketplace. Evidence shows that foreign entities are exploiting U.S. defense contractors and military research, development, testing, and evaluation facilities to obtain leading-edge research and technology. In addition, U.S. industry no longer is the leader in many areas of

technology. Therefore, our adversaries may have access to many key defense-related technologies.

- *Transitioning technologies to production has proven to be difficult* . The objective of technology transition is to make the desired technology available to the operational units as quickly as possible and at the lowest cost. However, program managers have not always supported, through funding, technology transition efforts.

To respond to these 21st century challenges, DOD must not only field new technology rapidly, but also must maintain the technological edge in systems that will remain in service for decades. DOD must be able to:

- Leverage the best technology available from both government and commercial sources;
- Rapidly transition the technology into new materiel systems;
- Refresh the technology, as needed, to maintain the advantages that our warfighters need throughout the life of a system; and
- Protect sensitive leading-edge research and technology against unauthorized or inadvertent loss or disclosure.

Technology development and transition has always had its challenges and considerations. During the S&T phase of development in government, industry and academia, the focus is on the development of knowledge. Meanwhile in the acquisition community the focus is on the application of technology to improve performance and/or reduce cost. The entire process of developing and transitioning technology must be carefully managed in a way that these two communities work together to ensure that the warfighter receives the greatest benefit from on-going technology developments. This section will address the following challenges and considerations associated with technology development and transition:

- Inserting enabling technologies;
- Identifying and selecting available technologies;
- Staying abreast of available technology development programs;
- Planning for technology transitions;
- Maturing technology;
- Reducing technology development risk;
- Protecting intellectual property; and
- Export controls.

8.6.1 Inserting Enabling Technologies

One of the major challenges facing DOD is modernizing legacy systems using state-of-the-art technology. Therefore, from the start of an acquisition program, DOD must consider not only how to get a useful military capability to the field quickly, but also how it can upgrade a system later. Considerations include the latest technology, increasing mission performance, reducing O&S costs, and enhancing supportability.

Although basic and applied research are the foundations for meeting future technology needs, other programs - such as ATDs, ACTDs, warfighter experiments, and other approaches - are key to accelerating the transition from S&T to military weapons systems. Managers of S&T, R&D, and acquisitions must collaborate on their efforts if a technology is to be transitioned into weapons systems.

8.6.2 Identifying and Selecting Available Technologies

Identifying and selecting technologies are important early steps in developing or upgrading weapon systems. Numerous technology "clearinghouses" exist for identifying technologies. Often PMs rely on prime contractors to identify and select technologies to insert into systems, believing the contractor will always use the best source for technology, and use it to develop the system. However, this is not always the case and may not be the best way to find leading technologies that are applicable to weapons systems. Working together, the communities for capability needs, S&T, R&D, T&E, acquisition, and sustainment, must work hard to communicate program requirements and identify the technologies, regardless of their source, that most benefit the warfighters.

S&T leaders (government and industry) must maintain close and continuous ties with the warfighters or other users of systems, as well as with acquisition and sustainment PMs. Maintaining these ties can help ensure that S&T leaders understand the needs, develop technologies that will be useful for satisfying those needs, have a sense for the timing needed for integration, and anticipate future warfighting needs. The ties can be maintained through formal forums or, even more effectively, through frequent interactions between technologists and acquisition or sustainment PMs. The interaction will help keep S&T projects focused on increasing the effectiveness of a mission capability while decreasing cost, increasing operational life, and incrementally improving products through planned product upgrades.

8.6.3 Staying Abreast of Available Technology Development Programs

PMs often do not effectively use the technology development programs available to them, either because they are unaware of them or because they have not institutionalized an approach for using them to develop technology solutions and have not integrated them into their Technology Development or Acquisition Strategies.

A good approach for staying abreast of available technology development programs is to assign someone in your organization to work SBIR, STTR, ManTech, and other programs for the PM. That person should review applicable programs and come up with strategies for accessing their resources. Network with those who have successfully accessed these programs, and be sure proposals are thoughtfully developed and adequately address the criteria against which funding will be granted.

To access technology in commercial non-traditional laboratories, a good first step is to determine which laboratories have a track record in the technologies that can be precursors to those of interest. Then, determine whether their laboratories have technical personnel who are recognized leaders in the field, a corporate reputation in the technology, related equipment available, and/or a number of related patents and technical papers.

If a program needs advanced revolutionary technology that may have significant commercial potential, then very likely the only way to identity potential sources is to find firms that have funding from a university or non-profit laboratory doing work in precursor technologies that have been hiring their graduates. Many of the non-traditional businesses that are funding these developments do so in order to have a leading-edge product for which they will be the exclusive source for a number of years.

8.6.4 Planning for Technology Transitions

If you are using an evolutionary approach vice a single-step approach to developing weapons systems, breaking up the program into increments of militarily useful capability may be critical. Increment 1, for instance, would be the initial deployment capability, and other increments would follow in the order in which the system is developed. The PM must describe in the acquisition strategy how the program will be funded, developed, tested, produced, and supported. The description should include the plan for technology insertion, and the PM should have a weapons system support strategy that addresses how the PM and other responsible organizations will maintain appropriate oversight of the fielded system. Oversight shall identify and properly address performance, readiness, ownership cost, and support issues, and shall include post-deployment evaluation to support planning for assuring sustainment and implementing technology insertion to continually improve product affordability. Probably the best way to begin is to establish an IPT that can work its way through these issues.

Planning early to insert technology continually is crucial to acquisition program success. The rapid and effective transition of technology from the science and technology base to weapon systems is a process that requires the S&T community to understand and respond to the time-phased needs of the warfighters. Because the process requires the acquisition community to plan for the initial system capability and to incrementally introduce new technology, the acquisition community must thoroughly understand the technology's readiness for transition. One of the tools available to program and S&T managers is the Technology Transition Plan or Technology Transition Agreements.

8.6.5 Maturing Technology

While technology is being developed, its readiness for insertion into current technology must continually be evaluated. You need a systematic process for measuring that enables you to determine the maturity of specific technologies and compare different types of technology.

Many programs have found that using Technology Readiness Levels (TRLs) is beneficial for assessing technologies. TRLs provide a systematic measurement system for assessing the maturity of a technology and for consistently comparing maturity of different types of technology. NASA has used TRLs for many years for planning its space technology, and, as described in the *Interim Defense Acquisition Guidebook* , the use of TRLs is a "Best Practice" for all new DOD programs. Furthermore, component S&T executives are required to assess technology readiness for critical technologies identified in Acquisition Category (ACAT) ID (Major Defense Acquisition Programs where the USD(AT&L) is the Milestone Decision Authority) and ACAT IAM (Major Automated Information Systems) programs before Milestone

B. PMs in other programs will also find that using TRLs is beneficial for assessing technology maturity because the criteria will help them to identify risk early. In addition, Manufacturing Readiness Levels (MRLs) and Sustainment Maturity Levels (SMLs) can be used to help identify production, manufacturing and quality risks and logistics/sustainment risks early on technology programs.

8.6.6 Reducing Technology Development Risk

No matter how well a technology's development is proceeding, the possibility always exists that it will not be totally successful in producing the solution needed by weapon system acquisition programs. Even if solutions become available, they may not be available in time. Therefore, some forethought is required to identify alternative approaches to ensure the program will meet its objectives.

PMs need to define Critical Success Factors (CSFs) - critical management activities that define an acceptable deliverable or series of deliverables for a technology solution. CSFs are activities that can be tracked and measured and are based on performance. CSFs are used in addition to the detailed project plan and other project documentation. Using CSFs requires not only identifying the factors and their appropriate measurements, but also analyzing the underlying constraints. The analysis will help PMs to devise ways to manage risk in case technology providers are unable to deliver the technology when needed.

Another key activity in mitigating risk is to constantly explore alternatives for meeting the technology requirement. The SBIR program, in particular, is a good base of technology alternatives. Some PMs or PEOs are very aggressive and quite successful in using this program for developing alternatives to the incumbent technological approach, especially if progress is slow and milestones are missed. Competition can be an excellent motivator to the technology provider.

8.6.7 Protecting Intellectual Property

In the past, the government was the major impetus for R&D. Now, technologies shaping the economy are funded mostly by private industry, and we must foster an environment in which industry is willing to share its commercially generated technologies. Intellectual Property (IP), which includes patents, copyrights, trademarks, and trade secrets, is intangible property that is critical to the financial well-being of a company. Because of the value of IP, companies, especially non-traditional businesses, want to ensure IP is protected before they do business with the government. Yet, you must consider long-term support and competitive strategies, early in the acquisition process, to protect core DOD interests. On the one hand, DOD's policy is to take minimum rights; and a recent policy letter specifically states, "Much of the intellectual property mindset culturally embedded in the acquisition, technology, logistics, and legal communities is now obsolete." On the other hand, it is equally important that you identify strategies and outcomes that will protect DOD interests and IP, and ensure that contractors invest in core technologies and do business with DOD.

The larger leading commercial (non-traditional) firms ensure their continued existence and growth predominately by selling products and services they developed in the highly competitive global commercial market. Virtually every technology-rich commercial business aggressively protects its proprietary data. These data define the business and its potential. These firms keep their proprietary data (especially data related to important commercial developments) well protected in the organization; usually it is as well protected as DOD protects its top secret information. Normally, only a relatively few trusted business and technical employees with a vested interest in the commercial success of the development will have access to the data.

In dealing with IP rights, the government has promulgated policies and regulations about patents, copyrights, technical data, and computer software. When acquiring IP license rights, the DOD acquisition community should consider certain core principles highlighted below.

- Integrate IP considerations fully into acquisition strategies for advanced technologies to protect core DOD interests.
- Respect and protect privately developed IP because it is a valuable form of intangible property that is critical to the financial strength of a business.
- Resolve issues before awarding a contract by clearly identifying and distinguishing the IP deliverables from the license rights in those deliverables.
- Negotiate specialized IP provisions whenever the customary deliverables or standard license rights do not adequately balance the interests of the contractor and the government.
- Seek flexible and creative solutions to IP issues, focusing on acquiring only those deliverables and license rights necessary for meeting the acquisition strategy.

8.6.8 Export Controls

Commercial companies may be reluctant to sell to DOD, because DOD sales may restrict the future export of their technology. Controls on exporting technology discourage potential commercial technology solutions from entering defense markets. Export controls are considered excessively long and complex. Selling to DOD can introduce delays, uncertainties, and limitations that may inhibit the ability to export advanced products to worldwide commercial markets. Specifically, a firm with a dual-use technology may be reluctant to have its technology used in defense-related applications because of subsequent limitations to offshore production, the added costs of oversight by the Department of State (DOS) rather than the Department of Commerce (DOC), and possible restrictions on what capabilities can be offered in commercial markets.

Exports and access to foreign markets are critical to the success of firms selling high-technology products and services. These products and services may constitute commercial and dual-use technologies or defense items and services, including commercial satellites. The rapid obsolescence of high-technology items may affect the commercial success of an item adversely if the contract process delays access to the export market.

Basically, two control regimes exist, each administered by a different cabinet-level department of the executive branch. The DOC administers exports of most commercial and dual-use technology under the Export Administration Act (EAA) and its implementing regulations. The DOS administers another parallel environment (munitions export licenses) for goods, services, and software that are either critical to the military or are a part of a multilateral control of missile technology. In general, the DOS's actions are covered by the Arms Export Control Act (AECA) and the International Traffic in Arms Regulations (ITAR). Although DOD does not have a direct statutory or regulatory role in controlling exports, it nevertheless does affect exports.

Another law, the Invention Secrecy Act of 1951, requires the government to impose "secrecy orders" on certain patent applications whose disclosure would be detrimental to national security. A secrecy order restricts disclosing an invention by withholding the granting of patents, ordering that the invention be kept in secrecy, and restricting the filing of foreign applications.

The U.S. Patent and Trademark Office imposes the secrecy orders that DOD recommends. The Armed Services Patent Advisory Board coordinates the review in DOD. Approximately 5,000 secrecy orders are in effect. This number has been fairly constant during the past four years, with about 80150 new orders issued annually and about 100200 orders rescinded annually. The issue of streamlining export controls has been discussed since the end of the Cold War and has gained increased attention over the past several years. A Rapid Improvement Team (RIT) was formed several years ago to deal with export control licensing reengineering.

8.7 Implementing A Technology Development Program

The Technology Development Strategy (TDS) is an acquisition document that is approved at Milestone A to guide the conduct of the Technology Development (TD) phase. The TDS contains a preliminary description of how the potential acquisition program will be divided into increments based on mature technologies; a preliminary program strategy to include overall cost, schedule, and performance goals; specific cost, schedule, and performance goals, including exit criteria, for the TD phase; the approach for management of data assets, a list of known or probable Critical Program Information (CPI) and potential countermeasures; a time-phased workload assessment, and other elements described in the Defense Acquisition Guidebook. The TDS is the forerunner for the program's Acquisition Strategy (AS) required at Milestone B. Together, the Technology Development Strategy and the Acquisition Strategy guide how a technology gets developed and transitioned into a weapon system platform.

8.7.1 Pre-Systems Acquisition

The Pre-Systems Acquisition Activity is composed of activities primarily related to technology development work and those activities leading to the refinement of the material solution identified in the approved Initial Capabilities Document (ICD). Pre-systems acquisition consists of two phases, Material Solution Analysis (MSA) and Technology Development (TD). This activity is usually managed at the labs.

The MSA phase begins with a Material Development Decision (MDD) by the Milestone Decision Authority (MDA) and ends with a successful Milestone A decision that allows the program to transition into the next phase. The primary focus of MSA is the refinement the initial concept. Additionally, the Technology Development Strategy (TDS) is drafted and a plan for the conduct of the Analysis of Alternatives (AoA) is crafted. The AoA shall assess the critical technologies associated with each proposed materiel solution, including technology maturity, integration risk, manufacturing feasibility, and, where necessary, technology maturation and demonstration needs. The emphasis in this phase is on innovation and competition and on drawing from existing solutions from a wide range of sources.

The TD phase begins after a successful Milestone A decision. The primary focus of this phase is to reduce technology risk and determine the appropriate set of technologies to integrate into a full system. A number of technology demonstrations are usually conducted to illuminate the most mature and affordable technologies that will in turn support the most operationally useful solution. TD concludes when the technology for an affordable increment of militarily useful capability has been demonstrated in a relevant environment. At this point two critical reviews should have been completed, the Preliminary Design Review (PDR) and the Technology Readiness Assessment (TRA).

8.7.2 Systems Acquisition

The Systems Acquisition Activity consists of the Engineering and Manufacturing Development (EMD) and Production and Deployment (P&D) phases. In this activity enabling technologies are integrated and the system is fully developed, tested, produced, and deployed to the operational user.

EMD begins at Milestone B, which is normally formal program initiation. This phase is to complete the development of a system or increment of capability, leveraging design considerations; complete full system integration; develop an affordable and executable manufacturing processes, complete system fabrication, test and evaluation. A key emphasis during EMD is to ensure operational supportability with particular attention to minimizing the logistics footprint.

The purposes of EMD are to:

- Develop a system or increment of capability;
- Reduce integration and manufacturing risk;
- Design-in critical supportability aspects to ensure materiel availability with particular attention to reducing the logistics footprint;
- Integrate hardware, software, and human systems;
- Design for producibility;
- Ensure affordability and protection of critical program information; and
- Demonstrate system integration, interoperability, supportability, safety, and utility.

EMD consists of two major, sequential efforts: Integrated System Design and System Capability and Manufacturing Process Demonstration. The EMD systems engineering work effort typically completes the Integrated System Design (including all initial technical reviews not previously completed in Technology Development, and technical reviews intended to occur during EMD) and a System Capability and Manufacturing Process Demonstration. EMD begins when the program manager has an allocated baseline for the system or increment of capability but has not developed or integrated the end item components and subsystems into a fully operational and supportable system. EMD systems engineering work also completes any remaining initial systems design activities not finished during the Technology Development phase (i.e., System Requirements Review, System Functional Review, or Preliminary Design Review.

The P&D phase begins with a successful Milestone C decision and launches the system into the first effort, Low Rate Initial Production (LRIP), of the two efforts that comprise this phase. The second effort is the Full Rate Production and Deployment (FRP&D) effort. The primary goal of this phase is to achieve an operational capability that satisfies the operational need of the warfighter or end user. The Full Rate Production Decision Review (FRPDR) separates the two efforts of this phase. LRIP results in the assurance of adequate manufacturing capability, establishes an initial production base, provides production articles for operational testing, and begins an orderly ramp-up to full rate production. During FRP&D the system is produced in quantity and deployed to the warfighter or end user. Some follow-on testing might occur during this phase to ensure that deficiencies identified earlier have been corrected.

8.7.3 Technology Transition Agreements

A Technology Transition Agreement (TTA) documents the commitment of the requirements/resource sponsor, science and technology activity (developer and provider of the technology/product), and acquisition program sponsor (intended receiver of a technology or capability development) to develop, deliver, and integrate a technology/product into an acquisition program. The TTA can help bridge the gap in the " *Valley of Death* ." The funding gap between the time a capability gets developed and the time that capability gets funded as part of an acquisition program. The TTA should include the following elements:

- Description of Technology or Capability to be Delivered;
- Target Acquisition Program;
- Acquisition Program Technology Need;
- Integration Strategy;
- Program Manager/Project Officer;
- Technology Manager;
- Capability Requirement Basis; and
- Resource/Requirements Officer.

The TTA needs to identify the key parameters or attributes that will be used as exit criteria to measure whether or not the technology effort is proceeding as scheduled. Include parameters to be tracked, current state, interim progress estimates and final objective. TRLs are a good measure of technical maturity and can be used to assess readiness to transition. The TTA should provide dates when each higher TRL rating is expected to be achieved.

8.7.4 Contracting For Technology Development

Technology Development Strategies and Acquisition strategies need to include a team approach to solving technology problems. The strategies must be flexible and motivate organizations to use their best talent for government S&T and R&D. Top-notch personnel are a premium resource that the government needs to attract high-quality technology solutions.

Ensure that your contract provides incentives for continuously inserting and refreshing value-added technology. These incentives must motivate both the contractor's business and the technical community. For example, award fees measured against a baseline technology insertion plan would help to maintain a focus on technology insertion.

Use performance-based statements of work to clearly establish what the government wants; and, using that information, create performance incentives that encourage contractors to focus on providing value to the government. Having the discipline of firm goals at every stage of the process, especially under spiral development, is important. The government can define its goals (e.g., increased reliability) and measure and reward contractor performance against those goals through business arrangements, such as award-fee and incentive-fee contracts. Historically, the choice of contract type has been the primary strategy for structuring contractual incentives, but performance incentives can be used in conjunction with various contract types and are not associated with one type of contract.

Examine both financial performance incentives, with values derived from the worth of increased performance to the government, and non-financial performance incentives, such as long-term contracting.

Attract top-notch resources to create high-quality technology solutions by including fair and reasonable IP provisions. To provide incentives, allow commercial firms to retain their IP rights in key areas. Avoid using onerous government-unique provisions (e.g., an unneeded requirement for cost and pricing data, when other pricing methods can be used). Flexible business instruments can help.

8.8 Summary

Developing technology, maturing technology and transitioning technology are all difficult and fairly high risk activities. Fortunately OSD has several programs that can provide program managers an avenue for reducing those risks and funding their technology risk mitigation plans. Even with the technology programs and funding there are still challenges. S&T managers and program managers need to continue to work closely to ensure that the development of technologies has the highest potential for insertion and success.

8.9 Related Links and Resources

Numerous reference documents impact the manufacturing management function throughout the acquisition process. These documents originate from many sources and range across academic disciplines, functional activities, and job specialties.

The following is a reference list of DOD Directives (D), Instructions (I) Manuals (M), Pamphlets (P), Military Standards (MS), and other documents. The documents listed contain DOD policy guidance applicable to the manufacturing management function. They are listed as sources of DOD manufacturing management information.

Note: Many of the documents listed are no longer required (due to acquisition reform), but still contain some very valuable information.

Number	Title
	Managers Guide to Technology Transition in an Evolutionary Environment
	The DoD Manufacturing Technology Program Strategic Plan 2009
	DoD ManTech homepage
	Air Force ManTech homepage
	Navy ManTech homepage
	Army ManTech homepage

Defense Manufacturing Management Guide for Program Managers
Chapter 9 - Manufacturing Cost Estimating

9.1 Objective

The focus of this chapter is on the identification and characterization of manufacturing costs as they are estimated and incurred by defense contractors. This chapter describes the nature and structure of manufacturing costs and the various techniques used to estimate cost. The objective is to establish an understanding of the composition of manufacturing costs and discuss the manufacturing cost estimating process. At the end of this chapter you should be able to:

- Identify the nature of manufacturing cost;
- Identify the requirements for Cost Accounting Standards;
- Describe the various cost estimating methodologies in use today;
- Define and describe Learning Curves;
- Describe the relationship between rate, quantity and costs; and
- Identify other cost considerations and methodologies.

9.2 Background

In an era of affordability, the ability to estimate costs and then manage to expectations is extremely important. Since 2008 DOD's total planned investment in major defense acquisition programs has increased by $45 billion to $1.68 trillion. GAOs analysis of 98 programs in DOD's 2010 portfolio of major defense acquisition programs allowed them to make the following observations about the overall portfolio, as well as about the performance of individual programs.

1. DOD's portfolio has grown by about $135 billion, or 9 percent, over the last two years, of which about $70 billion cannot be attributed to quantity changes.

2. Over half of the total cost growth over the last two years is driven by ten of DOD's largest programs, which are all in production.

3. About half of the programs in the portfolio have experienced cost increases that exceed cost performance goals agreed to by DOD, OMB, and GAO.

4. Almost 80 percent of the programs in the portfolio have experienced an increase in unit cost when compared to their original estimates; thereby reducing DOD's buying power on these programs.

5. Most of the cost growth materialized after programs entered production, meaning they continued to experience significant changes well after the programs and their costs should have stabilized.

9.3 Introduction

In 2010, America was at war with major simultaneous operations in two different countries. Given budget constraints, a weak economy the country was forced to rethink defense spending by eliminating wasteful, excessive and unneeded spending. Not every defense program was seen as necessary and not every defense dollar was being well spent. The Under Secretary of Defense for Acquisition, Technology and Logistics (AT&L), in a memo, created a mandate that targeted affordability and the control of cost growth. The November 3, 2010 memo directed the following:

" *Milestone (MS) A: You will establish an affordability target to be treated by the program manager (PM) like a Key Performance Parameter (KPP). This affordability target (initially, average unit acquisition cost and average annual operating and support cost per unit) will be the basis for pre-MS B decision making and systems engineering tradeoff analysis. This analysis should show results of capability excursions around expected design performance points to highlight elements that can be used to establish cost and schedule trade space* ."

Cost is one of the primary measures of management effectiveness, along with performance and schedule, as applied to defense programs. Certain government and contractor policies and actions, which can have significant impact on manufacturing cost, need to be considered during the planning and execution of weapon system development programs. These activities include decisions on production rate, long lead funding, and capital investment.

9.4 Nature of Manufacturing Costs

The cost to manufacture a weapon system or equipment results from a combination of the design, the physical facility, and the five M's (manpower, materials, methods, measurements, and machines) used to build the design and the management efficiency of the operation. This is illustrated in Figure 9-1. As such, the manufacturing cost for a product should be viewed within the context of the factory in which the product will be built. Three other very significant cost factors will need to be identified to support the estimating activity, and these are rate, quantity and efficiency.

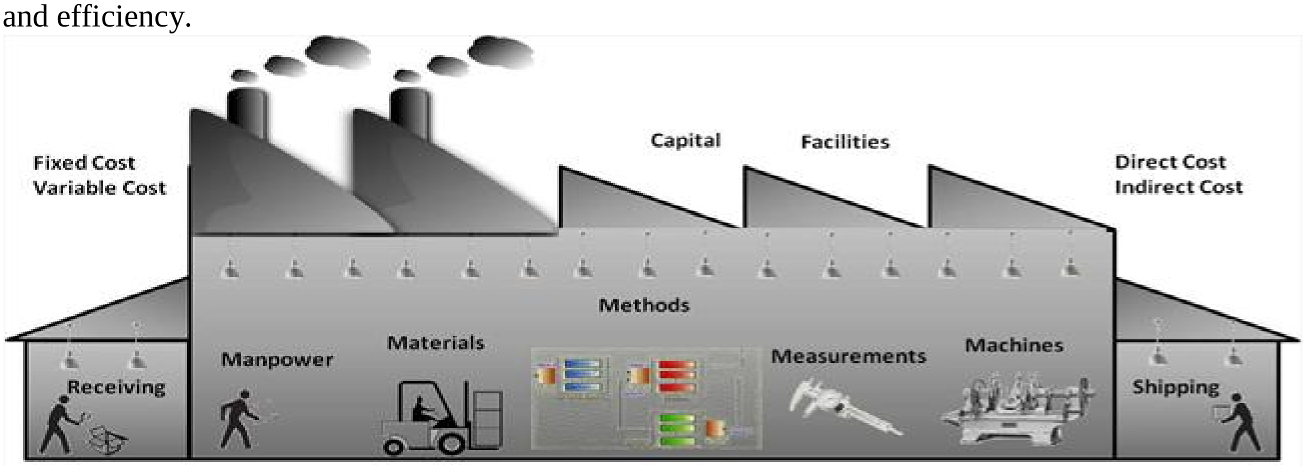

Figure 9-1 Manufacturing Cost

You will need to have a basic understanding of several accounting terms, especially as they relate to the manufacturing environment, if you are to understand manufacturing costs. These terms include:

- Fixed Cost,
- Variable Cost,
- Direct Cost,
- Indirect Cost,
- Nonrecurring Cost, and
- Recurring Cost.

A classic division of manufacturing cost is between direct and indirect costs. Costs can also be described as fixed or variable based on their behavior as production volume changes within broad limits. Finally, costs can be described as nonrecurring or recurring depending on when and how often costs are accumulated. Finally, costs can be described in multiple terms, thus materials could be both a direct and a variable cost.

9.4.1 Fixed Cost

Fixed costs are those costs that remain constant or fixed and do not vary with output or activity. Fixed costs are further subdivided into committed fixed cost and discretionary fixed costs. Committed fixed costs are costs that typically cannot be changed (up or down) over a short term and often include buildings and facilities, insurance on the buildings, taxes on buildings, salaries of permanent employees, and major pieces of equipment. Discretionary fixed costs are costs that can change over a short period, often due to management decisions about certain cost activities. Examples of discretionary fixed cost can include the budget for research and development, maintenance, advertising, and programs to develop managers, employees or interns.

9.4.2 Variable Cost

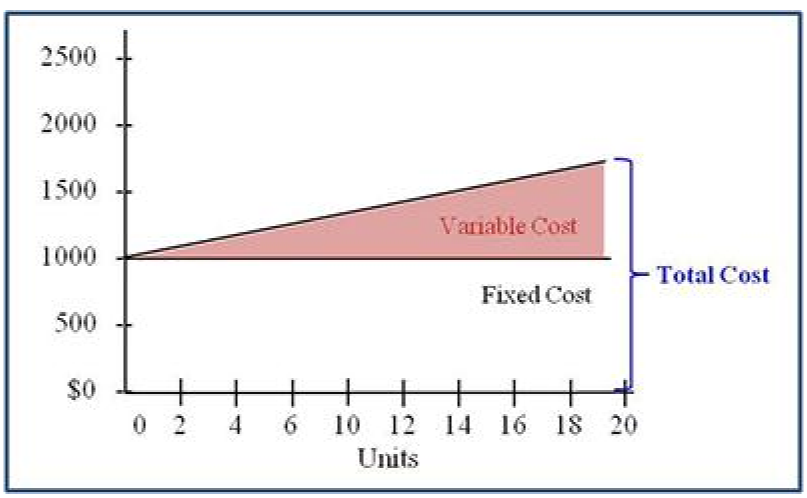

Figure 9-2 Variable Cost

Variable costs, as the name implies, are costs that vary with production or the level of activity. So as you produce more units your costs go up as you use more material, energy, direct labor, etc. Variable costs include direct materials, direct labor, indirect materials, energy, and a portion of manufacturing overhead.

Fixed and Variable costs can be further broken down into two other cost types.

1. Direct, and

2. Indirect.

Direct and indirect costs classify the costs of production (fabrication and assembly) and are critical to calculating shop overhead rates.

9.4.3 Direct Cost

A direct cost can be defined as " *any cost that is specifically related to a particular final cost objective, but not necessarily limited to items that are incorporated in the end item as material or labor* ." The majority of the direct cost is involved in the direct material and direct labor used in designing and fabricating the system or equipment.

Direct material includes the cost of material used in producing a specific product and that cost is not shared among other products. For example, an aircraft manufacturer may buy aluminum sheets in bulk, but the material cost gets allocated to a specific aircraft family (F-14, A-6, C-2) which uses the material. One way to look at direct costs is to look at the bill of material (BOM). A BOM (Figure 9-3) lists the materials, components and quantities of materials that go into a specific job or end product. The typical BOM accounts for hardware only and does not take into consideration other manufacturing costs such as fabrication and assembly cost. A BOM supports the determination of the final cost for direct material.

8'x12' Shed			
Item	**Qty.**	**Cost**	**Price**
Floor Frame			
2" x 4" x8' spruce	7	$10.00	$70.00
2" x 4" x 12' spruce	2	$15.00	$30.00
5/8" plywood	3	$20.00	$60.00
joist hangars	14	$1.00	$14.00
Wall Frame			
2" x 4" x 8' spruce	32	$10.00	$320.00
2" x 4" x 12' spruce	4	$15.00	$60.00
Roof			
2" x 4" x 10' spruce	8	$12.00	$96.00
2" x 4" x 14' spruce	2	$20.00	$40.00
3/8" plywood	4	$15.00	$60.00

asphalt shingles (pack)	4	$15.00	$60.00
Misc.			
nails (box)	8	$5.00	$40.00
paint (gal)	2	$20.00	$40.00
Totals			$890.00

Figure 9-3 Bill of Material

Direct labor includes the cost of the workmen or craftsman used in producing a specific product and that cost is not shared among other products. For example, labor used to fabricate parts for the Saratoga (a light weight, mobile, multipurpose vehicle produced by Navistar for the U.S. Army) or for assembly and test operations on the Saratoga, are kept separate from the fabrication, assembly and test costs for the Navistar MXT Cargo vehicle.

Direct costs are important elements of cost and often account for 30 to 60 percent of total cost. But equally important consideration is that direct costs form the basis for allocating most of the indirect (overhead) cost. Direct costs of material and labor (manufacturing and engineering), in particular, often serve as bases for the application of costs from overhead pools. If the price to the government (Figure 9-3) is the total of direct cost (material and labor), indirect cost, general and administrative cost, cost of facilities capital and profit, then a change in direct cost can produce a much larger change in price to the government. This is due to the wrap rates of G&A (25 percent) and Profit (15 percent) multiplies the effect of changes.

9.4.4 Indirect Cost

An indirect cost can be defined as " *any cost not directly identified with a single, final cost objective, but identified with two or more final cost objectives or an intermediate cost objective* ." After direct costs have been determined and charged directly to the contract or other work, indirect costs are those remaining to be allocated to the cost objectives. Indirect costs cannot be directly attributed to the manufacturing of a specific product. Utilities are an example of indirect costs because it is extremely difficult to identify which products used the energy. Employee's who are not working on specific products are considered indirect. Another way to look at indirect cost is to look at costs or expenses that are shared by more than one product or function. So the company's legal organization is usually considered an indirect cost as they support all other organizations and functions and usually do not allocate cost to specific products.

Direct material	$ 40,000
Material handling 10%	4,000
Direct engineering labor	6,000
Engineering overhead 100%	6,000
Direct manufacturing labor	12,000

Manufacturing overhead 150%	18,000
Other direct costs	6,000
Subtotal	92,000
General and administrative 25%	23,000
Total cost	115,000
Profit 15%	17,250
Cost of money for facilities capital	1,500
Price	$ 133,750

Figure 9-4 Indirect Cost

9.4.5 Nonrecurring Cost

At the beginning of a production program, the contractor expends funds to establish the specific capability to manufacture the weapon system or equipment. These nonrecurring costs are a one-time expenditure and generally include such things as special tooling, special test equipment, plant rearrangement and the preparation of manufacturing instructions. The objective of the contractor and program office should be the definition and achievement of a level of nonrecurring cost that will minimize total cost of manufacture. The investment in nonrecurring costs can be evaluated as a tradeoff decision in that improved tools, test equipment and planning can result in lower recurring cost.

9.4.6 Recurring Cost

Recurring cost are the costs which must be incurred each time a unit of equipment is produced, such as direct labor and direct materials. The relative levels of recurring and nonrecurring costs can be evaluated in investment terms since the nonrecurring costs should provide the capability to manufacture the equipment with a lower direct labor input per unit. The total cost to manufacture is the sum of the recurring cost plus an amortized share of the nonrecurring cost. As a result of the relationship, decisions on the level of nonrecurring cost should be based on a specific quantity to be produced and rate of production.

9.4.7 Other Cost

Two other cost types of manufacturing cost will be reviewed. They include:

1. Tooling Cost, and

2. Special Test Equipment.

9.4.7.1 Tooling Cost

Tooling is one of the major categories of preproduction and production cost. Tooling refers to special tooling consisting of jigs, dies, fixtures, and factory support equipment used in the production of end items, and does not include machines, perishable tool items, or small hand tools. Tooling cost can be a very significant budget item. The Joint Strike Fighter programs planned investment for production was estimated to go from $100 million a month in 2007 to $1 billion a month in 2013. And an additional $1.2 billion in tooling would be needed to ramp up the production rate to 143 aircraft a year.

The key issue in estimating and analyzing tooling costs is the planned rate and duration of production. The production rate and duration will establish whether there will be hard (durable) or soft (limited life) tooling; whether the tooling will be limited to the production rate required under the proposed contract, or whether it also anticipates production rates of future requirements or the need for surge or mobilization. If tooling is planned in anticipation of future orders, the justification for these plans should be verified. Follow-on purchases should always be analyzed in light of the type and extent of tooling authorized by the government in prior contracts. Any changes to the rate of production or quantity may have a significant impact on tooling costs. It is important that the contractor's tool planning be based on the needs of present and reasonably predictable future purchases.

There should be an inverse relationship between the amount of tooling and the number of direct labor hours expended per unit of product as tooling if often used to reduce touch labor. Analysis of tooling cost requires evaluation of material requirements recognizing that many contractors purchase all or a significant part of their basic tooling requirements. Analysis of the labor hours, labor rates, and overhead rates applied to the tool design, fabrication and maintenance efforts is still a significant cost item to be examined, even though passed on to a vendor.

9.4.7.2 Special Test Equipment Cost

The Federal Acquisition Regulation (FAR) Subpart 45.1 defines special test equipment, as "either single or multipurpose integrated test units engineered, designed, fabricated, or modified to accomplish special purpose testing in performing a contract. It consists of items or assemblies of equipment including standard or general purpose items or components that are interconnected and interdependent so as to become a new functional entity for special testing purposes. It does not include material, special tooling, facilities (except foundations and similar improvements necessary for installing special test equipment), and plant equipment items used for general plant testing purposes."

An example of special test equipment might be a microprocessor linked to a printout device so that specific reliability data required by the contract can be accumulated. If the cost of this equipment is large and the equipment has a useful life beyond the contract, the contractor should consider the equipment as a capital investment subject to depreciation over its useful life. While the capitalization of special test equipment may be determined by a policy consistently applied by the contractor, certain contracting rules will govern. The contractor's policy on capitalization should be discussed with the Administrative Contracting Officer (ACO) as to what practices would apply under the circumstances.

9.5 Cost Accounting

The Cost Accounting Standards (CAS) were developed to promulgate accounting practices designed to achieve uniformity and consistency in the cost accounting practices followed by defense contractors and subcontractors under Federal contracts as a condition of contracting. Vice Admiral Rickover and Senator Proxmire pushed for the development of standards in the late 1960's because of criticism in accounting practices of defense contractors. In 1970 the Cost Accounting Standards Board (CASB) was formally established and that board developed the cost accounting standards still in use today. The CASB has issued 19 cost accounting standards (Table 9-1) that have the full effect of law.

Standard No.	Title
401	Consistency in Estimating, Accumulating and Reporting Costs
402	Consistency in Allocating Costs Incurred for the Same Purpose
403	Allocation of Home Office Expenses to Segments
404	Capitalization of Tangible Assets
405	Accounting for Unallowable Costs
406	Cost Accounting Period
407	Use of Standard Costs for Direct Material and Direct Labor
408	Accounting for Costs of Compensated Personal Absence
409	Depreciation of Tangible Capital Assets
410	Allocation of Business Unit G&A Expenses to Final Cost Objectives
411	Accounting for Acquisition Costs of Material
412	Composition and Measurement of Pension Costs
413	Adjustment and Allocation of Pension Cost
414	Cost of Money as an Element of the Cost of Facilities Capital
415	Accounting for the Cost of Deferred Compensation
416	Accounting for Insurance Cost
417	Cost of Money as an Element of the Cost of Capital Assets Under Construction
418	Allocation of Direct and Indirect Costs
420	Accounting for IR&D Costs and Bid and Proposal Costs

Table 9-1 Cost Accounting Standards

Full CAS coverage applies to a contractor business unit that:

- Receives a single CAS-covered contract award of $50 million or more; or
- Receives $50 million or more in net CAS-covered awards during its preceding cost accounting period.

Contractors subject to full CAS coverage are required to:

- Disclose in writing their cost accounting practices;
- To follow the disclosed practices consistently; and
- To comply with duly promulgated cost accounting standards.

Modified CAS applies to a negotiated non-exempt contract of less than $50 million, but more than $500,000 awarded to a business unit that received less than $50 million in net CAS-covered awards during its preceding cost accounting period. Modified CAS coverage requires only that the contractor comply with CAS 401, 402, 405 and 406.

FAR 52.230-2 and FAR 52.230-3 requires that prime contractors flow the CAS requirements down to subcontractors and require subcontractors to flow them down to lower tier subcontractors.

9.5.1 Uniformity in Cost Accounting Systems

Cost accounting and cost data plays a large role in contract negotiation and settlement on contracts where there is less than full and open competition. The method of cost accounting can make a substantial difference in how costs are assigned and how costs are calculated on these non-competitive contracts.

Manufacturing control requires an understanding of how a contractor accumulates cost data and how costs are estimated. Contractor decisions regarding the estimated effort required to manufacturing a system will be largely influenced by the contractor's cost accounting system and the data generated from that system. Thus, planned production effort must be reviewed from a systems standpoint. The planned production effort (fabrication, assembly, etc.) can be further broken down into specific operations (welding, setup, windings, etc.). Cost accounting systems need to reflect the breakdown of the design components (WBS) and the breakdown (work packages) of the manufacturing processes used to fabricate those parts. It is at these levels that the process of cost incurrence and measurement must be understood (Figure 9-5).

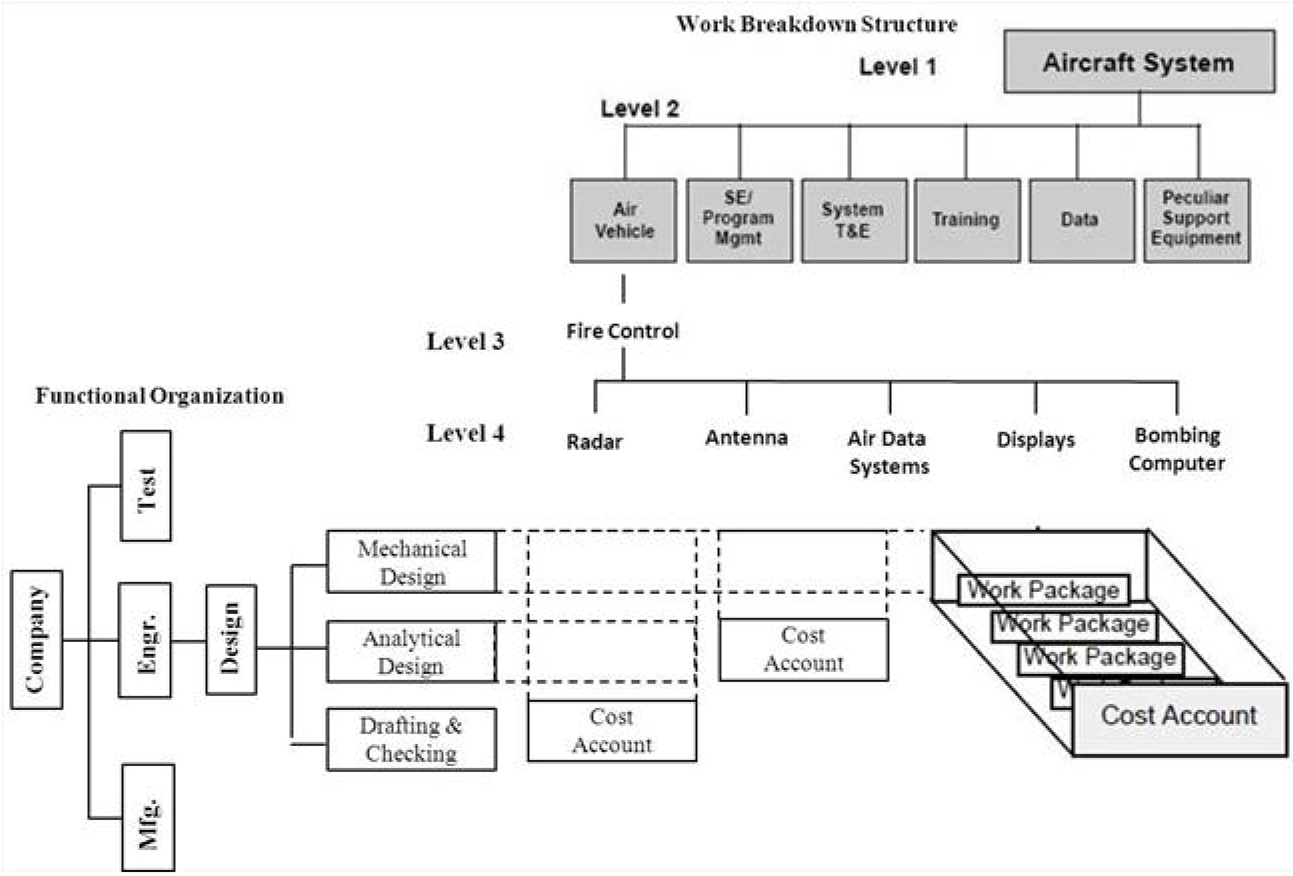

Figure 9-5 Aircraft WBS

The idea of standards is used to a considerable extent in all business and accounting data. If cost figures are to be used with confidence, they must meet standards as to their content. Direct costs should be discernible from indirect costs, not by how computations are made or by convenience in making such computations, but by some specified idea of what makes them different.

Public Law (PL) 91-379 represented a major step toward uniformity in cost reporting. This law requires contractors to ensure consistency and uniformity in their cost accounting practices in estimating, accumulating, and reporting cost; and to disclose such practices to the government.

Consistency in charging cost means that contractors must be consistent in charging both direct and indirect costs to government contracts. If a particular cost is identified as a direct costs, then it must be charged as a direct charge to all work projects for which it is intended. If a particular cost is identified as an indirect costs, then it must be charged to cost pools and allocated to direct work projects over an appropriate basis.

Incurring costs based on causation or benefit means that if you work on a specific project, then you charge your time to that project. If you buy material for a specific project, then it is charged to that project and not another project.

A firm's accounting system consists of the methods and records established to identify, assemble, analyze, classify, record, and report the firm's transactions and to maintain accountability for the related assets and liabilities. The accounting system should be well-designed to provide reliable accounting data and prevent mistakes that would otherwise occur. A cost accounting system that is unreliable can provide data that are not current, accurate, and complete data in support of an offeror's proposal. The defective cost data can create inaccurate estimates no matter how well the estimating uses the data provided.

Every firm has its own characteristics and individuality. These characteristics are often useful in adapting to the environment as to markets, products, supply or resources, and other factors and arise from sources that may even be somewhat beyond the control of owners or managers. Further, the operation of systems to collect and process data about operations is a part of the task of management, and the outputs of such systems are generally regarded as proprietary to the company. Therefore, while these costs are available to the government the information must be protected accordingly.

9.5.2 Cost Accounting Systems

There are two commonly-used systems for cost accounting, job-order and process. Either system can provide adequate results, when it is properly maintained by the firm. Each can be classified as either a historical cost system or a predetermined cost system, which makes possible four "pure" types of cost systems: (1) the historical job order cost system; (2) the predetermined job order cost system; (3) the historical process cost system; and (4) the predetermined process cost system. Most contractors, however, accumulate both historical data end predetermined data for use in estimating contract costs, and many contractors apply their own variations to the job order cost system and the process cost system.

9.5.2.1 Job Order Cost System

Under a job-order cost system the firm accounts for output by specifically identifiable physical units. The costs for each job or contract normally are accumulated under separate job orders.

- When a contract is for a limited number of units that are neither very complex nor costly, the costs of all units may be accumulated under one job order without any further breakdown.
- When the contract is for items that are both complex and costly, the total quantity may be broken down into smaller production lots. The job order for the total contract may be supported by a separate job order for each lot.
    - The use of lots permits the contractor to establish better control over the work, and the historical cost data from a series of lots lend themselves to a projection of estimated costs for future production.
    - Experience with the product normally determines the number of units for which costs are to be accumulated.

9.5.2.2 Process Cost System

Under a process cost system, direct costs are charged to a process even though end-items (which may not be identical) for more than one contract are being run through the process at the same time. At the end of the accounting period, the costs incurred for that process are assigned to the units completed during the period and to the incomplete units still in process.

- Process cost systems are typically used by firms that continuously manufacture a particular end-item, like automobiles which require identical or highly similar production processes. A process is one part of a complete set of activities that an item must pass through during manufacture.
- Normally an item will go through more than one process. When an item comes out of one process and enters another, its cost from the process just completed will be charged to the next process, usually as material cost. This continues until the completed end-item emerges from its last process.
- A process cost system identifies which factory employees charged their time to which processes, what their rates of pay were, and the total cost charged to the process.

9.5.3 Historical Cost Systems

When actual cost data are accumulated after operations have taken place, the cost accounting system is a historical cost system. Historical data are used in all cost accounting systems, at least as a base for comparing actual results with predicted results. The accumulation and application of historical data are important ingredients of a reliable cost estimate. To prevent distorted projections from "historical data, the following should be analyzed in determining expected costs for new products.

- Changes in plant layout and equipment;
- Changes in products, materials, and methods;
- Changes in organization, personnel, working hours, conditions, and efficiency;
- Changes in cost;
- Changes in managerial policy;
- Lag between incurrence of cost and reporting of manufacturing; and
- Random influences such as strikes and weather.

9.5.4 Predetermined Cost Systems

Predetermined cost systems are cost accounting systems in which data about the manufacture of an end product are accumulated before the end product is produced. A contractor using a predetermined cost system uses process and material information about a job to predict the costs for doing that job. When contractors use predetermined cost data, normally these data are substantiated by actual costs identified on previous end products.

9.6 Importance of Cost Estimating

Affordability is the degree to which an acquisition program's funding requirements fit within the agency's overall portfolio plan. Whether a program is affordable depends a great deal on the quality of its cost estimate. Therefore, agencies should follow a well defined estimating process to ensure that they are creating and making decisions based on credible cost estimates. Best practices would have them addressing the following:

- Defining the program's purpose;
- Developing the estimating plan;
- Defining the program's characteristics;
- Determining the estimating approach;
- Identifying ground rules and assumptions;
- Obtaining data;
- Developing the point estimate;
- Conducting sensitivity analysis;
- Performing a risk or uncertainty analysis;
- Documenting the estimate;
- Presenting it to management for approval; and
- Updating it to reflect actual costs and changes.

Following these steps ensures that realistic cost estimates are developed and presented to management, enabling them to make informed decisions about whether the program is affordable.

A program's approved cost estimate is often used to create the budget spending plan. This plan outlines how and at what rate the program funding will be spent over time. Since resources are not infinite, budgeting requires a delicate balancing act to ensure that the rate of spending closely mirrors available resources and funding. And because cost estimates are based on assumptions that certain tasks will happen at specific times, it is imperative that funding be available when needed so as to not disrupt the program schedule.

According to a GAO report (Implementation of a Cost-Accounting System for Visibility of Weapon Systems Life-Cycle Costs, dated Aug 2001) " *the lack of a common, robust cost-accounting process is one of the biggest obstacles to controlling and managing the cost of weapon systems for their useful life. Existing DOD accounting systems neither communicate with each other effectively nor organize program information in a way that is most useful to management. As a result, the DOD accounting systems provide only limited insight into the total cost of buying, operating, maintaining, and disposing of DOD inventories. The DOD Acquisition Reform Goal 10 required DOD to define requirements and establish an implementation plan for a cost-accounting system that provides routine visibility into weapon system life-cycle costs through activity-based costing and management. The system must deliver timely, integrated data for management purposes to permit understanding of total weapon costs, provide a basis for estimating costs of future systems, and feed other tools for life-cycle cost management* ."

9.7 Estimating Methodologies

Generally, the cost estimating technique used for an acquisition program progresses from the analogy to actual cost method as that program becomes more mature and more information is known. The analogy method is most appropriate early in the program life cycle when the system is not yet fully defined. This assumes there are analogous systems available for comparative evaluation. As systems begin to be more defined (such as when the program enters EMD), estimators are able to apply the parametric method. Estimating by engineering tends to begin in the latter stages of EMD and LRIP when the design is fixed and more detailed technical and cost data are available. Once the system is being produced or constructed (i.e., LRIP and Full Rate Production), the actual cost method can be more readily applied (See Figure 9-6).

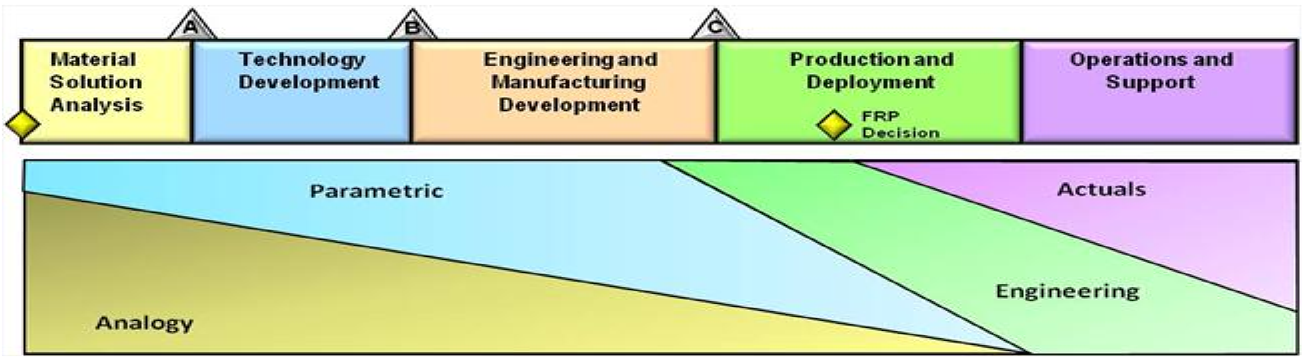

Figure 9-6 Cost Estimating Methodologies

Estimating is the method of generating a measure of an amount of work to be accomplished or resources required. It requires systematic study of the activity to be estimated and application of knowledge and skills to form a valid judgment regarding the cost of the work. The resulting estimate provides management with quantitative data for making decisions concerning these programs.

The initial decision that must be made in most estimating situations is the selection of an approach that will yield the most accurate, timely and current cost estimate. The choice of an estimating technique is not solely dependent upon the estimator's preference but is dictated by the estimating environment. The conditions that must be considered are:

- Comprehensiveness of the statement of work.
- Availability of pertinent actual cost data and product information.
- Type of contract, program and category of estimate.
- Customer and program requirements.
- Time available for preparation.
- End use of the estimate.

Cost estimating is based on interpretations of observed historical factors relevant to the task to be performed which are then projected into the future. These projections can be made in several different ways as discussed below.

The selection of a particular cost estimating method will be guided by the following considerations:

- Availability of historical data;
- Level of estimating detail required;
- Adequacy of the technical description of the item being estimated;
- Time constraints; and
- Purpose of the estimate.

The manufacturing cost estimator should consider using more than one method to generate the cost estimate. One may use a catalog price or an estimate prepared by a specialist to arrive at a cost estimate for a piece of equipment that represents a technological advance over existing hardware. The estimator may compare the cost of an analogous system element with that derived from using a Cost Estimating Relationship (CEA). Finally, even if one estimating method will suffice to estimate the cost of an item, the estimator should, whenever possible, use a different estimating method to check on the initial estimate.

9.7.1 Analogy

The analogy method compares a new or proposed system with one homogeneous (i.e., similar) system in which the form, fit, and function are alike. The analogous system should be acquired in the recent past, for which there is accurate cost and technical data. There must be a reasonable and logical correlation between the proposed and "historical" systems identified by the cost estimator. This subjective evaluation of the differences between the new system of interest and the historical system is documented by the estimator. The analogy method is typically performed early in the cost estimating process, such as the pre-Milestone A and Milestone A stages of a program. This is early in the life of a potential acquisition program when there may be a limited number of historical data points and the cost estimator may be dealing with technology that experiences rapid change. The analogy method is also a very common technique used for cross checking more detailed estimates (i.e., sanity check).

With so many new and emerging technologies and ideas, an analogy is often the only method available. Estimating by analogy may be the best technique for estimating the cost of state-of the-art systems such as a space vehicle, next-generation submarine, a future computer or a proposed microprocessor.

9.7.2 Parametric (Statistical)

The parametric, or statistical, method uses regression analysis of a database of two or more similar systems to develop cost estimating relationships (CERs) which estimate cost based on one or more system performance or design characteristics (e.g., speed, range, weight, thrust). The parametric method is most commonly performed in the initial phases of product description, such as after Milestone B when the program is in the EMD phase. Although during this phase an acquisition program is unable to provide detailed information (e.g., drawings and standards), the program can specify top-level system requirements and design characteristics. In other words, estimating by parametrics is a method to show how parameters influence cost.

Parametric estimating is used widely in government and industry because it can yield a multitude of quantifiable measures of merit and quality (i.e., probability of success, levels of risk, etc.). Additionally, CERs developed using the parametric method can easily be used to evaluate the cost effects of changes in design, performance, and program characteristics. Note the parametric method, which makes statistical inferences about the relationship between cost and one or more system parameters is very different from drawing analogies to multiple systems.

A critical consideration in parametric cost estimating is the similarity of the systems in the underlying database, both to each other and to the system which is being estimated. A good parametric database must be timely and accurate, containing the latest available data reflecting technologies similar to that of the system of interest (design, manufacturing/assembly, material). Of course, a general rule when collecting data for statistical analysis is the more data, the better. Finally, as with estimating by analogy, parametric data must be normalized to represent a given economic year and remove any quantity effects.

9.7.3 Engineering (Bottoms-Up)

The engineering or "bottoms-up" method of cost analysis is the most detailed of all the techniques and the most costly to implement. It reflects a detailed build-up of labor, material and overhead costs. Estimating by engineering is typically performed after Milestone C (i.e., Low Rate Initial Production (LRIP) approval) when the design is firm, minimal design changes are expected to occur, data is available to populate the Work Breakdown Structure (WBS), drawings and specifications are complete and production operations are well-defined in terms of labor and material.

This method is often used by contractors and usually involves industrial engineers, price analysts, and cost accountants. Based on the system's specifications, engineers estimate the direct labor and material costs of a work package. In calculating labor costs, company or industry standards are often used to estimate what labor categories are required and how many hours will be required for the task. The remaining elements of the work package cost, such as tooling, quality control, other direct costs and various overhead charges are calculated using factors based on the estimated direct labor and or material content of the work.

9.7.3.1 Hypothetical Example of Estimating by Engineering

With this technique we start at the lowest level of definable work within the Work Breakdown Structure (WBS) (i.e., milling a flange). The direct labor hours required to complete the work are estimated from engineering drawings and specifications, usually by an industrial engineer (IE) using company or general industry "standards." The engineers also estimate raw materials and purchase parts requirements. The remaining elements of cost, such as tooling, quality control, other direct costs, and various overhead charges including systems engineering and project management, are factored from the estimated direct labor and/or material content of the work. The actual portion of the cost estimated directly is thus a fraction of the overall cost of the system.

The IE may use a variety of techniques in estimating the direct labor and material cost of each discrete work element. For example, the IE may use an analogy to estimate one work element; a parametric CER based on an industry database of like work elements to estimate a second work element; and a set of work standards based on work activities (e.g., milling .002 inches from a 6 inch diameter rod 3 inches long) to estimate a third work element. Uncertainty in this type of cost estimate is due to the use of multiplicative factors derived from various methods on the relatively small direct labor/material base that was estimated. This can result in significant error in the total system cost estimate. The uncertainty, however, can be assessed and managed. Another potential problem is that because the cost estimate is the summation of many estimates, it may be hard to maintain the documentation to support the estimate.

Since, in most cases, the engineering estimate is based on standards, either company-specific or industry-wide, the contractor's cost estimate should be "attainable." By definition, standards are attainable values for specific work under given conditions. The engineering estimate is thus a tool for the manufacturer to control the work on the floor (process control). The technique has its greatest value once the design has stabilized and the system is in production.

9.7.4 Actuals

Actual cost experience on prototype units, early engineering development hardware and early production hardware for the program under consideration should be used to the maximum extent possible. If development or production units (or components) have been produced, the actual cost information should be provided as part of the documentation. Estimates for Full Rate Production decision reviews are to be based at least in part on actual production cost data for the systems under review.

Estimating by actual costs is essentially, an extrapolation of current program cost. In other words, you would estimate a trend from your current contract to estimate your final system's cost. The cost data is internal to current system being constructed, not the same as "actual" historical data. There are several conditions that enable this estimating method to be possible.

- A program must be in low rate initial production (LRIP) or full rate production (FRP) otherwise there is nothing "actual" from which to base actual costs.
- There must be a data management system already in-place that enables the DOD agency the ability to review accumulated actual costs as the system or prototype is being fabricated and assembled. The reporting process typically a.) occurs monthly or quarterly; b.) requires the contracting agent to provide percent-of-work completed to date; and c.) requires the contracting agent to provide the cumulative cost it has expended for the completed work-to-date.

9.7.5 Estimating Considerations

Estimating techniques may be different for every cost element and may change due to:

- Acquisition Phase of the Program, and
- Maturity of the Individual WBS Element.

9.7.5.1 Acquisition Phase as a Consideration

The techniques used to develop the estimates for cost elements should take into account the acquisition phase that the program is in when the estimate is made and the quality of the data that might be available for the estimate. The matrix presented in Table 9-2 provides a summary of each of the four estimating methods. Each method is described in terms of what it is, when it typically should be or could be used, how it is accomplished, and the advantages (pros) and disadvantages (cons) of using that particular estimating method.

	Estimating by ANALOGY	**Estimating by PARAMETRICS**	**Estimating by ENGINEERING**	**Estimating by ACTUAL COSTS**
What is it?	Single value from single data point	Measure of trends across programs	Detailed build-up of Lab, Mtl & OH $	An extrapolation of current program cost
When used?	Early in Program Pre-MS A & MS A	MS B	Late in Program MS C & LRIP	LRIP Full Rate Production
How is it done?	Adjust analogous system cost or create cost factor	Apply statistical methods to cost of 2 or more systems: i.e. Develop a CER	Estimate at lowest cost level & sum costs by WBS	Use trend from your current contract to estimate your final system $
Pros	Fast, Inexpensive Easy to change	Based on > 1 data point => less risky Can measure error Easy for what-ifs	More detail enables better visibility into cost drivers	Most costs are known CAIG prefers over other methods
Cons	Based on single historical data point => risky! Tends to be more subjective	Constrained by amount & quality of data (GIGO) Statistics can be misleading	Labor Intensive Slow, Expensive Can lose sight of "big picture"	Usually too late to use actual costs to adjust or build budget Not a 1:1 correlation of prototype-to-production costs

Table 9-2 Cost Estimating Matrix

9.7.5.2 WBS Maturity as a Consideration

While the program or system may be in a particular acquisition phase if you take a close look at the work breakdown structure (WBS) you will most likely find that some elements of the WBS are more mature than other elements. Thus you may have more accurate estimates for the more mature elements.

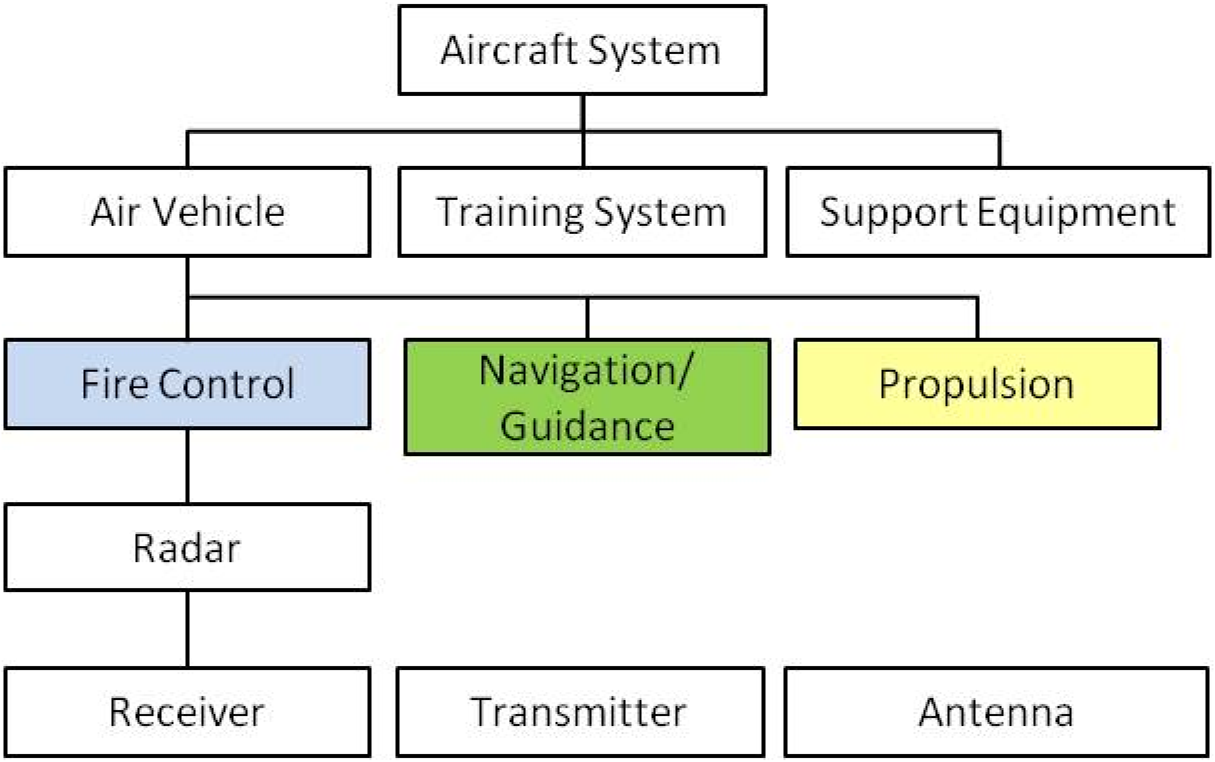

Figure 9-7 Maturity as a Consideration

Figure 9-7 is a good example of how different levels of product maturity within a WBS may impact the cost estimate. In this case the propulsion system is a new start and has several new technologies, therefore the estimator may opt to use analogy to estimate the cost. The navigation/guidance unit is already in production on another like system and there are no intended design or manufacturing changes, therefore the estimator will probably elect to use actuals to estimate costs. The final example is the fire control, which has been prototyped and the contractor has experience on several like systems, therefore the estimator may elect to use parametrics to estimate cost. At the air vehicle level, the cost estimate is a composite estimate using several different estimating techniques based on the maturity of the lower level WBS elements.

9.8 The Learning Curve

When we estimate the cost or price of an item, whether it is based on a detailed cost build-up, an analogy, catalog price, or a cost estimating relationship, the cost or price may not address the effect of quantity or of learning. The learning curve (cost improvement curve, or experience curve) is a well-known approach to modeling the effect of quantity on cost. This technique was first discussed in the journals of the 1930's and continues as an industry standard today both in commercial and non-commercial (government) applications.

9.8.1 Concept

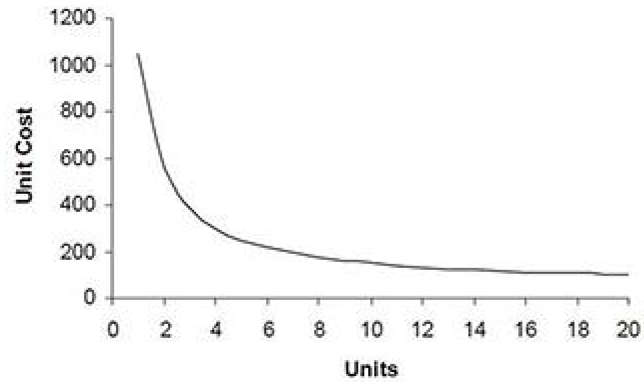

Figure 9-8 Learning Curve

Learning curve theorizes that people and organizations learn to do things more efficiently when performing repetitive tasks. The more often the task is performed or repeated, the more efficient the worker becomes and the less time it takes to perform those task. There is a usable pattern (Figure 9-8 learning curve) to the learning. And that pattern is different for different conditions. For that reason a number of different learning curves have been developed. Learning curves are generally drawn showing that as the number of units produced doubles, the unit cost decreases in a predictable pattern.

The learning curve was adapted from the historical observation that individuals performing repetitive tasks exhibit an improvement in performance as the task is repeated a number of times. Empirical studies of this phenomenon yielded three conclusions on which the current theory and practice is based:

1. The time required to perform a task decreases as the task is repeated.

2. The amount of improvement decreases as more units are produced.

3. The rate of improvement has sufficient consistency to allow its use as a prediction tool.

9.8.2 Components of Improvement

Theodore P. Wright created the "learning curve" math model in 1936 and the model was used during World War I to estimate aircraft production costs. The initial studies attributed the improved productivity or efficiency to improved motor skills as the workers repeated their tasks. Thus tasks with a lot of touch labor tended to get the most attention. However, worker learning is just one of the components which contribute to efficiencies and it was later realized that management could also be a contributor to the achievement of efficiencies. From Table 9-3 it can be seen that the total improvement is a combination of personnel learning and management action. While some study has been done, there is no general rule concerning the relative contribution of the specific elements.

- Worker Learning
- Supervisor Learning
- Reductions in Crowded Workstations
- Tooling Improvements
- Design Producibility Improvements
- Improved Work Methods
- Improved Planning and Scheduling
- Increased Lot Sizes
- Reduced Engineering Change Activity
- Reduction in Scrap and Rework
- Better Operation Sequencing and Synchronizations

Table 9-3 Factors Leading to Manufacturing Improvement

9.8.3 Characteristics of Learning Environment

While learning is found in almost all elements of the defense industry, its impact is most pronounced when certain characteristics are present.

1. The first characteristic is the building of a large complex product. requiring a large number of direct labor hours.

2. The second is continuity of manufacturing to preclude loss of accrued improvements during production breaks.

3. The third characteristic is an element of continuing change in the product. This third characteristic can present some problems in analysis using the manufacturing improvement curve.

The historical data on which a company's improvement curve is based contain the effects of an engineering change activity which can be characterized as "normal." During the analysis of the program of interest, changes which are developed need to be evaluated to determine whether they are "normal" and already accounted for by the learning curve, or major changes which must be the subject of a contract modification. The decision needs to be made on the basis of the unique situation involved in the program. This should be done in the context of the nature of the historical contractor activity which was used to develop the learning curve used in the contract negotiation.

9.8.4 Key Words Associated With Learning Curves

To utilize learning curve theory, certain key phrases listed below are of importance:

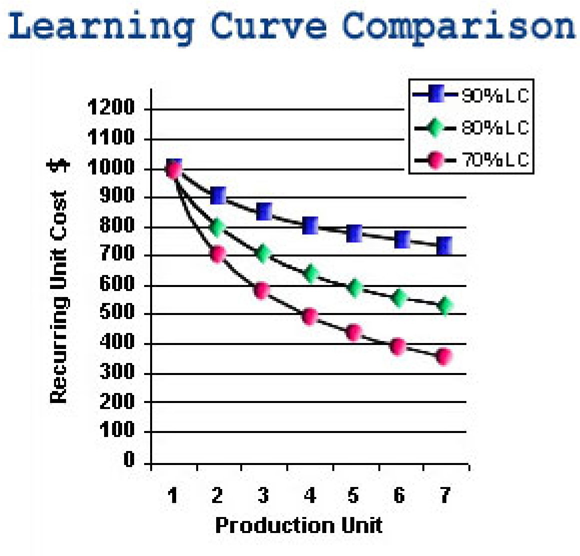

Figure 9-9 Learning Curve Comparisons

- Slope of the Curve - Is a percentage figure that represents the steepness (Figure 9-9 shows the slopes of three different learning curves) of the curve. Using the unit curve theory, this percentage represents the value (e.g., hours or cost) at a doubled production quantity in relation to the previous quantity. For example, with an learning curve having an 80 percent slope, the value at unit two is 80 percent of the value of unit one; the value at unit four is 80 percent of the value at unit two; the value at unit 1,000 is 80 percent of the value at unit 500.
- Unit One - The first unit of product actually completed during a production run, This is not to be confused with a unit produced in any preproduction phase of the overall acquisition program.
- Cumulative Average Hours - The average hours expended per unit for all units produced through any given unit.
- Unit Hours - The total direct labor hours expended to complete any specific unit.
- Cumulative Total Hours - The total hours expended for all units produced through any given unit.

9.8.5 Learning Curve Theories

There are two fundamental models of the learning curve in general use:

1. The cumulative average curve, and

2. The unit curve.

The cumulative average curve's (T. P. Wright) underlying hypothesis is that the direct labor man-hours necessary to complete a unit of production will decrease by a constant percentage each time the production quantity is doubled. If the rate of improvement is 20 percent between doubled quantities, then the learning percent would be 80 percent (100-20=80). The cumulative average combines each sequential lot with the preceding lots and calculates an average cost. This is sometimes referred to as smoothing the data. This technique helps to reduce the effect of variation in the data and produces better statistical models. While the learning curve emphasizes time, it can be easily extended to cost.

The unit curve was developed by James R. Crawford in 1947 and used by the Army Air Corps to study airframe production. The unit curve focuses on the hours or cost involved in specific units of production and treats each lot as a separate reference point. The theory can be stated as follows:

- As the total quantity of units produced doubles, the cost per unit decreases by some constant rate.
- The constant rate by which the costs of doubled quantities decrease is called the rate of learning.
- The "slope" of the learning curve is related to the rate of learning. It is the difference between 100 and the rate of learning. For example, if the hours between doubled quantities are reduced by 20 percent (rate of learning) it would be described as a curve with an 80 percent slope.

The difference or amount of labor-hour reduction is not constant. Rather, it declines by a continually diminishing amount as the quantities are doubled. The amount of change over the "doubling" period has been found to be a constant percentage of cost at the beginning of the doubling period.

When selecting a learning curve model keep in mind the expected production environment. Certain production systems or environments favor one theory over the other:

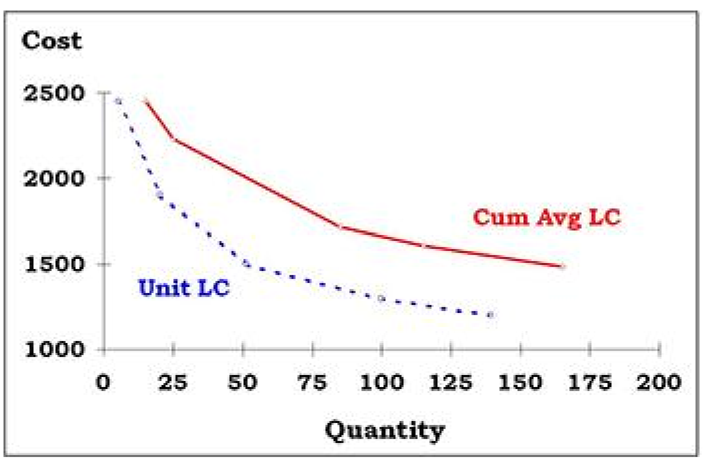

Figure 9-10 Cum vs Unit Learning Curves

- Unit Curve (Crawford method) is best used if the contractor is starting production with prototype tooling, has an inadequate supplier base established, expects design changes or is subject to short lead times.
- Cumulative Average Curve (Wright method) is best used if the contractor is well prepared to begin production in terms of tooling, suppliers, lead times, etc.

The cum average curve is based on the average cost of a production quantity rather than on the cost of a particular unit. This makes the cum average cost less responsive to cost trends than the unit cost curve. A larger change is needed in the cost of an unit or lot of units before there is a change in the cum average curve. This is the reason the cum average curve is always higher than the unit cost curve (Figure 9-10). Most government negotiators prefer to use the unit cost curve since it is lower than and more responsive to recent trends than is the cum average cost curve.

9.8.6 Developing Slope Measures

Activity	Typical Slope
Aerospace	85%
Shipbuilding	80 - 85%
Electronics	90 - 95%
Machine Tools	75% - 85%
Machining	90 - 95%
Welding	90%
Raw Materials	93 - 96%
Purchased Parts	85 - 88%

Source: http://cost.jsc.nasa.gov/learn.html

Figure 9-11 Typical Learning Curve Slopes

Research by the Stanford Research Institute revealed that many different slopes were experienced by different manufacturers, sometimes on similar manufacturing programs. In fact, manufacturing data collected from the World War II aircraft manufacturing industry had slopes ranging from 69.7 percent to almost 100 percent. These slopes averaged 80 percent, giving rise to an industry average curve of 80 percent. Other research has developed measures for other industries such as 95.6 percent for a sample of 162 electronics programs. Learning percent is usually determined by statistical analysis of actual cost data for similar products or processes. Figure 9-11 shows typical slopes for a variety of activities. Unfortunately, the industry average curve is frequently misapplied by practitioners who use it as a standard or norm. When estimating slopes without the benefit of data from the plant of the manufacturer, it is better to use learning curve slopes from similar items at the manufacturer's plant, rather than the industry average.

The analyst needs to know the slope of the learning curve for a number of reasons. Accordingly, the slope of the learning curve is usually an issue in production contract negotiation. The slope of the learning curve is also needed to project follow-on costs using either the learning tables or the computational assistance of a computer.

9.8.7 Selection of Learning Curves

Existing learning curves, by definition, reflect past experience. Trend lines are developed from accumulated data plotted on logarithmic paper (preferably) and "smoothed out" to portray the curve. The data may have been accumulated by product, process, department, or by other functions or organizations. But whichever learning curve or method of data accumulation is selected for use, the data should be applied consistently in order to render meaningful information to management. Consistency in curve concept and data accumulation cannot be overemphasized because existing learning curves play a major role in determining the projected learning curve for a new product. This in turn plays a major role is estimating cost.

When selecting the proper curve for a new production item when only one point of data is available and the slope is unknown, the following, in decreasing order of magnitude, should be considered:

- Similarity between the new item and an item or items previously produced;
- Addition or deletion of processes and components;
- Differences in material, if any;
- Effect of engineering changes in items previously produced;
- Duration of time since a similar item was produced;
- Condition of tooling and equipment;
- Personnel turnover;
- Changes in working conditions or morale;
- Other comparable factors between similar items;
- Delivery schedules;
- Availability of material and components;
- Personnel turnover during production cycle of item previously produced; and
- Comparison of actual production data with previously extrapolated or theoretical curves to identify deviations.

It is feasible to assign weights to these factors as well as to any other factors that are of a comparable nature in an attempt to quantify differences between items. These factors are again historical in nature and only comparison of several existing curves and their actuals would reveal the importance of these factors.

When production is underway, available data can be readily plotted, and the curve may be extrapolated to a desired unit. However, if production has yet to be started, actual unit one data would not be available and a theoretical unit one value would have to be developed. This may be accomplished in one of three ways:

- A statistically derived relationship between the preproduction unit hours and first unit hours can be applied to the actual hours from the preproduction phase.

- A cost estimating relationship (CEA) for first unit cost based upon physical or performance parameters can be used to develop a first unit cost estimate.
- The slope and the point at which the curve and the labor standard value converge are known. In this case a unit one value can be determined. This is accomplished by dividing the labor standard by the appropriate unit value.

9.8.8 Production Breaks

A manufacturing or production break is the time lapse between the completion of an order or manufacturing run of certain units of equipment and the commencement of a follow-on order or restart of manufacturing for identical units. This time lapse disrupts the continuous flow of manufacturing and constitutes a definite cost impact. The time lapse under discussion here pertains to significant periods of time (weeks and months) as opposed to the minutes or hours for personnel allowances, machine delays, power failures, and the like.

Since the learning curve has a time/cost relationship, a break will affect both time and cost. Therefore, the length of the break becomes as significant cost factor. It is important to determine the cost of this break in manufacturing. Figure 9-12 graphically depicts how a production break causes the learning curve to shift upwards based on the amount of learning that has been lost. This reset in the learning curve also causes the cost to go up. Take for example what might happen if there were a break in the production of submarines. Welders who work on submarines are required to be specially trained and certified. The training and certification process takes 18-24 months to complete. Imagine what would happen to manpower utilization and cost if the workers lost their certification and had to be recertified before production could restart.

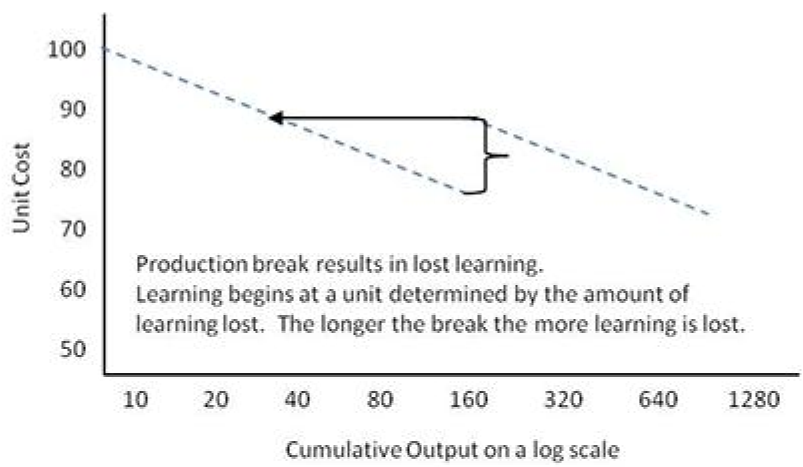

Figure 9-12 Effect of Production Breaks

9.9 Manufacturing Rate and Quantity Cost Relationship

The rate at which items are completed and delivered is directly related to the manufacturing cost of the program. Any time the rate of manufacturing and/or the overall quantity to be manufactured changes, production efficiency can suffer, leading to increased cost. An effective production line is designed to produce at a cost-effective rate and quantity depending on the product/process structure (Figure 9-13). Increases and decreases to the projected rate and quantity can result in under- (too little) or over- (too much) production capacity. Both situations can result in cost increase to the program. Generally, higher manufacturing rates will allow for greater economies of scale and result in lower unit cost and lower program cost for a fixed quantity.

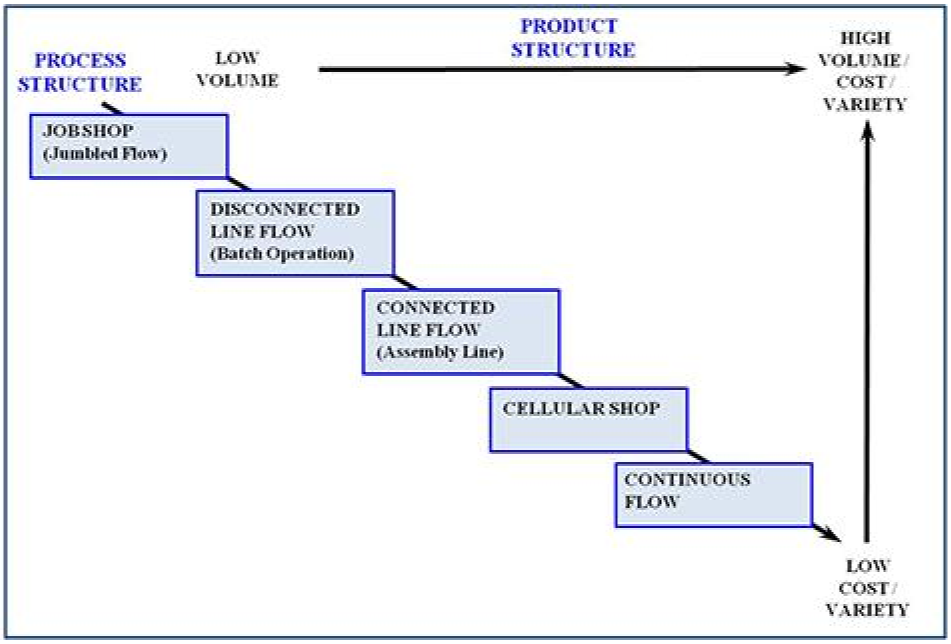

Figure 9-13 Rate and Quantity Cost Relationship

The PM must be aware of manufacturing rate characteristics impacting cost. These characteristics include the extent to which the manufacturing process is machine paced or labor paced, the number of shifts employed or available, and the mechanism by which different rates are accommodated. Each program's manufacturing characteristics will be unique - ranging from low volume, labor intensive, and high cost to highly automated, high volume and low cost. The variety of circumstances encountered might include steady manufacturing rates, breaks in manufacturing, rates buffeted by multinational considerations, extended periods of low rate manufacturing while awaiting improved version approval, and the like.

Within many manufacturing facilities, total overhead is relatively insensitive to changes in manufacturing rate. Increases in the rate thus provide more units to which those costs can be applied within a specific area. The facility also benefits from some of the economies of scale such as:

- Increased specialization,
- Greater opportunity for tooling,
- Increase use of shop aids, and
- More intense facility usage.

Figure 9-14 Rate Boundaries

Figure 9-14 defines some of the general boundaries for the rate decision. If the program has a high level of technical risk, It is generally better to hold to lower rates until the risk is reduced and the value of the manufacturing output is known. There is a boundary shown on the right side of the figure relating to the issue of technological obsolescence. If the rate is held too low, it is possible that units produced at the end of production phase of the program will represent technology that is obsolete in terms of its ability to meet the defined threat. Somewhere between the maximum and minimum rate is where most DOD programs operate.

There also tends to be a maximum rate which can be supported by the defined manufacturing facility. These rates are rarely reached in most DOD programs except for short periods. This is due in part to the effects of the learning curve on the manufacturing environment and in part to other economic factors. Take for example the decision by the administration and NASA to cancel the Constellation program in the 2011 budget. That decision sent gigantic ripples throughout the prime contractors supply chain but nowhere was it felt more than at American Pacific Corporation (AMPAC) maker of Ammonium Perchlorate (AP) used in the production of solid rocket motors. As a result of the cancellation of the Constellation program, production at the AP plant was cut by almost 80 percent. Given the fact that fixed costs remained fixed, this left the company one option, charge the government (through the prime contractor) more money. A lot more money to cover the change to the "envelope of reasonable time/rate options."

Government and industry both benefit from economic order quantity (EOQ) rates of production, and from stability in production year after year. Unfortunately, quantity cutting and turbulence to meet budget targets is widespread. Production rates are a critical part of any acquisition strategy. These concerns caused AT&L to issue a memo (14 Sep 2010) that directed that " *production rate to be part of the affordability analysis presented at Milestones A and B. Furthermore, at Milestone C, I will set a range of approved production rates. Deviation from that range without my prior approval will lead to revocation of the Milestone* ."

Recent examples where the Department ensured cost savings by implementing economical production rates include the Navy's E-2D Advanced Hawkeye program and the Air Force's Small Diameter Bomb (SDB) II program. During reviews for initial production for both programs, business case analyses demonstrated significant dollar savings and more rapid achievement of operational capability, with the use of aggressive but attainable production profiles. Those EOQs were directed and are expected to realize savings of $575 million for the E-2D and $450 million for the SDB II as a result.

9.10 Other Cost

There are several other cost methodologies or cost tracking systems that should be considered in our efforts to understand, manage and control manufacturing costs. These other methodologies include:

- Design to Cost,
- Should Cost,
- Will Cost,
- Activity Based Cost Accounting,
- Earned Value Management, and
- Work Measurement.

9.10.1 Design to Cost

The Design to Cost (DTC) approach was created in the mid-1970's as a cost cutting initiative. The underlying objective of DTC was to identify cost drivers early in the systems life cycle so that trade-off decisions could be considered and ways to mitigate those costs identified. DTC accomplished this by making cost a design parameter by constraining design options to a fixed cost limit. The focus of DTC at that time was on designing the system to minimize development and production costs for a particular performance level with little or no attention given to reducing operating and support (O&S) costs.

DTC is a management concept that historically emphasized cost-effective design (minimizing cost while achieving performance) and targeting an Average Unit Procurement Cost (AUPC). DTC concentrates on the contractors' activities associated with tracking/controlling costs and performing cost-performance analyses/tradeoffs. Cost as an Independent Variable (CAIV) came along in 1996 and refocused DTC to consider cost objectives for the total life cycle of the program and to view CAIV with the understanding it may be necessary to trade off performance to stay within cost objectives and constraints. DTC is now those actions that are undertaken to meet cost objectives through explicit design activities. DTC has fallen into disuse since the development of CAIV and the emphasis on fixed price production contracts.

9.10.2 Will Cost

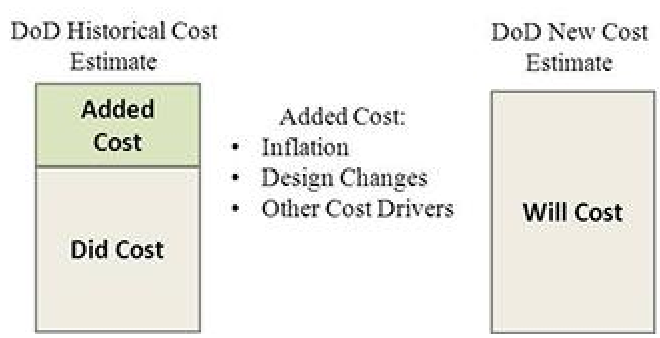

Figure 9-15 Did Cost vs. Will Cost

The DOD currently employs a two-tier cost, funding and management approach that utilizes two separate cost estimates. A "will cost" is used to for budgeting while the "should cost" is used for program execution.

The programs budget baseline is based on a will cost estimate and is sometimes referred to as the Independent Cost Estimate (ICE) or verified Program Office Estimate. This estimate is historical in nature (Figure 9-15) and aims to provide sufficient funds to execute the program under normal conditions (average program risks). This will cost estimate is used to supports the budget and ensures sufficient funding to provide confidence that:

- The program can be completed without the need for a significant adjustment to the budget; and
- The program can avoid Nunn-McCurdy or other critical change breeches.

Will cost estimates shall be verified by an office that is external to and independent of the program office. Additionally, it is DOD policy that programs actively manage the budget baseline using the current will cost estimates for all acquisition, budget and program execution decisions (e.g. source-selection, contract negotiations, major reviews, etc.).

9.10.3 Should Cost

Should cost is not new, the practice has been around since the 1980's. But the current thinking on should cost is quite different from the should cost reviews conducted almost three decades ago. Today's should cost reviews represents a dramatic change from the assumption that you should use historical data to establish a program's cost. Service and Agency independent cost estimates (ICE), sometimes referred to as independent government cost estimate (IGCE), were often calculated using historical data (using analogy, parametrics, engineering or actuals) to come up with the government estimate. But these estimates did not take into consideration the inefficiencies inherent in the manufacturing system that will be employed to fabricate and assemble the final product.

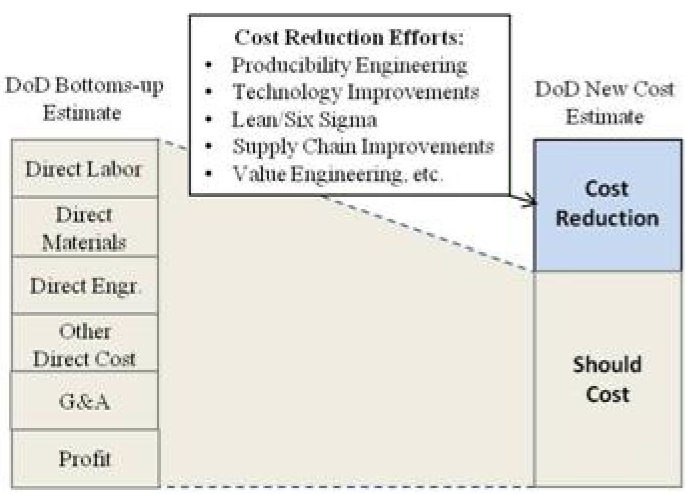

Figure 9-16 Should Cost

A should cost review recognizes that it is to everyone's advantage to promote greater efficiency than is currently in place. A should cost review uses an integrated team to conduct coordinated, in-depth cost analysis at a contractor's planning and on-going efforts. The purpose of the review is to identify inefficient and uneconomical contractor practices, to quantify the impact of these practices on system cost, and to use the findings to develop a realistic price objective (Figure 9-16). The approved cost reduction efforts or initiatives will be used to incentivize contractor performance towards achievement of the new "should cost" target.

The should cost analysis is intended to not only evaluate proposed contractor costs, but to then track and monitor those costs and to identify further savings opportunities that will lead to further cost reductions. There are three recommended approaches to developing a should cost estimate. These include:

1. The should cost estimate is developed using the will cost estimate as the base, and applying discrete, measurable items and/or specific initiatives for savings against the baseline. This is the recommend approach for all programs with an established will cost estimate.

2. The should cost estimate is developed using a bottoms-up approach without a detailed FAR/DFARS should cost review and includes actionable content that will lead to achieving cost below the will cost estimate or budget baseline. The bottoms-up approach can be performed at the very lowest levels or at higher levels, and is primarily defined as using methods distinctly different from the will cost estimate development.

3. The should cost estimate is developed using a bottoms-up approach with a FAR/DRAFS should cost review and includes actionable content that will lead to achieving cost below the will cost estimate or budget baseline.

9.10.4 Activity Based Cost (ABC) Accounting

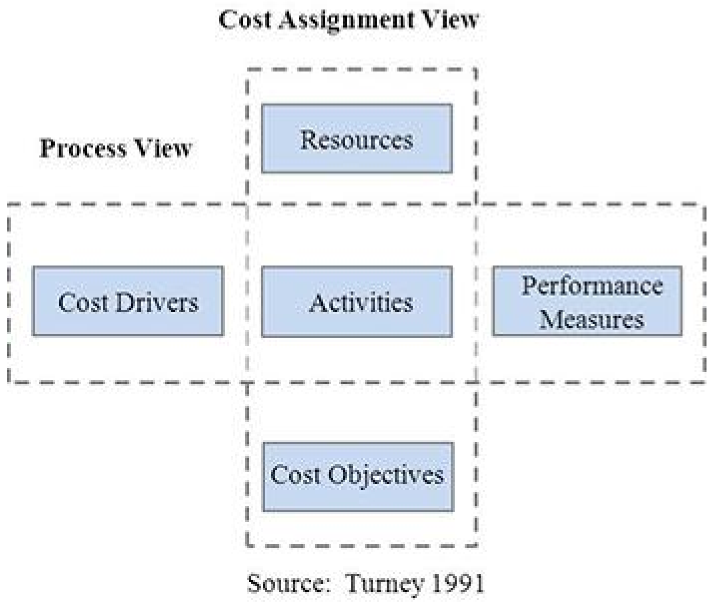

Figure 9-17 Two Views of ABC

ABC is a methodology that measures the cost and performance of activities, resources, and cost objects to provide more accurate cost information for managerial decision making. Understanding cost is a necessary management task. If a manager does not know how much it cost to produce an item, then they will not know what to charge for it. If the item is underpriced, the company loses money. If the item is overpriced, the company will lose customers and market share. Traditional cost accounting systems allocate overhead evenly. This is fine if the company is producing only one product, but what happens if they are producing more than one product. It is important to understand which products use the most resources or have the most activities associated with their production.

Under ABC costs are expressed in terms of resources, activities, and products. ABC assumes that work or activities are performed to create products and that resources are consumed by the work. As shown in Figure 9-17, there are two views of ABC: a cost assignment view and a process view. The cost assignment view assigns costs to the significant activities of an organization. Activities are then assigned to a cost object that uses the activities such as a product or customer. The process view provides operational intelligence about the processes of an organization. A process is a series of activities that are linked together to achieve an objective. The process view provides information about cost drivers and performance measures for each activity or series of activities in a process.

Activity Based Cost (ABC) accounting assigns overhead costs based on the number of units produced, or the number of machining hours, or labor hours used to produce an item. ABC assumes that there is a relationship between overhead and volume measures that is usually functionally oriented.

ABC is not an accounting exercise, but rather a methodology that produces a bill of activities that describes the cost buildup for individual products, services, or customers. By recognizing the causal relationships among resources, activities, and cost objects such as products or customers, ABC allows one to identify inefficient or unnecessary activities and opportunities for cost reduction or profit enhancement.

9.10.5 Earned Value Management

The primary objective of EVMS guidelines is to ensure that contractors use effective internal cost and schedule control systems that provide contractor and government managers with timely and auditable data to effectively monitor their programs, meet requirements, and control contract performance.

Earned value is a management technique that relates resource planning to schedules and to technical cost and schedule requirements. All work is planned, budgeted, and scheduled in time-phased "planned value" increments constituting a cost and schedule measurement baseline. There are two major objectives of an earned value system:

- To encourage contractors to use effective internal cost and schedule management control systems; and
- To permit the customer to be able to rely on timely data produced by those systems for determining product-oriented contract status.

EVMS surveillance begins with the award of the contract, continues through initial compliance and acceptance, and extends throughout the period of contract performance. In accordance with DOD policies and procedures, EVMS surveillance of the contractor's system after acceptance, and review of data emanating from that system, is to be accomplished by qualified individuals from the Contract Management Office (CMO) and DCAA. The objectives of EVMS surveillance are:

- To ensure that the contractor's management control system continues to: (1) provide valid and timely management information; (2) comply with the DOD EVMS guidelines; (3) provide timely indications of actual or potential problems; and (4) provide baseline integrity.
- To ensure that the contractor's required external cost and schedule reports contain: (1) information that is derived from the same data base as that used by contractor management; (2) explicit and comprehensive variance analysis including proposed corrective action in regard to cost, schedule, technical, and other problem areas; and (3) information that depicts actual conditions.

9.10.6 Work Measurement

Work Measurement is a technique used to establish labor standards to measure and control the time required to perform a particular tasks. Labor standards are often developed and applied in manufacturing operations and are used to:

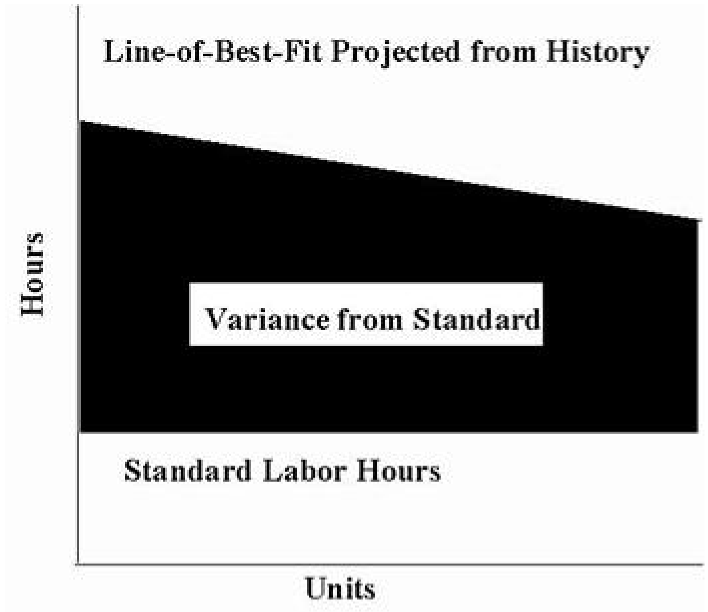

Figure 9-18 Typical Labor Standard

- Analyze the touch labor content of an operation;
- Establish labor standards for that operation;
- Measure and analyze variances from those standards; and
- Continuously improve both the operation and the labor standards used in that operation.

A labor standard is a measure of the time it should take for a qualified worker to perform a particular operation. The standards developed define the time necessary for a qualified worker, working at a pace ordinarily used, under capable supervision, and experiencing normal fatigue and delays, to do a defined amount of work of specified quality when following the prescribed method. As a result, you can use engineered standards to examine contractor estimated labor hours (costs) and to identify any projected contractor variances from that estimate. Figure 9-18 is a log-log graph that presents a line-of-best-fit developed using actual labor-hour history. Note that this line follows the form of the improvement curve. Without labor standards, the firm and the government would likely project the improvement curve to estimate the labor hours required to produce future units.

Labor standards provide additional information that can be used in estimate development and analysis. The vertical distance between the labor-hour history and the labor standard represents the variance from the standard. Some of that variance may be related to inefficiencies that cannot be resolved. However, all elements should be targeted for identification and analysis. Key elements include:

- Technical factors (e.g., manufacturing coordination, engineering design changes, fit problems, design errors, operation sheet errors, tooling errors, work sequence errors, and engineering liaison problems).
- Logistics (e.g., incorrect hardware and parts shortages).
- Miscellaneous factors (e.g., unusual working conditions, excessive overtime, and excessive fatigue).

- Worker learning (e.g., familiarity with processes and methods).

Variance analysis should be used to identify, categorize, and develop plans to control all variances from standard. Plans will typically concentrate on the operations with the largest variances from standard, because these operations present the greatest opportunity for cost reduction.

9.11 Some Interesting Points

Point 1 : Some people try to apply a standard learning curve (e.g. 85 percent for aerospace) without doing the analysis. And others try to assign an arbitrary number to a learning curve for purposes of negotiations or to make the cost match the budget. Learning curves are not driven by what the financial people want to see. They are driven by:

- The inherent factory floor and 5Ms (manpower, machines, material, methods and measurements) that is being used or will be used to produce the product;
- By the design of the item being produced and how "producible" or "unproducible" the design is; and
- By technology.

Thus an aerospace firm that has a product with a lot of touch labor will probably have a lower learning curve that one with a product that does not have much touch labor.

Point 2 : Do not mix products technologies and learning curves and come up with a composite curve (Figure 9-22). For example, a factory producing three different products, one is very labor intensive, another is driven by material or subcontractor costs, and a third may use different technologies. Each of these has their own learning curve and associated costs (see discussion on activity based cost accounting). Assigning the same learning curve to each may make one look profitable when in fact it is losing the company money.

Point 3 : The cost of "unit 1" or the first unit is the baseline cost and future cost come off of this unit. Thus it is important to establish "affordability" up front and early. Many people make the mistake of trying to force the cost to meet the budget under the guise of DTC or CAIV and then plan on achieving cost goals at "unit 100." This is in itself not a bad approach, but if you do nothing to drive down the cost of unit 1 from the very beginning, then you probably will have no chance of achieving your DTC or other cost/affordability goals. Producibility engineering, for example, is a key determinant of affordability. Yet producibility engineering is often one of the first things program managers trade-off to achieve early budget constraints. Money for manufacturing improvements to help reduce quality related defects and costs or to improve efficiencies often comes in two forms, late and never.

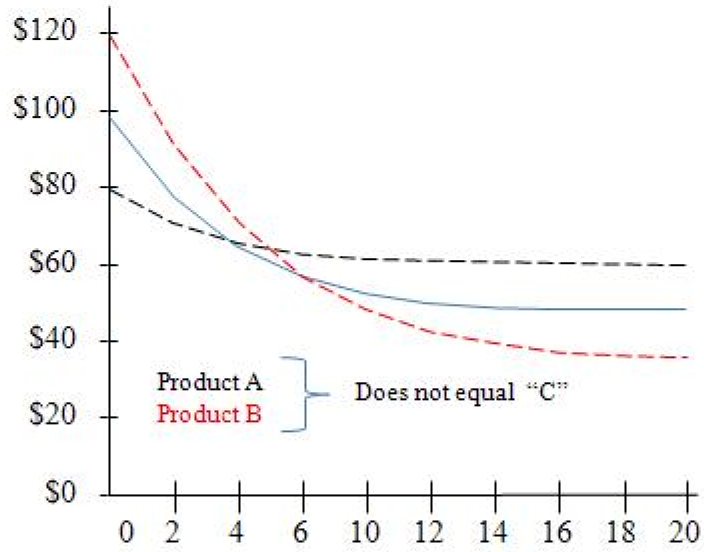

Figure 9-19 Learning Curve Analysis

Point 4 : Using Figure 9-19, which of the two learning curve gives you the better cost, Product A or B? Product A starts off (unit 1) at a lower cost, but has a shallower learning curve. Product B starts off at a higher cost, but has a steeper curve. If you are trying to determine the cost of production, look at the area under the curve and then compare the two areas as that will give you the cost. The classic DAU answer, "it depends," is appropriate here. Product A is the cheaper product if you are only going to by a few units (less than 8), but if you are buying more than eight units, then Product B is cheaper. The lesson here is not to go by just the learning curve slope in making a decision.

Point 5 : A final note is that at some time learning stops impacting costs as the curve flattens out. At this point the only way to impact cost is to improve efficiency, or quality, or improve the design or improve the technology. Lean and Six Sigma practices continues to be a great way to drive your program towards affordability. One of the things you do not want to do is to improve performance or efficiency on non-valued activities. Getting rid of non-value added activities gets rid of cost forever.

9.12 Summary

The focus of this chapter is on the identification and characterization of manufacturing costs as they are estimated and incurred by defense contractors. This chapter describes the nature and structure of manufacturing costs and the various techniques used to estimate cost. The objective is to establish an understanding of the composition of manufacturing costs and discuss the manufacturing cost estimating process. At the end of this chapter you should be able to:

- Identify the nature of manufacturing cost,;
- Identify the requirements for Cost Accounting Standards;
- Describe the various cost estimating methodologies in use today;
- Define and describe Learning Curves;

- Describe the relationship between rate, quantity and costs; and
- Identify other cost considerations and methodologies.

9.13 Related Links and Resources

Numerous reference documents impact the manufacturing management function throughout the acquisition process. These documents originate from many sources and range across academic disciplines, functional activities, and job specialties.

The following is a reference list of DOD Directives (D), Instructions (I) Manuals (M), Pamphlets (P), Military Standards (MS), and other documents. The documents listed contain DOD policy guidance applicable to the manufacturing management function. They are listed as sources of DOD manufacturing management information.

Note: Many of the documents listed are no longer required (due to acquisition reform), but still contain some very valuable information.

Number	Title
	Department of the Army Cost Analysis Manual
	DAU Teaching Note Cost Estimating Methodologies
	The Nunn-McCurdy Act: Background, Analysis, and Issues for Congress
	DAU Work Measurement Guide (Chapter 8)
DOD 5000.4-M	Cost Analysis Guidance and Procedures
	FAR Cost Principles Guide
	DAU Learning Curve Workshop: Treatment of Breaks in Production
	BCF 106 Fundamentals of Cost Analysis: Learning Curves
Mil-Std-1567A	Work Measurement

Table 9-4 Related Links and Resources

Defense Manufacturing Management Guide for Program Managers
Chapter 10 - Contracting Issues in Manufacturing

10.1 Objective

The contract is the vehicle used to establish the formal relationship between the government and a prime contractor. Government business processes include the business strategy or acquisition strategy, contracting approach, contracting strategies, contract language, and financial strategies. Programs that do address manufacturing considerations in their business processes will fail. This chapter will focus on manufacturing related contracting issues to include:

- Identify contract types, formats and provisions;
- Describe the acquisition process as it relates to contracting;
- Outline the requirements for a manufacturing/quality program;
- List any contactor data requirements;
- Outline requirements for subcontract management; and
- Describe contractor and government requirements for a make-or-buy program.

10.2 Background

The Second Continental Congress established the legal framework for government procurements when they set up the Commissary General's office in 1775. The Commissary General faced many of the same acquisition issues that program managers face today. Namely, they were looking for fair prices, competition, and on-time delivery of materials and supplies. However, the Quartermaster General's office had many problems getting proper food, uniforms and arms to the troops. A notable example is how ill housed, fed and clothed General Washington's forces were at Valley Forge in 1777. The U.S. Civil War had similar problems. One of the suppliers was so bad that the uniforms they provided fell apart during foul weather. The supplier of the uniforms was William Shoddy and to this day poorly quality is referred to as "shoddy merchandise."

10.3 Introduction

The majority of defense systems are produced by contractors making the contractual relationship critically import. The contracting approach and contract provisions need to be addressed early in the acquisition planning cycle to ensure that proper requirements are generated during each phase of the systems acquisition process and are included in the acquisition contracts. This chapter provides information on a number of manufacturing management issues from the perspective of the contract relationship.

10.4 Contracting

A contract is a legal instrument that defines the relationship between the government and a contractor whenever the principal purpose of the instrument is the acquisition of property or services for the direct benefit of the government.

10.4.1 Contract Types

The contract type defines the expectations, obligations, incentives, and rewards for both government and contractor during an acquisition. The government contracting officer selects the contract type based on analysis of the most effective way to satisfy mission requirements.

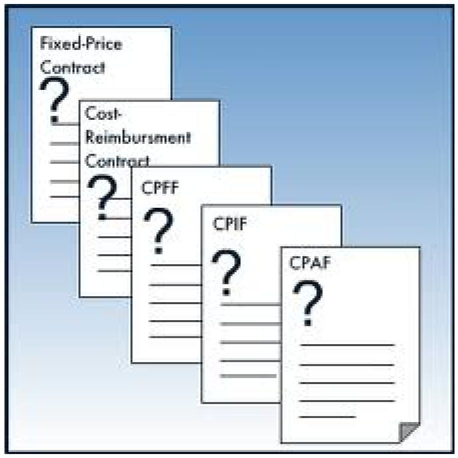

Figure 10-1 Contract Types

Contract types fall into two general categories:

1. Fixed-price contracts, and
2. Cost-reimbursement contracts.

Fixed-price contract types provide for a firm price, or in some cases, an adjustable price. Fixed-price contracts providing for an adjustable price may include a ceiling price, a target price, or both. Unless otherwise specified in the contract, the ceiling price or target price is subject to adjustment or revision of the contract price under stated circumstances. Government contracting officers are required to use firm-fixed-price or fixed-price with economic price adjustment contracts when acquiring commercial items or when awarding contracts resulting from seal bidding procedures.

Cost-reimbursement contract types provide for payment of allowable incurred costs to the extent prescribed in the contract. The contracts establish an estimate of total cost for the purpose of obligating funds and establishing a ceiling that the contractor may not exceed (except at his/her own risk) without the approval of the government contracting officer. Cost-reimbursement contracts are suitable for use only when uncertainties involved in contract performance do not permit costs to be estimated with sufficient accuracy to use a fixed-price contract. The contract type dictates:

- The degree and timing of the responsibility assumed by the contractor for the costs of performance; **Figure 10-1 Contract Types**
- The amount and nature of the profit incentive offered to the contractor for achieving or exceeding specified standards or goals.

The most advantageous contract type from the government's perspective is firm-fixed price, as the contractor has full responsibility for the performance costs and resulting profit (or loss). The most advantageous contract type from the contractor's perspective is cost-plus-fixed-fee, in which the contractor has minimal responsibility for the performance costs and the negotiated fee (profit) is fixed. Between these two extremes are various incentive contracts in which the contractor's responsibility for the costs of performance and the profit or fee incentives are tailored to the uncertainties involved in contract performance. Factors to be considered when selecting contract type can include:

- Price competition and price analysis;
- Type and complexity of the requirement;
- Urgency of the requirement;
- Contractor's technical capability and financial responsibility;
- Extent and nature of proposed subcontracting; and
- Acquisition history.

10.4.2 Uniform Contract Format

Contracts follow a specific sequence in which they must be arranged. The use of a uniform contract format facilitates preparation of the solicitation and contract as well as reference to, and use of, those documents by offerors, contractors, and contract administrators. The Uniform Contract Format is as follows:

Section A:	Solicitation/Contract Form
Section B:	Supplies or Services and Prices/Cost
Section C:	Description/Specifications
Section D:	Packaging and Marking
Section E:	Inspection and Acceptance
Section F:	Deliveries or Performance
Section G:	Contract Administration Data
Section H:	Special Contract Requirements
Section I:	Contract Clauses
Section J:	List of Documents, Exhibits and other Attachments
Section K:	Representations, Certifications, and Other Statements of Bidders
Section L:	Instructions, Conditions, and Notices to Bidders, Offerors, or Quoters
Section M:	Evaluation Factors for Award

Table 10- 1 Uniform Contract Format

Section L, of the contract, contains information to guide bidders, offerors, or quoters in the preparation of bids, and offers quotations. Section M, of the contract, contains the evaluation factors and subfactors by which offers will be evaluated and the relative importance of these factors and subfactors. Sections L and M are especially significant for manufacturing managers as these are the sections in which manufacturing requirements are identified and evaluated. Below are a couple of examples of manufacturing subfactors and their related evaluation criteria.

Sample Section L: Engineering for Affordability and Producibility. The offeror shall describe their:

- Processes for allocating cost requirements to lower level IPTs and suppliers.
- Formal programs, tools, and techniques to be used in engineering for affordability.
- Methods for including cost and producibility considerations in design trade studies.
- Flow-down of affordability requirements, tools, techniques, and practices to appropriate suppliers.
- Anticipated cost drivers for this program and plans for controlling those costs.

Sample Section M: Engineering for Affordability and Producibility. This subfactor is met when the offeror's proposal:

- Describes processes that allocate cost requirements to lower level IPTs and suppliers.
- Details specific programs, tools, or techniques to effectively incorporate affordability goals or requirements into the design process.
- Describes how cost and producibility factors are considered in design trade studies.
- Describes specific affordability requirements that will be flowed to suppliers.
- Lists specific program cost drivers, demonstrating an understanding of program requirements, and proposes sound methods to control those cost drivers.

10.4.3 Work Breakdown Structure (WBS)

The Work Breakdown Structure (WBS) organizes system development activities based on system and product decompositions. The WBS has the following attributes:

- It is a product-oriented hierarchy of hardware, software, services, data, and facilities that are required for system development, deployment, and sustainment.
- It displays and defines the product(s) to be developed and/or produced, and it relates the elements of work to be accomplished to each other and to the end product.
- A WBS requires at least three levels for reporting purposes unless the items identified are high cost or high risk. Then, and only then, is it critical to define the product at a lower level of WBS detail.
- The program WBS represents the total system. Figure 10-2 shows a notional program WBS for an aircraft system. WBS element descriptions and templates for aircraft systems other defense materiel items are described in MIL-HDBK-881A.

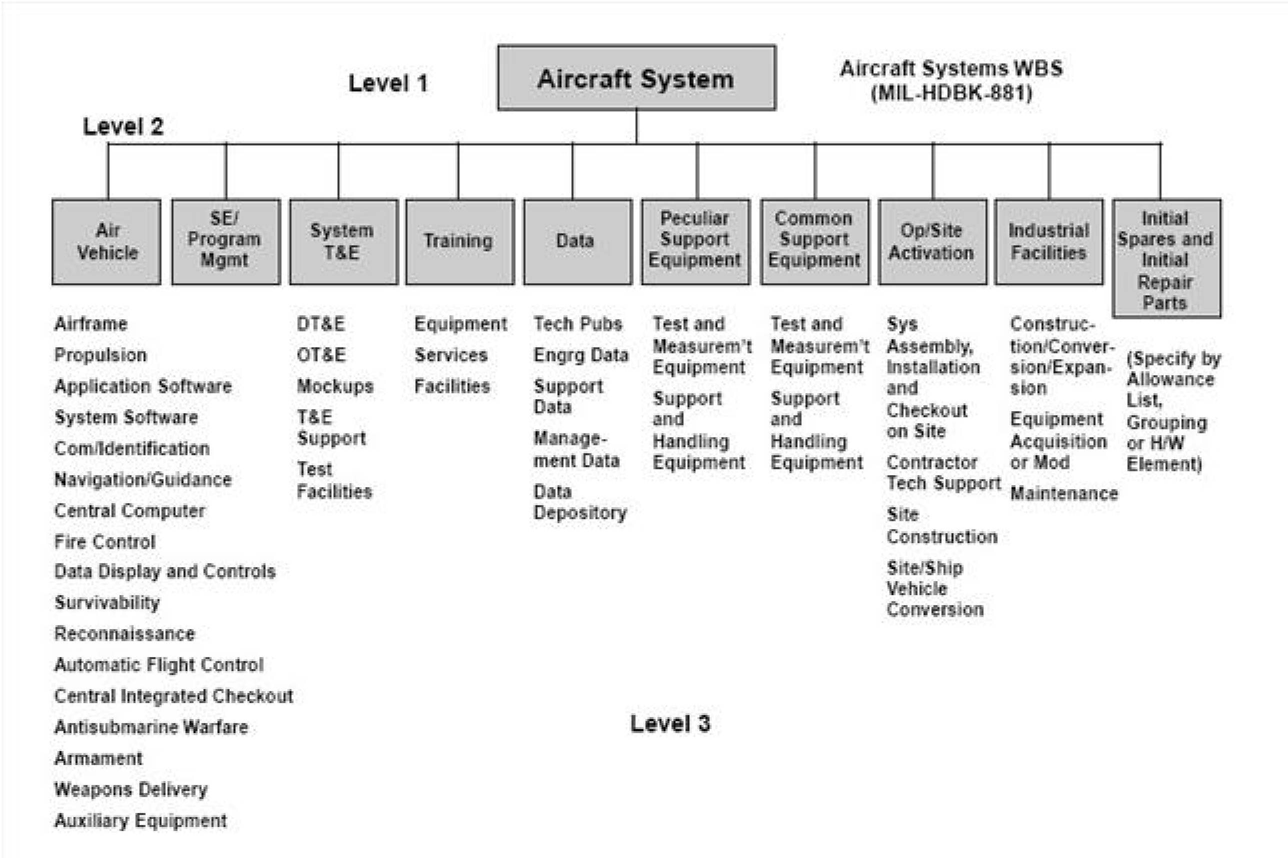

Figure 10- 2 Sample Work Breakdown Structure

The WBS is developed using the physical and system architectures that are a result of the top-down systems engineering design processes. The top-down structure provides a continuity of flow down for all tasks and requirements. Programs need to develop enough levels to provide work packages for cost and schedule control purposes. If too few levels are identified, management visibility and integration of work packages may suffer. If too many levels are identified, program review and control actions may become excessively time-consuming. Levels below the first three levels represent component decomposition, typically down to the configuration item level. In general, the government is responsible for the development of the first three levels. The contractor is responsible for levels below the first three levels. WBS development is a Systems Engineering activity, but it also impacts other program functional types (cost and budget, contracting, test, logistics, manufacturing and quality assurance). An integrated product team (IPT) representing these stakeholders should be formed to support WBS development.

10.4.4 Financial Considerations

An incentive contract motivates contractors by providing the opportunity to earn larger profits through improved performance, effective cost control, reduced lead time, and new or additional efforts. The two basic categories of incentive contracts are fixed-price incentive contracts and cost-reimbursement incentive contracts. Fixed-price incentive contracts are preferred when contract costs and performance requirements are reasonably certain. The contractor assumes substantial cost responsibility and an appropriate share of the cost risk with fixed-priced contracts.

Incentive contracts are designed to obtain specific acquisition objectives by establishing reasonable and attainable targets that are clearly communicated to the contractor; and by including appropriate incentive arrangements designed to:

- Motivate contractor efforts that might not otherwise be emphasized; and
- Discourage contractor inefficiency and waste.

Figure 10-3 depicts several important manufacturing management elements commonly considered in contract incentive structures.

Cost	Schedule	Technical
• Cost Reduction	• Expedited Development	• Quality
• Design-to-Cost	• Early Delivery	• Reliability
• Life-Cycle Cost	• On-Time Delivery	• Maintainability
		• Product Improvement

Figure 10-3 Incentive Improvement Goals

When incentives on technical performance or delivery are included, increases in profit or fee are provided only for achievement that surpasses the targets, and decreases are provided for to the extent that such targets are not met. The incentive increases or decreases are applied to performance targets rather than minimum performance requirements.

10.5 Acquisition/Contracting Process

The contracting process involves all activities associated with identifying and justifying a mission need, formulating an acquisition strategy to meet this need, and implementing the strategy by means of a contractual relationship with the private sector. The contracting process follows the five phases as outlined in Figure 10-4. The objective of a source selection is to select the proposal that represents the best value to the government.

Figure 10-4 The Acquisition Process

10.5.1 Requirements Definition

The contracting process is a partnership between the contracting office and project personnel. The Contracting Officer molds and shapes the procurement and is ultimately responsible for contract award and administration. However, a cohesive effort between the Contracting and Project Officer including the participation of both contractual and technical subject matter experts is essential to managing and completing the steps in this phase of the contracting process. The requirements phase includes:

- Customer requirements: This is a very important activity. If this is wrong then there is little chance of satisfying the warfighter. One of the problems programs face is that often manufacturing considerations are not identified as warfighter needs. The warfighter may want an aircraft the " *flies fast, flies far, flies undetected, and can drop a lot of ordinance* ." The warfighter would never ask for an aircraft that is producible, or one that has low manufacturing risks. If programs are to be successful PMs need to craft manufacturing requirements in a way that helps programs to achieve cost, schedule and performance or other warfighter requirements.
- Market research: Is used to determine current industrial base capabilities and to:
    - Identify products and technologies, particularly to determine if a commercial item can meet the Government's requirements.
    - Identify the size and status of potential vendors.
    - Assess the competitiveness of the market.
    - Identify commercial practices.
- SOW/SOO: The Statement of Work (SOW) is used to identify the offeror's required terms that need to be performed in order for the contractor to be paid. After the SOW becomes a part of the contract, it is used to measure contractor performance. The Statement of Objectives (SOO) is a brief description of the basic, top-level objectives of the acquisition in the Request for Proposal (RFP). Offerors use the SOO as a basis for preparing the SOW, which is then included in their bid and gets evaluated during the source selection.

10.5.2 Acquisition Strategy

The Acquisition Strategy should describe what the basic contract buys; how the items are defined; options, if any, and prerequisites for exercising them; and the events established in the contract to support appropriate exit criteria for the phase or immediate development activity. In addition, the Acquisition Strategy should include market research, address competition, and identify any incentive strategies needed to promote the attainment of selected program priorities, such as cost and/or schedule goals. DFARS 207.105 describes the required contents of written acquisition plans. Major acquisition programs are required to address the following manufacturing and industrial base related items:

- An analysis of the capabilities of the national technology and industrial base to develop, produce, maintain, and support the program, including consideration of factors related to foreign dependency:
    - The availability of essential raw materials, special alloys, composite materials, components, tooling, and production test equipment for the sustained production of systems fully capable of meeting the performance objectives established for those systems; the uninterrupted maintenance and repair of such systems; and the sustained operation of such systems.
    - The identification of items available only from sources outside the national technology and industrial base (recall that this base includes the U.S. and Canada).
    - The availability of alternatives for obtaining such items from within our industrial base if such items become unavailable from sources outside the national technology and industrial base; and an analysis of any military vulnerability that could result from the lack of reasonable alternatives.
    - The effects our industrial base that result from foreign acquisition of U.S. firms.
- Consideration of requirements for efficient manufacture during the design and production of the systems to be procured under the program.
- The use of advanced manufacturing technology, processes, and systems during the research and development phase and the production phase of the program.
- The use of contracts that encourage competing offerors to acquire modern technology, production equipment, and production systems that increase the productivity and reduce the life-cycle costs.
- Methods to encourage investment by U.S. domestic sources in advanced manufacturing technology production equipment and processes through:
    - Recognition of the contractor's investment in advanced manufacturing technology production equipment, processes, and organization of work systems that build on workers' skill and experience, and work force skill development in the development of the contract objective; and
    - Increased emphasis in source selection on the efficiency of production.
- Expanded use of commercial manufacturing processes rather than processes specified by DoD.
- Elimination of barriers to, and facilitation of, the integrated manufacture of commercial items and items being produced under DoD contracts.
- Expanded use of commercial items, commercial items with modifications, or to the extent commercial items are not available, nondevelopmental items.
- Acquisition of major weapon systems as commercial items.

10.5.3 Request for Proposal (RFP)

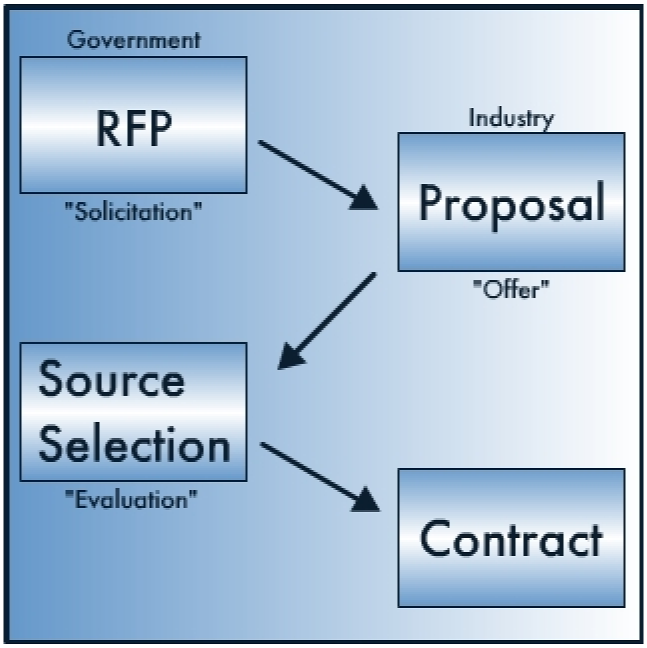

Figure 10-5 Request for Proposal

An RFP is a formal negotiated solicitation issued for buys over $100,000 resulting in a formal contract. This phase is about contract formulation. It includes the contract form, contract clauses, work statements, specifications, the delivery schedule and payment terms.

The contract's primary function is technical with the administrative function secondary. The RFP must contain clear and sufficient technical guidance so the contractor has a definite picture of how the system is envisioned to perform once delivered. It is also important that a technical functional description of software and hardware requirements is included and that those requirements are clearly scoped. Inconsistencies, insufficient detail, and inappropriate requirements will result in an inadequate response from industry. Manufacturing considerations appropriate for RFPs could include:

- Production Cost,
- Quality Systems,
- Manufacturing Development and Demonstration,
- Production, Quality and Manufacturing Efficiency,
- Producibility Engineering, and
- Process Control and Capability.

10.5.4 Evaluation Phase

The vision for the Federal Acquisition System is to deliver, on a timely basis, the best value product or service to the customer. This is accomplished by using contractors who have a track record of successful past performance or who demonstrate a current superior ability to perform a contract.

Proposal evaluation is an assessment of the proposal and the offeror's ability to perform the prospective contract successfully. Evaluations may be conducted using any rating method or combination of methods, and may include:

- Cost or Price evaluation,
- Past performance evaluation,
- Technical/Quality evaluation,
- Cost information, and
- Production capabilities.

The proposal evaluation criteria must be clearly identified and defined in the request for proposal (RFP). Proposal evaluations must be conducted so the government can select the proposal providing the best value to the government. Best value can be determined using one of two methods: lowest price, technically acceptable or tradeoff. Proposal evaluation is also conducted for sole source acquisitions as part of agency preparations to assist agencies prepare for negotiations with suppliers.

Proposal Evaluation Stages:

- *Stage One Planning* . This stage includes establishing the evaluation criteria for award and submitting the evaluation criteria to the source selection authority for approval.
- *Stage Two Forming The Evaluation Team* . This stage includes:
    - Determining the specific teaming approach to be used;
    - Nominating team members and selecting supporting contractor personnel;
    - Briefing panel members on their responsibilities;
    - Distributing documents and instructions to be used during the proposal evaluation; and
    - Convening the evaluation panel.
- *Stage Three Conducting The Evaluation* . This stage is tailored based on whether the tradeoff, lowest price and technically acceptable (LPTA), or sole-source approach is used.

Successful proposal evaluation depends on:

- Appropriate, well-defined evaluation criteria;
- Evaluation rating standards that are understood and applied consistently among evaluators and among all proposals being evaluated;
- A careful review of the language in each proposal to ascertain how the offeror will meet the requirements of the RFP and to identify assumptions and statements that may indicate increased cost/price and/or risk to the government; and
- Fully documented evaluation findings.

10.5.5 Contract Award

The contract is awarded upon completion of final evaluations and approval of the required clearance documentation. The Contracting Officer will notify the successful offeror by furnishing the executed contract. Based on the procurement/contract type, the award should occur via one of the following forms:

- Standard Form (SF) 26 Award/Contract;
- SF 33 Solicitation, Offer and Award;
- SF 1449 Solicitation/Contract/Order for Commercial Items; and
- DD 1155 Order for Supplies or Services.

The contracting officer publishes the notice of contract award via synopsis, which in turn posts all notifications to (FedBizOpps). Following a contract award, the Contracting Officer may, on behalf of Contractors, choose to publish a notice of subcontracting opportunity, if appropriate, under the following circumstances:

- A Contractor is awarded a contract exceeding $100,000 that is likely to result in the award of any subcontracts.
- A subcontractor or supplier, at any tier, under a contract exceeding $100,000, has a subcontracting opportunity exceeding $10,000.

The notice must describe the business opportunity, any pre-qualification requirements, and where to obtain technical data needed to respond to the requirement.

The Contracting Officer shall provide written notification to each unsuccessful offeror. The notice shall include the following:

- Number of Offerors solicited.
- Number of offers received.
- Name and address of each offeror receiving an award.
- Items, quantities, and any stated unit prices of each award.
- In general terms, reason(s) the offeror's proposal was not accepted, unless the price information readily reveals the reason.

The Contracting Officer may delegate contract administration functions to the Defense Contract Management Agency (DCMA), see FAR 42.302 and DFARS 242.302.

10.6 Manufacturing and Quality Assurance Program

MIL-HDBK-896, Manufacturing and Quality Program, serves as a concise collection of Manufacturing and Quality best practices. It may be cited in a Request for Proposal (Section L, Instructions to Offerors; Statement of Work; or Statement of Objectives) to clearly describe to the offerors what activities they are expected to undertake. This handbook is not intended to be a detailed, "how-to" guide. The Manufacturing Development Guide, maintained by HQ AFMC (ASC/ENSM), contains additional information and details that will be helpful in the application of this handbook. Chapter 5 of the Mil-HDBK identifies major manufacturing areas of emphasis along with an expanded description of that area.

Industrial Capability	Assess the capability of the industrial base to support program

	requirements. Identify sole sources and foreign sources and determine their risk.
Manufacturing Technology	Identify and implement manufacturing technology development projects.
Engineering for Affordability and Producibility	Establish and maintain formal affordability and producibility programs. Consider affordability and producibility constraints during cost and trade studies.
Key Characteristics	Identify key characteristics (KCs) on the engineering drawings.
Trade Studies	When performing design trade studies, consider production process capabilities and manufacturing costs. During the trade studies, treat manufacturing issues as equal to product performance issues.
Design Maturity	Assess design maturity and its impact on manufacturing process and technology development. Design maturity may be assessed during technology readiness assessments, design reviews, and qualification testing.
Materials Maturity	Ensure that materials are sufficiently mature and available to meet program requirements.
Supplier Management	Establish, implement, and maintain a supplier management program to track and report supplier performance. This program should identify major/critical suppliers as well as suppliers with critical processes.
Diminishing Manufacturing Sources (DMS) and Obsolescence	Develop and maintain a comprehensive DMS management program that addresses identification and risk mitigation of all parts and material obsolescence or discontinuation. The DMS program should encompass the DoD system, including support equipment, for which the prime contractor has design responsibility.
Special Handling	Identify special handling requirements and develop special handling procedures, as needed.
Cost	Estimate production costs for the program. Estimates should include the most recent design, manufacturing plans, and relevant actual manufacturing costs. During major program reviews, evaluate and present the estimated production costs and the achievability of production cost goals. Develop and execute budgets for manufacturing development and risk reduction projects.
Virtual Manufacturing	Use virtual manufacturing techniques to evaluate the producibility and affordability of proposed design and manufacturing concepts before the product and process designs are released. Virtual manufacturing techniques should address material properties, production processes, tooling, test equipment, facilities, transportation, personnel, inventory levels, and resource constraints involved in producing the product.

Variability Reduction	Implement a variability reduction program to reduce part to part variation of key characteristics.
Process Control	Develop, document, and implement process control plans for all critical processes. Update plans based on design and process changes.
Process Capabilities	Calculate the process capability index (Cpk) for each critical process.
Process Failure Modes Effects and Criticality Analyses (PFMECA)	PFMECAs should be performed to identify potential failures in critical and safety-related manufacturing processes, rank the criticality of the failure types and identify actions to mitigate the failures.
Process Control	Accomplish all production operations under controlled conditions.
Quality Systems	The primary focus of the quality management system is defect prevention and achievement of stable and capable processes, as well as continuous improvement. In case of nonconformance, conduct root cause analyses and implement corrective actions.
First Article Inspections	Perform first article inspections (FAIs) on parts that have not previously been built or on which significant design changes have been made. FAIs should only be performed on production-representative parts and processes.
Supplier Quality	Establish and maintain a program to assess supplier quality.
Manufacturing Personnel	Identify workforce requirements, special skills and training requirements.
Manufacturing Capability Assessment & Risk Management	A formal process is needed to identify and manage manufacturing risk issues consistent with documented program risk methodology. In identifying risks, consider the capability of planned production processes to meet anticipated design tolerances. Also consider the suppliers capacity and capabilities.
Factory Efficiency and Continuous Improvement	Establish, implement, and maintain a continuous improvement program across the entire enterprise, including suppliers. This program should identify improvement opportunities both on the factory floor as well as the processes that support production.
Process Proofing	Develop and implement a plan to demonstrate the proposed production processes, tooling, and test equipment (including Special Tooling and Special Test Equipment) will meet program requirements.
Manufacturing Integration	The manufacturing management function should ensure the activities described in this handbook are integrated to achieve manufacturing maturity. Manufacturing approaches should be integrated with program management, engineering, and business management strategies.

Table 10-2 Manufacturing Areas of Emphasis

10.6.1 Manufacturing Strategy

A manufacturing strategy is a detailed plan for assuring timely and cost effective production of an item which meets all operational effectiveness and suitability requirements. To be effective, the strategy must be developed in consonance with program engineering, contracting, test, and logistics strategies, considering current and projected constraints, risks, and opportunities in the industrial-technological base.

The major elements of the manufacturing strategy are listed in Table 10-3 below. For each element in the strategy, decisions must be made relatively early in the acquisition process to ensure that the required actions are taken in a timely manner. Tradeoffs are made, often within the context of the development of the program acquisition strategy.

- Level of production competition
- Type of production competition
- Role of producibility engineering and planning
- Quality planning
- Quality assurance approach
- Manufacturing process proofing
- Role of industrial modernization incentives program
- Manufacturing technology insertion
- Government manufacturing review process
- Tooling and test equipment
- GFP and component breakout approach
- Contract provisions and reporting
- Production rate

Table 10-3 Elements of a Manufacturing Strategy

Each element has associated with it a set of costs and risks which need to be assessed against the specific program realities and technological challenges.

10.6.2 Contract Provisions

In addition to incentives provided by the various types of contracts, there are a variety of contract provisions that may be included in contracts to motivate contractors toward desired objectives. Here are some manufacturing related provisions:

- Value Engineering (VE),
- Warranties,
- Capital Investment Incentives,
- Quality Systems,
- Manufacturing Development,
- Production, Quality and Manufacturing Efficiency, and
- Manufacturing Risk Assessments.

10.6.2.1 Value Engineering

Value engineering can help the government reduce costs, increase quality, and improve mission capabilities across the entire spectrum of DoD systems, processes, and organizations. Value engineering provisions may be included in contracts to reward voluntary value engineering suggestions or to require value engineering analysis to identify methods of performing more economically. Value engineering attempts to eliminate, without impairing essential functions or characteristics, anything that increases acquisition, operation, or support costs.

A Value Engineering Change Proposal (VECP) is a proposal submitted by a contractor under the Value Engineering (VE) provisions of the Federal Acquisition Regulation (FAR 48 Value Engineering) that, through a change in the contract, would lower the project's life-cycle cost to DoD. VECPs are applicable to all contract types, including performance based contracts. The basic VE contract provision is the VE incentive clause. The VE clause is included in most supply/service contracts when the contract price exceeds $100,000. It is also included in most spares/repair kit contracts over $25,000.

Typical VE Clauses: *The contractor is encouraged to develop, prepare, and submit value engineering change proposals (VECPs) voluntarily. The contractor shall share in any net acquisition savings realized from accepted VECP's, in accordance with the incentive sharing rates outlined in paragraph (x) of this clause* .

10.6.2.2 Warranties

The government's objective is to motivate contractors to improve the quality and reliability of their products, so that they would reap financial benefit by avoiding the warranty cost of repairs and replacements. Warranties are no substitute for quality, and should not be used as a crutch. Simply put, when a system fails to accomplish the mission for which it was intended, the warranty can never compensate for potentially devastating results. In determining whether a warranty is appropriate for a specific acquisition, FAR Subpart 46.703 requires the contracting officer (CO) to consider the nature and use of the supplies and services, the cost, the administration and enforcement, trade practices, and reduced requirements.

The SOW/SOO may include a short paragraph stating that the Contractor shall manage warranties in accordance with Section H of the contract (this is where the warranty clause is located). The SOO may also require the Contractor to submit Failure Analysis Reports, incurred Warranty Costs Report, Warranty Activity Report, and any other special reports designated by the PM. Any additional data requirements related to the warranty may be identified in this section of the SOO. The importance of addressing the warranty in the SOO is that the Contractor will then be required to set up a work breakdown structure (WBS) for warranties and actually manage and control his warranty activities. This is especially useful if the contract includes Contractor support such as ICS or CLS. It is important that the Contractor's management plan be comprehensive and compatible with the Program Office Warranty Plan.

10.6.2.3 Industrial Modernization and Capital Investment

The government's objective is for the contractor to invest in manufacturing modernization. Industrial Modernization and Capital Investment may be negotiated and included in contracts for research, development, and/or production of weapons systems, major components, or materials. The purpose is to motivate the contractor to undertake productivity improvement efforts that can be used to drive down cost and help achieve affordability. Several programs discussed in Chapter 8 can be used to help implement industrial modernization and capital investments to include:

- Defense Production Act Title III,
- Industrial Base Innovation Fund, and
- North American Technology and Industrial Base Organization Funds.

10.6.2.4 Quality Systems

The government's objective is for the contractor to implement an overarching quality system that ensures effective execution, integration, and administration of the design, manufacturing, and deployment processes and systems needed to manage risk, ensure achievement of all performance requirements, and prevent the generation of defective product. The system should also include a means for measuring the effectiveness of and ensuring the continuous improvement of systems and processes.

10.6.2.5 Manufacturing Development

The government's objective is for the contractor to implement processes and systems that consider manufacturing, quality, and design functions in achieving a balanced product design which meets cost, schedule, and performance requirements with acceptable risk. Implement a Manufacturing and Quality program using MIL-HDBK-896 as a guide. Appropriate practices for implementation may include production cost modeling; identification of key characteristics and processes; variability reduction; electronic simulations of the manufacturing environment; cost/performance trade studies; manufacturing capability assessments; product and process validation; and key supplier relationships.

10.6.2.6 Production, Quality and Manufacturing Efficiency

The government's objective is that the contractor implements those processes and systems to assure program affordability through product quality and manufacturing efficiency. The following elements may be considered as appropriate practices for implementation: product improvement initiatives; variability reduction on product and process; manufacturing process control and continuous improvement; and key supplier relationships.

10.6.2.7 Manufacturing Risk Assessments

The government's objective is that contractor should conduct assessments of manufacturing risk periodically, at all major technical reviews, and prior to major program milestones to assess progress towards meeting the appropriate Manufacturing Readiness Levels as they are defined in DoD Policy. Manufacturing risk assessments may be conducted in coordination with the government program office, at the prime contractor facility and at selected subcontractor facilities.

10.7 Contractor Data

Manufacturing Management activities require the collection and evaluation of large amounts of data.

10.7.1 Data Requirements Definition

The purpose Contract Data Requirements List (CDRL) is a list of authorized data requirements for a specific procurement that forms a part of the contract. The purpose of the CDRL is to provide a standardized method of clearly and unambiguously delineating the government's minimum essential data needs. The CDRL is the standard format for identifying potential data requirements in a solicitation, and deliverable data requirements in a contract. CDRLs should be linked directly to SOW tasks and managed by the program office data manager. For example, manufacturing analyses, reviews, and preparation of plans, which result in the generation of data, must appear in the contract SOW. When properly developed, the CDRL permits DOD managers to attain the data objectives described in Table 10-4.

- Specify the minimum amount of data needed.
- Identify individual data item prices.
- Assure on-time acquisition of required data.
- Specify data requirements in solicitations or proposals to provide full, understanding of total data requirements at contract award.
- Provide for administration of contracts requiring data to ensure that all contract data provisions are fully satisfied.
- Provide quality assurance procedures to ensure the adequacy of the data for its intended purpose.
- Provide for the continued currency of acquired data.
- Prevent the acquisition of duplicate data.

Table 10-4 Contract Data Requirements List Objectives

The CDRL should contain an explanatory Data Item Description (DID) for each data item listed. DIDs specifically describe the purpose of the data item, applications involved, interface references, and data preparation requirements. Accordingly, they play a key role in obtaining needed information in such critical areas as production plan development and execution, production capability and feasibility assessments, production readiness review accomplishment, production progress reporting and engineering data.

10.7.2 Manufacturing Managemement Data Items

The need for manufacturing data exists throughout the product life cycle and can be defined as recorded information, regardless of form or characteristic, which may be retained by the contractor or provided to the government. Whether retained and made available for review or provided, data may be necessary for any number of purposes including those listed in Table 10-5.

- Manufacturing/Quality Assurance Planning
- Design Reviews
- Producibility Assessments
- Manufacturing Feasibility Assessments
- Manufacturing Capability Assessments
- Program Visibility (cost, schedule, performance and other measures of effectiveness)
- Risk Assessment
- Process Capability and Control Assessments
- Configuration Control
- Facilities Planning
- Subcontractor Management
- Manufacturing Surveillance

Table 10-5 Typical Manufacturing Management Data Items

10.7.3 Progress Reporting

A number of different techniques and reports are utilized by program managers to obtain status on manufacturing efforts. These include: Cost Performance Reports (CPR); Cost/Schedule Status Reports (C/SSR); Production Progress Reports (PPR); Line of Balance (LOB); Performance Evaluation and Review Technique (PERT) Critical Path Method (CPM) reports; Gantt or phase-planning charts; and internal contractor management information system outputs. No one technique is applicable to all programs or program phases.

The information generated is targeted for use at different levels of program management, procuring agency, or contract administration office. System requirements, such as the Cost/Schedule Control System Criteria (C/SCSC), are intended to provide criteria for the management system from which data will be generated for management visibility in five areas: organization, planning and budgeting, accounting, analysis, and revisions. Other requirements, such as PERT/CPM and Gantt charts, are intended to ensure that manufacturing progress is commensurate with the contract schedule.

10.7.4 Technical Data

A number of different techniques and reports are utilized by program managers to obtain status on manufacturing efforts. These include: Cost Performance Reports (CPR); Cost/Schedule Status Reports (C/SSR); Production Progress Reports (PPR); Line of Balance (LOB); Performance Evaluation and Review Technique (PERT) Critical Path Method (CPM) reports; Gantt or phase-planning charts; and internal contractor management information system outputs, No one technique is applicable to all programs or program phases.

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Cost/Schedule Control System Criteria (C/SCSC), are intended to provide criteria for the management system from which data will be generated for management visibility in five areas: organization, planning and budgeting, accounting, analysis, and revisions. Other requirements, such as PERT/CPM and Gantt charts, are intended to ensure that manufacturing progress is commensurate with the contract schedule.

• Personnel Training • Overhaul and Repair • Cataloging • Standardization • Modification • Interface Control	• Inspection • Product Surveillance • Packaging • Logistics Operations • Re-procurement • Service Test

Table 10-6 Uses of Technical Data

There is not necessarily a correlation between the government's need for technical data and the contractor's economic interest in such data. Commercial and non-profit organizations have property rights and a valid economic interest in technical data pertaining to items, components, or processes which they have developed at their own expense. Such technical data are often closely held in the commercial sector because their disclosure to competitors could jeopardize the competitive advantage they were developed to provide. Public disclosure of such technical data could cause serious economic hardship to the originating company and would not be in the interest of the United States in encouraging innovation as well as encouraging contractors to develop at private expense items, components, or processes for use by the government.

Because of the possible different government/contractor views on technical data, it is particularly important for the government to identify its various uses of and needs for technical data as early as is practicable in the acquisition of any item, component, or process. Such identification should be made before contract award or, for major weapons systems, prior to entering engineering and manufacturing development. It is also important that contractors be required to provide early identification of any technical data that they intend to deliver with any restrictions on government use.

Normally, delivery of the technical data package occurs at the end of engineering and manufacturing development or during the production phase. Timing of the delivery is based on the planned use of the data and the expected magnitude of design changes during the early part of the production phase.

Of all these uses, the one which provides the greatest difficulty is re-procurement. If DOD wishes to acquire systems, or spare and repair parts for the systems under competitive procedures, unlimited rights in data is normally required. Conflict with contractor economic interest is obvious. Most contractors are not anxious to support future competition. The technical data package for reprocurement needs to contain the information necessary to enable a competent manufacturer to build the part or component. This should include such items as: purchase specifications, inspection and test requirements, and packaging data. Special care should be taken to assure that data packages do not contain restrictive markings. Data packages must include explanations of references such as contractor specification numbers.

10.8 Subcontract Management

The prime contractor is responsible for managing the planning, placing, and administering of subcontracts. Make-or-buy program analysis considers the prime contractor's decisions in determining if certain components or services will be subcontracted. In this section, we will consider means available to the government to evaluate how those decisions are implemented.

Weapon systems contractors have always needed support from other firms in meeting their contractual obligations. Prime contractors must purchase a wide variety of raw materials, parts, subassemblies, and services.

In this age of increasing specialization, prime contractor reliance on subcontractors has become increasingly important. Typically, 70-80 percent or more of total prime contract dollars are eventually paid to subcontractors. Effective management of subcontractors therefore becomes essential to effective contract performance. As a result more government attention is being directed toward the prime-subcontractor relationship.

Special care must be exercised when considering government involvement in this relationship. The government has no privity of contract (direct contractual relationship) with subcontractors. Any government efforts to control subcontractors must be accomplished by affecting the prime contractor's management of subcontracts. Subcontractors should not be asked or expected to follow government direction. If they do and problems result, the government will likely be open to substantial claims from both the prime and subcontractors.

10.8.1 Consent

Government consent to subcontract placement may be required when subcontract work is complex, the dollar value is substantial, or the government's interests are not adequately protected by competition and the type of prime contractor subcontract. The consent requirement is implemented through the subcontract clause in the prime contract. This consent does not establish any direct contract relationship between the government and the subcontractor nor does it relieve the prime contractor of any responsibility for selection and management of subcontractors.

10.8.2 Contractor Purchasing System Review

A contractor purchasing system review (CPSR) is an on-site review of an institution's purchasing system. Each service uses contractor purchasing system reviews to evaluate the efficiency and effectiveness with which the institution spends government funds and complies with government policies when subcontracting. The review provides the administrative contracting officer (ACO) with information which is used as a basis for granting or withdrawing approval of the institution's purchasing system.

The CPSR objective is to evaluate the efficiency and effectiveness with which the contractor spends government funds and complies with government policy when subcontracting. Approval of the contractor's purchasing system significantly reduces requirements for review and consent to individual subcontracts.

The ACO shall determine the need for a CPSR based on, but not limited to, the past performance of the contractor, and the volume, complexity and dollar value of the subcontracts. If a contractor's sales to the government are expected to exceed $25 million during the next 12 months, perform a review to determine if a CPSR is needed. Sales include those represented by prime contracts, subcontracts under government prime contracts, and modifications. Generally, a CPSR is not performed for a specific contract. These reviews devote special attention to the items identified in Table 10-7.

- Degree of price competition obtained.
- Pricing policies and techniques.
- Methods of evaluating subcontractors responsibility.
- Treatment accorded affiliates and other concerns having close working arrangements with the contractor.
- Policies and procedures pertaining to labor surplus area concerns and small business concerns.
- Planning, award, and postaward management of manor subcontract programs.
- Compliance with Cost Accounting Standards (CAS) in awarding subcontracts.
- Appropriateness of types of contracts used.
- Management control systems, including internal audit procedures, to administer progress payments.

Table 10-7 Contractor Purchasing System Review Special Concerns

10.8.3 Subcontractor Evaluation Support

Because subcontractors are performing larger and larger portions of contract effort, government organizations are becoming more directly involved in prime contractor evaluation of subcontractor cost and price proposals and subcontractor ability to manufacture systems and deliver quality product. Government personnel have participated as team members on prime contractor reviews of Should Costs, Manufacturing Management/ Production Capability Reviews (MM/PCRs), and Production Readiness Reviews (PRRs) at subcontractor facilities. Government participation is based on government responsibility to evaluate the total contract effort and special provisions in the prime contract.

10.9 Make-or-Buy Program

The contractor's make-or-buy program is that part of a contractor's written plan for the development or production of an end item that outlines the subsystems, major components, assemblies, subassemblies, and parts the contractor intends to manufacture (make); and those the contractor intends to purchase from others (buy). A "make" item is defined as an item or work effort to be produced or performed by the prime contractor or its affiliates, subsidiaries, or divisions.

The prime contractor is responsible for managing contract performance, including planning, placing, and administering subcontracts as necessary to ensure the lowest overall risk to the government. Although the government does not expect to participate in every management decision, it may reserve the right to review and agree on the contractor's make-or-buy program when necessary to ensure: negotiation of reasonable contract prices; satisfactory performance; or implementation of socio-economic policies. A make-or-buy program is a contractor's written plan identifying major items to be produced or work efforts to be performed in the prime contractors facilities, and major items to be contracted.

The FAR 15.407-2 outlines the requirements for make-or-buy programs. For acquisitions requiring make-or-buy programs contracting officers may require prospective contractors to submit make-or-buy program plans for negotiated acquisitions requiring cost or pricing data whose estimated value is $10 million or more, except when the proposed contract is for research or development and, if prototypes or hardware are involved, no significant follow-on production is anticipated.

10.9.1 Government Evaluation

Contracting officers must evaluate and negotiate proposed make-or-buy programs as soon as practicable after their receipt and before contract award. In preparing to evaluate and negotiate prospective contractor's make-or-buy programs, the contracting officer must request the recommendations of appropriate personnel, including technical and program management personnel, and the small and disadvantaged business utilization specialist.

In the evaluation, primary consideration must be given to the effect of the proposed make or buy program on total contract price, quality, delivery, and performance. Socioeconomic considerations, such as labor surplus area and small business support, must also be considered. The government will not normally agree to proposed "make items" when the products or services are (1) not regularly manufactured or provided by the contractor and are available from another firm at equal or lower prices or when they are (2) regularly manufactured or provided by the contractor, but available from another firm at lower prices.

10.9.2 Post Award Changes

In addition to special provisions containing the make-or-buy program features, the FAR clause 52.215-21, "Changes or Additions to Make or Buy Program," must be included in the contract. This clause describes procedures that must be followed to make changes to the make-or-buy program described in the contract.

10.9.3 Component Breakout

Component breakout is technically not a part of a make-or-buy decision made by contractors, but is a decision made by the program office on whether to continue buying the item from the prime contractor or breaking out the item and have the program office buy that item directly. It is a DoD policy to breakout components of weapons systems or other major end items under the following circumstances:

- If the prime contract will be awarded without adequate price competition, and the prime contractor is expected to buy a component without adequate price competition, breakout that component if:
    - Substantial net cost savings probably will be achieved; and
    - Breakout action will not jeopardize the quality, reliability, performance, or timely delivery of the end item.
- If either the prime contract and the component will be acquired with adequate price competition, consider breakout of the component if substantial net cost savings will result from:
    - Greater quantity acquisitions; or
    - Such factors as improved logistics support (through reduction in varieties of spare parts) and economies in operations and training (through standardization of design).
- Breakout normally is not justified for a component that is not expected to exceed $1 million for the current year's requirement.

10.9.3.1 Component Breakout Issues

There are many issues of importance to the program manager in the implementation of a component breakout program. How are breakout candidates to be identified? What logistics system risks are involved? How will economic and quantity change factors influence cost? What responsibilities will the government share or assume as a result of providing government-furnished components? Will the item be purchased competitively or on a sole source basis? The answers to these questions cross many disciplines including production, engineering, finance, and contract administration. Most weapon systems involve relatively large numbers of end items procured over the program life cycle which often extends over a number of years.

10.9.3.2 Component Breakout Guidelines

The program manager should base each component breakout decision on an assessment of the potential risks of degrading the end item through such contingencies as delayed delivery and reduced reliability of the component, calculation of estimated net cost savings over the program life cycle, and analysis of the technical, operational, logistic and administrative factors involved. Particular emphasis should be placed on assessing the stability of the design, the availability of item data required to support the breakout decision, and the ability of the government to transfer the design description to a potential source.

10.10 Related Links and Resources

Numerous reference documents impact the manufacturing management function throughout the acquisition process. These documents originate from many sources and range across academic disciplines, functional activities, and job specialties.

The following is a reference list of DOD Directives (D), Instructions (I) Manuals (M), Pamphlets (P), Military Standards (MS), and other documents. The documents listed contain DOD policy guidance applicable to the manufacturing management function. They are listed as sources of DOD manufacturing management information.

Note: Many of the documents listed are no longer required (due to acquisition reform), but still contain some very valuable information.

Number	Title
DAG Chapter 2.3.10	Business Strategy
DAG Chapter 2.3.10.2	Contracting Approach
DAG Chapter 2.3.9	Industrial Capabilities
DFAR 207-105	Contents of Written Acquisition Plans
FAR 15.407-2	Make or Buy Programs
	Comparison of Major Contract Types
	Uniform Contract Format
	Work Breakdown Structure

10.11 Summary

Bottom-line: The contract is the vehicle used to establish the formal relationship between the government and a prime contractor. Programs that do address manufacturing considerations in their contract will fail. This chapter covered the following learning objectives:

- Identify contract types, formats and provisions;
- Describe the acquisition process as it relates to contracting;
- Outline the requirements for a manufacturing/quality program;
- List any contactor data requirements;
- Outline requirements for subcontract management; and
- Describe contractor and government requirements for a make-or-buy program.

11.1 Objective

Chapter 8 discussed DOD programs that facilitate technology transition. This chapter deals with the larger issue of transitioning an entire weapons system from development to Low Rate Initial Production (LRIP) and then to Full Rate Production (FRP). This chapter discusses some of the organizational and functional issues which are involved in the transition, and will explore the relationships among functional disciplines as they impact the transition process along the acquisition life cycle, and the changes in organizational focus and activity to support the transition process. Finally, it will outline current thoughts on the transition process, transition challenges and transition to production tools and initiatives.

11.2 Background

The F-22 program began in the early 1980's in response to expected developments in Soviet technology. The goal was to develop a successor to the F-15. The Figure 11-1 identifies some of the early milestones.

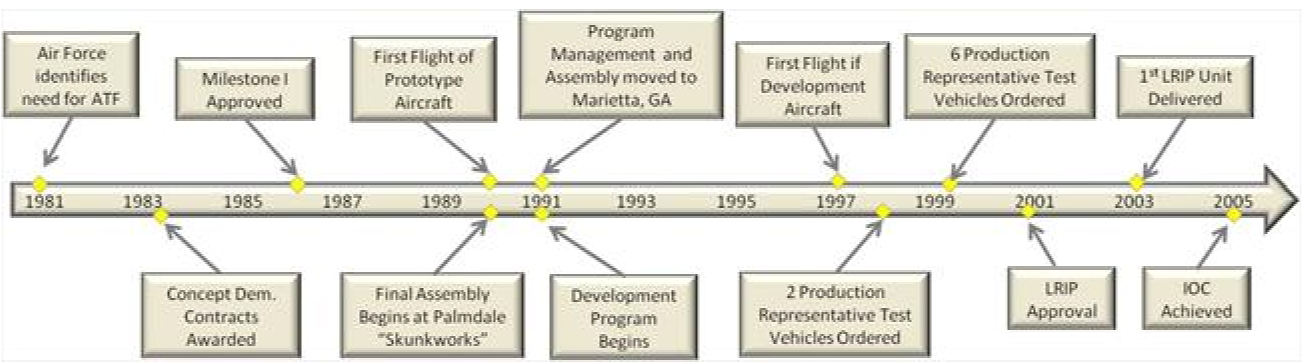


Figure 11-1 F-22 Timeline

The major contractors for the F-22 program were Lockheed Martin, Boeing (airframe), and United Technologies (F119 engines). Perhaps the most extensive transition effort occurred when Lockheed transferred assembly from Palmdale, CA to a new facility in Marietta, GA. This undertaking involved having to build new production capabilities in Marietta, GA. This included:

- Manufacturing/QA, engineering, testing and other personnel and their skills;
- Updating and building new facilities to meet F-22 production requirements;
- Developing and proofing long lead special tooling, fixtures and other production related items; and
- Coordinating requirements with hundreds of sub-contractors, suppliers and vendors.

While there were some problems with this transition from Palmdale's "skunkworks" that accomplished the original development and production, to Marietta's production facility, many things did go right because of the extensive planning, coordinating and management that took place to manage the transition process.

11.3 Introduction

This section will use commercial (Ford Motor Company) and DOD (V-22 Osprey) examples to illustrate the many transition to production considerations that are addressed in this document.

11.3.1 Model T's Transition

Henry Ford produced the first automobile that the average person could afford and could maintain. The first Model T was introduced in 1908. However his most famous innovation, the "moving assembly line," was not introduced until 1913. It took Ford five years to put into place many innovations that allowed for the moving assembly line to work and transition to a high rate production. Here a few of those innovations:

- Stable design made investments in expensive tooling and equipment a reasonable business decision.
- Interchangeable parts made assembly much easier.
- Commonality limited the types and amounts of parts and tools needed to assemble the final product.
- Standard measurement system made the gauging and calibration a standard practice and allowed the development of the interchangeable part.
- Factory floor planning and layout helped lead to not only the moving assembly line but to the interchangeable worker.

In craft production, the old way of producing automobiles, each part was created by an individual craftsman. Each craftsman used his own tools to manufacture his part of the production process. Once parts were created, the first piece and the second piece were put together with the craftsman filing and making adjustments until the pieces fit together perfectly. Then the third piece was added and adjusted accordingly, and so on. Then when the parts were fired to increase hardness they often warped and the part had to be reworked again to regain its original shape. The biggest problem was that each piece was made by a craftsman using a different gauge so there was no uniformity. The end result was a mere approximation of the original intended dimensions and no two vehicles were exactly the same.

Ford achieved interchangeability by controlling tooling and establishing a standard measurement system. Ford took away the individual tools the craftsmen carried and replaced them with Ford owned and controlled tools that were then put into a calibration program to ensure standardization. Taken together interchange-ability, simplicity of design, and ease of attachment - Ford was able to eliminate the skilled fitters and craftsmen who had always formed the bulk of the labor force.

Ford's moving assembly had the worker remaining in one spot and the product, components and tools coming to the worker. This created the unskilled worker who no longer needed to understand the whole production process but merely needed to be able to attach two nuts to two bolts on every car that came by all day long. Ford noted that "Any customer can have a car painted any colour that he wants so long as it is black." The genius behind this statement is that Ford paid so close attention to the production process that he knew that "black paint" dried faster than any other color.

Today's weapon systems are much more complex than the Model T. The management of a major weapon system from development through production is also much more complex and requires the effective administration and coordination of many functions and activities to include:

- Contracting to write the acquisition strategy and contracting documents.
- Budget and Finance to accomplish the cost estimates and work budgets and funding issues.
- Systems Engineering to guide the design and development process.
- Test and Evaluation to assess the product to ensure it meets the users requirements.
- Manufacturing and Quality Assurance to build the product and perform the necessary quality functions.
- Logistics to ensure that the product performs as needed, when needed and for as long as it is needed and at an affordable cost.
- Software Engineering and Management to guide the design and development of the software that is often embedded into the end item.

These functions and activities should be effectively exercised throughout the life cycle of any weapon system acquisition program. But what does that really mean to exercise functions that can support the transition from development to production. This chapter will use the V-22 Osprey program to further discuss transition to production issues and challenges.

11.3.2 V-22 Osprey's Transition

The V-22 Osprey began with a requirement in 1980 when a mission to rescue 52 Americans being held hostage in Iran, failed. Operation Eagle Claw called for eight RH-53D helicopters to fly from the USS Nimitz, stationed in the Arabian Sea, to a remote airstrip in Eastern Iran called Desert One where they were to meet up with other aircraft. However, two of the eight helicopters did not make it to Desert One. A third RH-53D had a secondary hydraulic system failure leaving only five helicopters when the mission called for six. A decision was made to abort the mission. What the U.S. needed was an aircraft that could take off and land on a short airfield and fly undetected over a long distance. A solution was about to present itself. The Secretary of the Navy at that time was John Lehman, and while at the 1981 Paris Air Show he was so favorably impressed with the XV-15, that he directed the Naval Air Systems Command (NAVAIR) to consider the XV-15 as a replacement for the H-46 helicopters. Lehman's vision was to replace the aging helicopters with a tiltrotor aircraft. But that vision took a long time coming to fruition and had several transition issues in question:

- "Did it come in on time?" This had several different answers. The original acquisition time was 117 months, as of 2008 that time grew to 295 months, and its development time was 27 years! According to the timeline below, the V-22 missed its original planned IOC of 1992, and a second IOC of 2001, finally making IOC in 2007.

- "Did it come in on cost?" The answer is no. The original unit cost was estimated at $39M and the final estimate comes in at $106M and the program has been re-baselined eight times.
- "Did the warfighter get what they asked for?" Again the answer is no. The cost was so high that the number of production units was cut from 913 to 458 units.

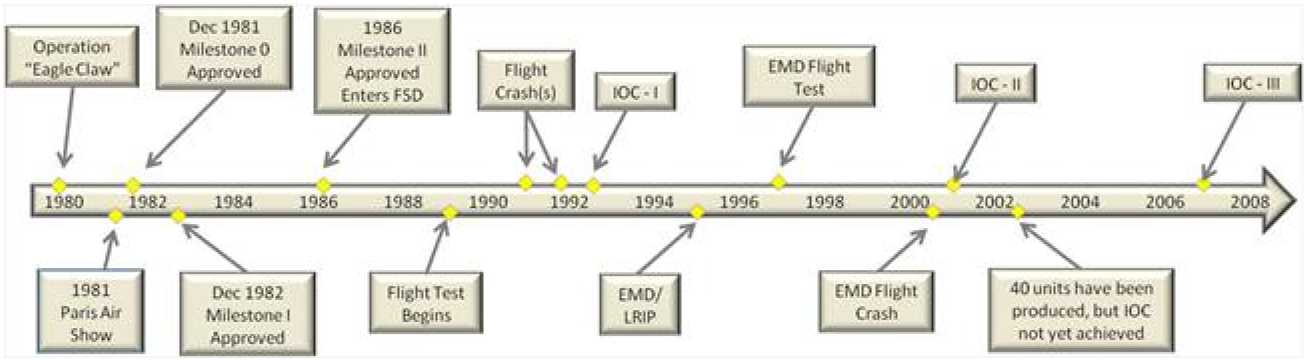


Figure 11- 2 V-22 Osprey Timeline

The V-22 Osprey transition to production was complicated by several program issues:

- There were challenging technologies to develop and insert:
    - Fly-by-wire digital controls;
    - Triple redundant hydraulic system;
    - Composite fuselage structure with wire laminate for lightening strike protection; and
    - Advanced tilt-rotors with lights in wing tips and de-icing blankets built into the rotors.
- The program structure was complex:
    - Joint service program, each service with some different requirements;
    - Conflicting service requirements (Army dropped out of the program early to support a helicopter program); and
    - Conflicting political climate (some groups supported the program others fought it).
- Flawed Program Management approach:
    - The first program manager came fresh out of the cockpit with only the Defense Systems Management College Program Managers Course under his belt and no PM experience;
    - The Acquisition Strategy included a high level of concurrent development and production to meet the Marines Corps' initial operating capability (IOC) date of fiscal year 1999; and
    - The Secretary of the Navy decided on a fixed-price incentive contract in 1985 despite the high level or risks on a development program.

11.4 Transition Process Overview

Many people think of transition to production as that period just prior to Low Rate Initial Production (LRIP). However, transition from development to production is not a single event with a readily identifiable starting point in the acquisition process. The transition process incorporates many interrelated and interdependent activities, that if not managed correctly, can cause significant cost growth and schedule delays. The lack of planning or poor coordination among the various functions will result in the lack of integration and could lead to conflicts. For example, if engineering is still making changes late in EMD, manufacturing may have to change their manufacturing plans and processes.

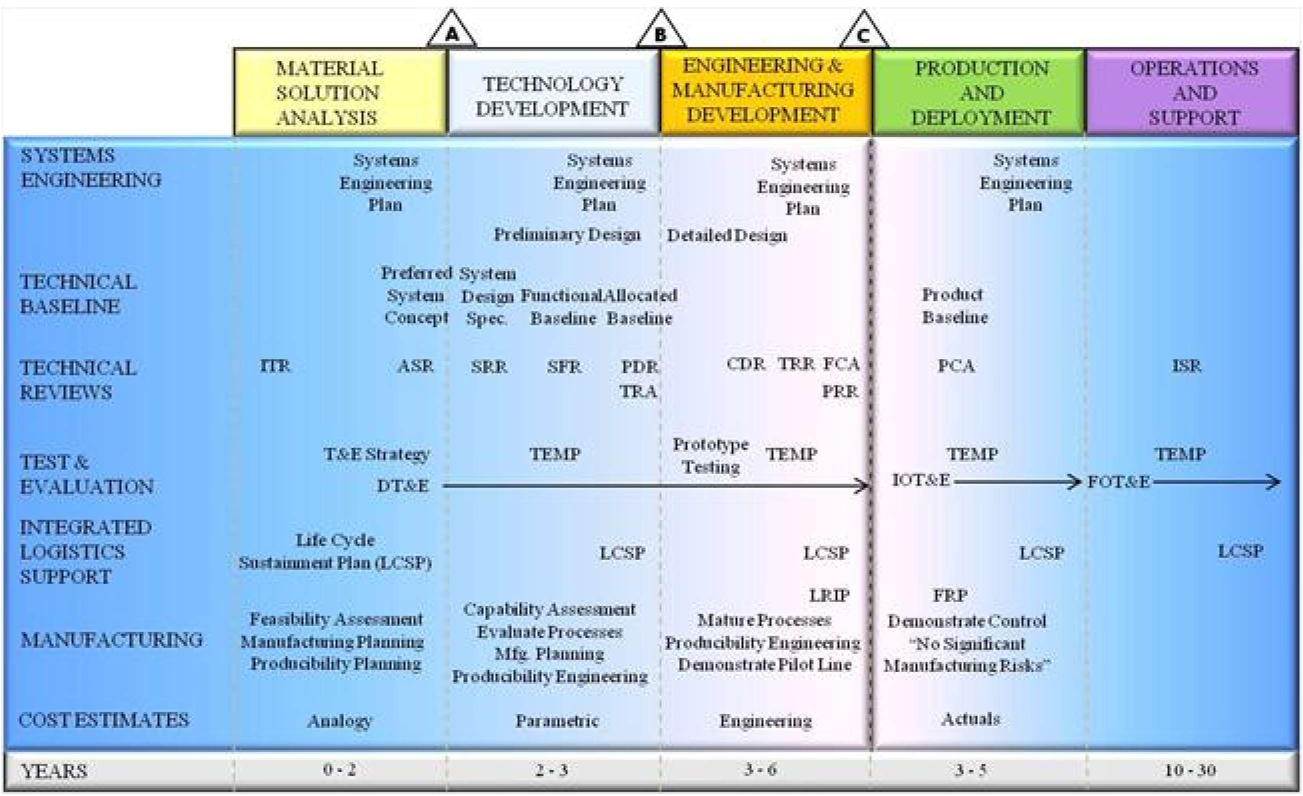


Figure 11-3 Acquisition Processes for Major Weapon Systems

In addition to the many functional activities identified above that play a role in transition, transition to production also includes the transition of the products form and where that form is produced. Figure 11-4, shows that the environments in which products are developed, produced and tested change over time. These environments are discussed in detail in other chapters where we discuss Technology Readiness Levels (TRLs) and Manufacturing Readiness Levels (MRLs), but for now understand that there is a difference between a laboratory environment, a relevant environment and other production environments and the transition from one environment to another environment needs to be carefully managed.

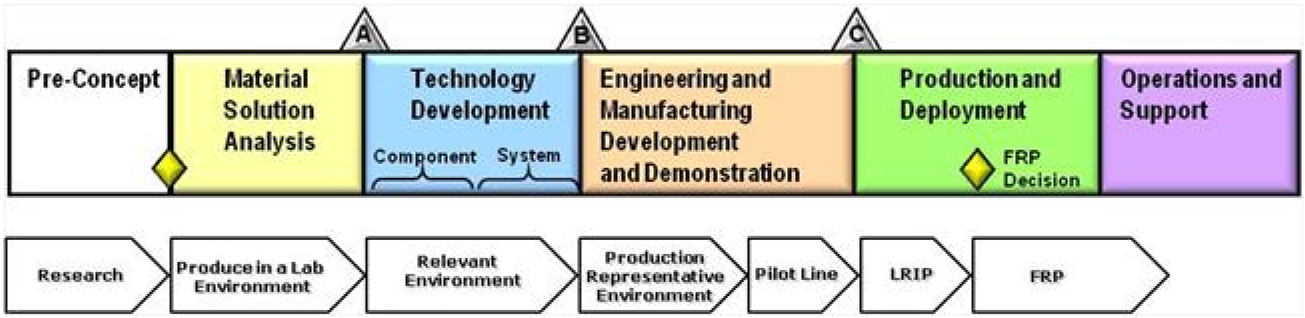


Figure 11-4 Development/Production Environments

The environments that produce our products include the following features or characteristics:

Environment	Development (Technology)	Production (Manufacturing)
Laboratory	Component is developed and validated in a lab environment.	The item is produced in a laboratory environment using highly skilled engineers and craftsmen.
Relevant (Component)	The component is developed and validated in a relevant environment.	The item is produced in a production relevant environment. This is an environment with some shop floor production realism (*e.g.* production facilities, personnel, tooling, processes, materials etc.). There is less reliance on laboratory resources and you have the ability to meet the cost, schedule, and performance requirements based production of prototypes.
Relevant (System)	System/subsystem model or prototype demonstration in a relevant environment.	
Representative	The (system) prototype is demonstrated in an operational environment.	The systems, subsystems or components are produced in a production representative environment. You have higher production realism based on a mature design. Production personnel, equipment, processes, and materials are used whenever possible. Work instructions and tooling are of high quality, and the only changes anticipated are associated with design changes that address performance or production rate issues.
Pilot Line	The actual system has been completed and qualified through test and demonstration.	You use a pilot line to build the items and are ready to begin low rate production. A pilot line incorporates all of the key production elements (equipment, personnel skills, facilities, materials, components, processes, work instructions, tooling, etc.) required to manufacture, subsystems or systems that meet the design in LRIP.

Low Rate Production	The actual system has been proven through successful mission operations.	Low Rate Production is demonstrated and the capability is in place to begin Full Rate Production. The LRIP line should utilize full rate production processes to the maximum extent practical.
Full Rate Production		Full Rate Production is demonstrated and lean production practices are being put into place.

Table 11-1 Technology and Manufacturing Considerations

11.4.1 Acquisition Process and Framework For Transition

There are two approaches to the acquisition process. The current approach is defined in DOD 5000-series documents. These documents spell out the various acquisition processes that programs must follow. But they do not describe the "industrial process," nor do they provide insight on the management and control of industrial processes and their related details that can either make or break a project.

The industrial process is a technical process focused on the design, test, and production of a product. And the industrial process will fail or falter if these processes are not performed in a highly disciplined manner. Design, test, and production processes are a continuum of interrelated and interdependent disciplines. A failure to perform well in one area will result in a failure to do well in all areas. Poor management of the industrial process can lead to late fielding of a system that costs more and does not perform as expected. The V-22 Osprey had problems in part because the industrial processes were not managed effectively.

The second approach is to understand the best practices associated with the industrial processes and then blend the management of these best practices into the acquisition processes. This section will outline the current acquisition processes and identify transition to production activities and opportunities. Section 11-5 will outline two documents that attempt to describe the industrial processes that must be managed and controlled in order to minimize the transition to production risks. These two documents are DOD 4245.7-M, Transition from Development to Production, and NAVSO P-6071, Best Practices.

While this chapter focuses on the V-22 it is important to recognize that the acquisition framework in 1980 was considerably different than the framework today (2011) with only the Production and Deployment Phase having the same name. Thus when we refer to Full Scale Development (FSD) you can substitute Engineering and Manufacturing Development

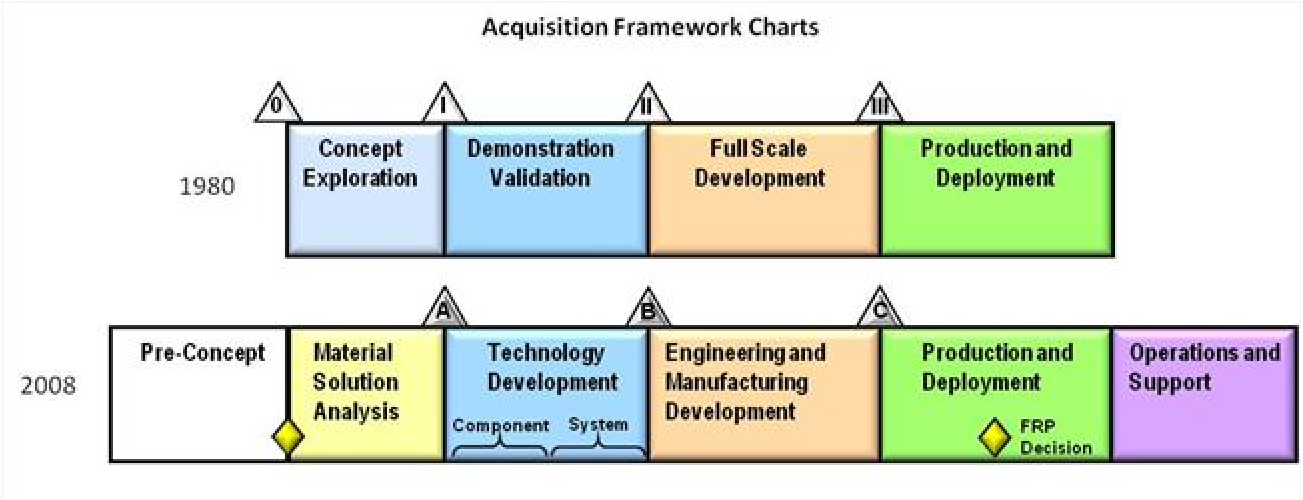


Figure 11-5 Old and New Acquisition Framework Chart

11.4.2 Material Solution Analysis (MSA) Phase

The purpose of the MSA phase is to assess potential materiel solutions and to satisfy the entrance criteria for the next program milestone. This phase is the first opportunity to influence systems supportability and affordability by balancing operational requirements against technology opportunities, production costs, and sustainment requirements. During this phase, various alternatives are analyzed in order to select a materiel solution and to fill any technology gaps. This phase includes developing the Technology Development Strategy (TDS), identifying and evaluating manufacturing feasibility, and assessing affordable product support alternatives to meet operational requirements and associated risks. The ability to transition from the MSA phase to the Technology Development (TD) phase requires the accomplishment of many activities:

- Assess all potential solutions for a stated need;
- Develop a preliminary acquisition strategy;
- Develop a Technology Development Strategy (TDS);
- Develop program goals for any needed development of critical enabling technologies;
- Conduct an Analysis of Alternatives (AoA) leading to selection and approval of a materiel;
- Develop a draft Capabilities Development Document (CDD);
- Develop a Systems Engineering Plan (SEP);
- Develop Initial Support and Maintenance Concepts; and
- Assess Manufacturing Feasibility.

The MSA phase is critical for establishing the trade space that will be available to the Program Manager in subsequent phases. User capabilities are examined against technologies, both mature and immature, to determine manufacturing feasibility and alternatives to fill user needs. Once the requirements have been identified, a gap analysis should be performed to determine the additional capabilities required to implement the manufacturing approach and support concept and its drivers within the trade space.

Transition involves the maturing of the design and the production conditions. During the MSA phase, the item or component was probably produced in a laboratory environment, using highly skilled engineers and craftsmen. Some of the materials, manufacturing processes, and skills may be new, requiring manufacturing maturation.

11.4.3 Technology Development (TD) Phase

The purpose of the Technology Development (TD) Phase is to reduce technology risk and to determine the appropriate set of technologies to be integrated into the system. The TD phase conducts competitive prototyping of system elements, refines requirements, and develops the functional and allocated baselines of the end-item system configuration. The objective of the TD phase is the buying down technical risk and developing a sufficient understanding of a solution in order to make sound business decisions on initiating a formal acquisition program and moving into the Engineering and Manufacturing Development Phase.

The TD phase develops and demonstrates prototype designs to reduce technical risk, validate designs, validate cost estimates, evaluate manufacturing processes, and refine requirements. Based on refined requirements and demonstrated prototype designs, Integrated Systems Design of the end-item system can be initiated. The ability to transition from the TD phase to the Engineering and Manufacturing Development (EMD) phase requires the accomplishment of many activities and outputs:

- Test and Evaluation Master Plan;
- Risk Assessment;
- Systems Engineering Plan;
- Programmatic Environment, Safety, and Occupational Health Evaluation;
- National Environmental Policy Act Compliance Schedule;
- Program Protection Plan;
- Technology Readiness Assessment;
- Validated System Support and Maintenance Objectives and Requirements; and
- Evaluate Manufacturing Processes.

The TD phase is critical for establishing that the program's technology and manufacturing processes have been assessed and demonstrated in a relevant environment. Transition involves the maturing of the design and the production conditions. During the TD phase, the component transitions out of the laboratory and into a production relevant environment. This is an environment with some production realism (e.g. production facilities, personnel, tooling, processes, materials, etc.), and programs have the ability to meet the cost, schedule, and performance requirements based production of prototypes. Then the system transitions out of a production relevant environment and into a production representative environment for the EMD phase.

11.4.4 Engineering and Manufacturing Development (EMD) Phase

EMD is where a system is developed, designed and validated before going into production. The EMD Phases starts after a successful Milestone B review and is considered the formal start of a program. The goal of EMD is to complete the development of a system, complete full system integration, develop affordable and executable manufacturing processes, complete system fabrication, and test and evaluate the system before proceeding into the Production and Deployment Phase. The purpose of the EMD Phase is to:

- Develop a system or increment of capability;
- Design-in critical supportability aspects to ensure materiel availability with particular attention to reducing the logistics footprint;
- Integrate hardware, software, and human systems;
- Design for producibility;
- Ensure affordability and protection of critical program information;
- Demonstrate system integration, interoperability, supportability, safety, and utility;
- Ensure operational supportability with particular attention to minimizing the logistics footprint; and
- Demonstrate reliability, availability, maintainability, and sustainment features are included in the design of a system.

Transition involves the maturing of the technologies and design so that by the Critical Design Review (CDR) the design is stable with relatively few changes coming after CDR. During the early part of the EMD phase, the system was probably produced in a production representative. Then in the second half of EMD, the systems production transitions into a pilot line environment.

11.4.5 Production and Deployment (PD) Phase

The purpose of the Production and Deployment Phase is to achieve an operational capability that satisfies mission needs. Operational test and evaluation determines the effectiveness and suitability of the system. The Production and Deployment Phase should accomplish the following:

- Update Product Baseline;
- Update Test and Evaluation Plan;
- Conduct a Risk Assessment;
- Update the Life-cycle Sustainment Plan;
- Ensure Environmental (NEPA and ESOH) Compliance;
- Update the Systems Engineering Plan;
- Provide Inputs to Cost and Manpower Estimate;
- Update System Safety Analyses to include finalizing hazard analyses; and
- Demonstrate Manufacturing Processes.

Entrance into EMD depends on having acceptable performance in developmental test and evaluation and operational assessment; mature software capability; no significant manufacturing risks; manufacturing processes under control; an approved ICD; an approved Capability Production Document (CPD); a refined integrated architecture; acceptable interoperability and operational supportability; and demonstration that the system is affordable, fully funded, and properly phased for rapid acquisition.

A PM should understand that weapon systems acquisition is an industrial process which demands both an understanding of industrial processes and the implementation of basic engineering disciplines and their control mechanisms. Transitioning from development into production requires an acquisition strategy that places specific demands on engineering design, test, manufacturing and logistics. The program needs to emphasize the need for design stability, maturing of new technologies, and the proofing of the manufacturing process. At the production phase, large financial commitments are made based on the detailed planning of previous phases. The transition is now a highly visible, highly reactive time that is characterized by emphasis on preparation for production and change management.

During the EMD phase, the system was produced in a pilot line environment. Then in the Production and Deployment phase, the system moves off of the pilot line and into Low Rate and/or Full Rate Production. Low Rate Production is intended to result in an "adequate and efficient manufacturing capability." Full Rate Production is intended to result in the demonstration that manufacturing processes are under control, and key and critical product characteristics are both capable and in control.

11.5 DOD 4245.7-M: Transition From Development to Production

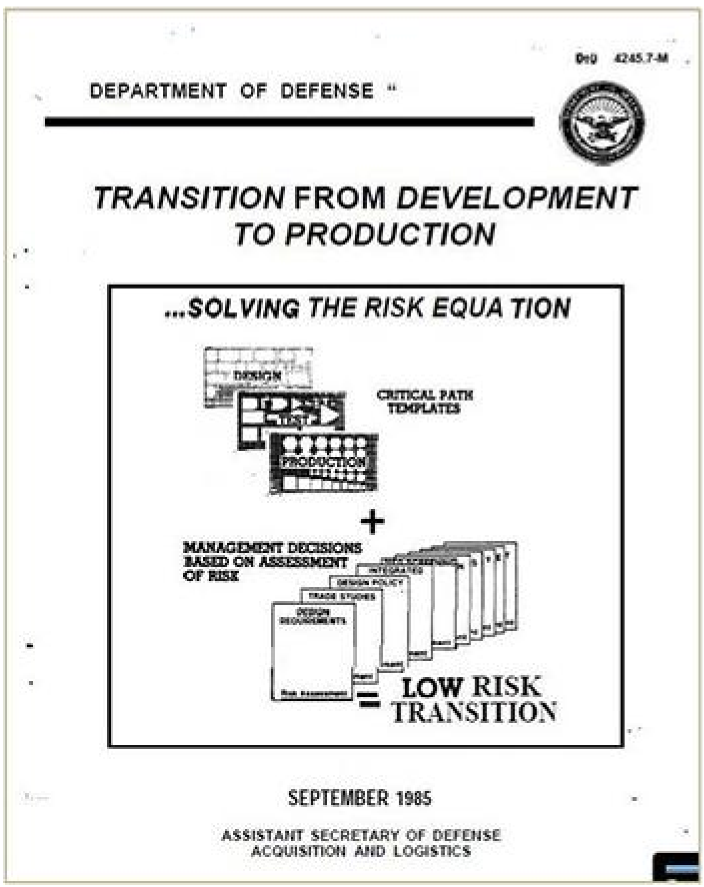


Figure 11-6 Transition from Development to Production

The transition process is very broad and dependent upon certain activities to take place in order for the program to have a smooth, orderly progression. The critical path, templates shown in Figure 11-7, outline those activities. The templates can be thought of as wickets to pass through before the major template function may be achieved. For example, the major template of design has fourteen supportive templates, each of which must be addressed in a disciplined manner before the design template can achieve design maturity and thus fulfill the requirements for transition from R&D to production.

DOD 4245.7-M, *Transition From Development to Production* , provides an overview of the critical path templates. These templates describe critical industrial processes and their control methods and include:

- Funding,
- Design,
- Test,
- Production,
- Facilities,
- Logistics, and
- Management.

The templates provide a way of assessing risk by evaluating risk in specific areas by asking:

- What is the problem?
- How can it be addressed?
- When should the risk be addressed?

The templates are arranged in a top-down fashion laying out the industrial processes that are an area of concern or risk. Each template or critical path describes an area of risk and then identifies technical methods for reducing that risk. Each template is further sub-divided into lower level templates.

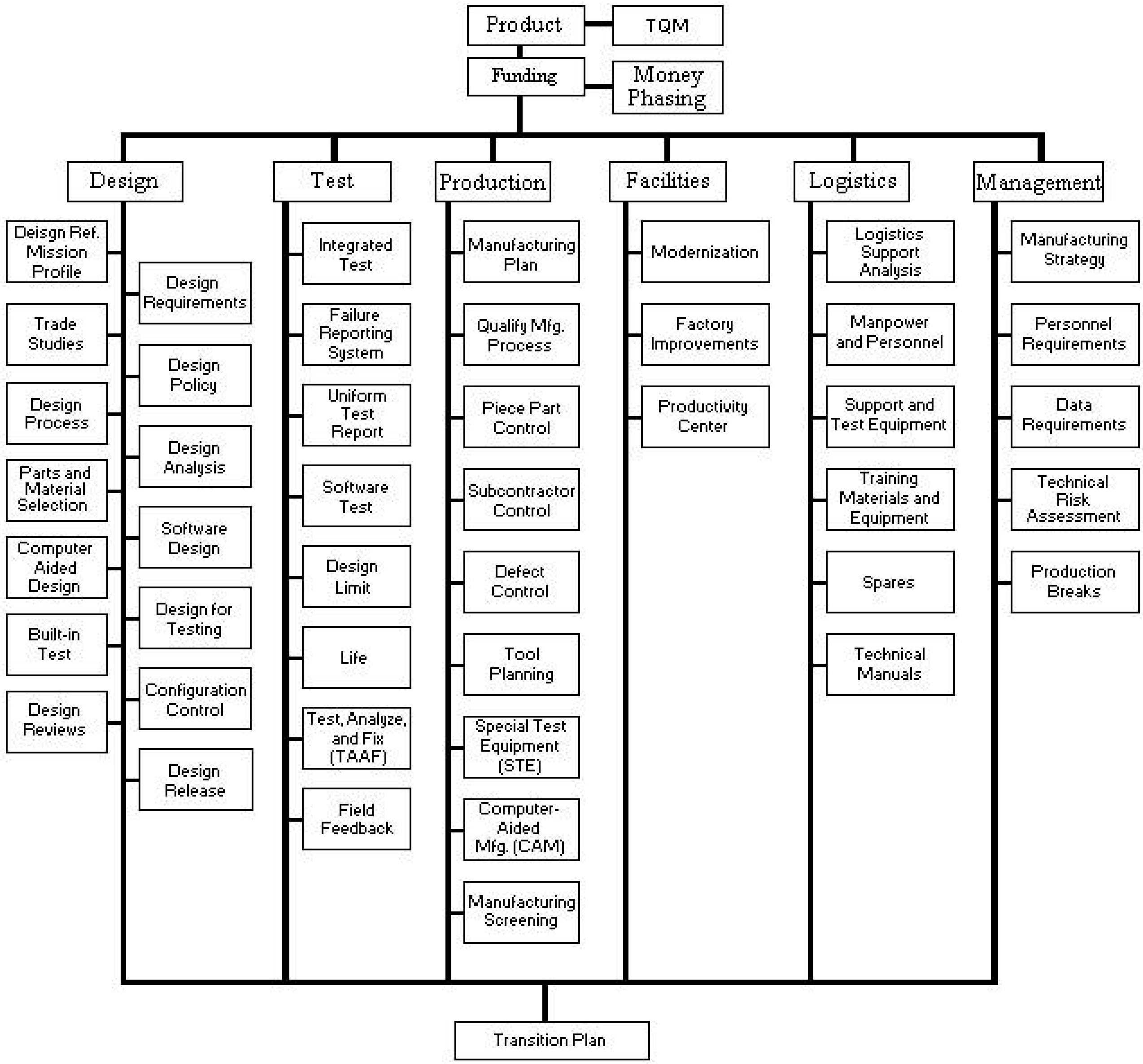


Figure 11-7 Critical Path Template

The templates are arranged in a logical sequence. For example, the Funding template is shown in a position that influences each of the other templates and the transition plan template is shown in a position of depending upon other, preceding templates. Figure 11-8 lays out the templates in a timeline showing an orderly transition process where the templates are interrelated and interdependent. The chart shows the activities of the templates and their starting times in relation to other template activities. For example, the production template activities are started after the initial activities of the design template, but in conjunction with some of the design templates. Note that the original template has been modified to show today's (2011) Milestones vs. what was active in 1984 when the templates were first unveiled.

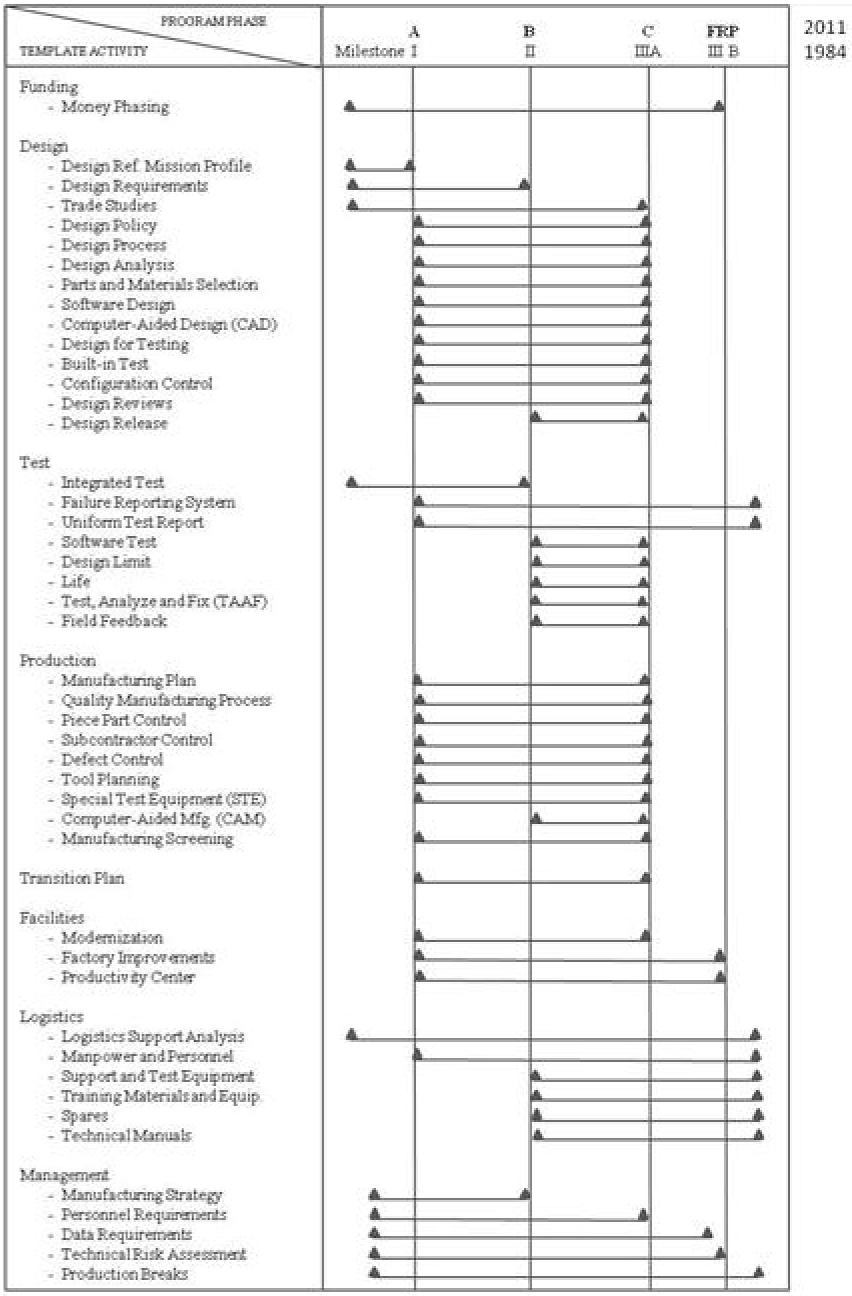


Figure 11-8 Transition Timelines

Figure 11-9 Best Practices

Note that the original template has been modified to show today's (2011) Milestones vs. what was active in 1984 when the templates were first unveiled. In addition, current thinking would have many activities beginning earlier in the acquisition life cycle than is depicted here. For example, the template (developed in 1984) shows only a few logistics considerations and many of them not beginning until after Milestone B, when in fact there are other logistics considerations (design for supportability) and they should begin before Milestone A. The Product Support Managers Guidebook (April 2011) outlines various risk areas and activities in their discussion on "sustainment maturity levels."

Below is a discussion of each of the seven critical templates and outlines each area of risk, when it should be assessed, ways to reduce the risk and any associated best practices. The best practices come primarily from the NAVSO P-6071, "Best Practices."

11.5.1 Funding and Money Phasing

Area of Risk : The critical path templates identifies two lower levels of templates that are areas of risk.

1. First, there never seems to be enough money to cover all of the risks and trade studies that should be conducted.
2. Funding is often late. For example, producibility engineering should be accomplished early but is often traded away because there is not enough funding. Testing is another area that is often accomplished later than required due to lack of funding.

The lack of timely and adequate funding often leads to cost growth, schedule delays, lower performance, and fewer assets. For example, the F-22 Raptor had an original unit cost estimate of $139M and it almost tripled to $412M and the quantities were reduced from 648 to 339 and then to 187.

When Assessed : Funding and money phasing should be assessed throughout the life cycle of a program. Cost is a constraint that must be managed and "Cost as an Independent Variable

(CAIV)" is one attempt at recognizing this constraint and providing program managers a way of integrating this constraint into the systems acquisition process.

Ways to Reduce Risk: The best way of reducing this risk is to know and understand how transition activities can contribute to the successful development and transition to production of an affordable weapon system. This will enable PMs to better defend budget request and assist them in making better trade decisions. For example, if programs do not correctly identify all of your technology risks, then they will miss budgeting for and funding an item that must be matured if the system is to transition to production.

Best Practice : Solving the Funding and Money Phasing risks begins with the development of an adequate budget within the Planning, Programming, and Budgeting System (PPBS). In compiling the budget, the program office needs to capture and understand all of the technical requirements and risks associated with the achievement of those requirements. The more knowledge PMs have of the risks the better the estimate will be. An understanding of the risks and costs will then put the program office in a better position to make trade-off decisions understanding the impact of delaying important industrial processes until later in the program's life. Then when trade-off decisions are made, use the knowledge of those technical decisions to restructure the budget and funding to develop a more realistic profile.

11.5.2 Design

Area of Risk : The critical path templates identifies thirteen lower levels of templates that are areas of risk.

1. Design Reference Mission Profile
2. Trade Studies
3. Design Policy
4. Design Process
5. Design Analysis
6. Parts and Materials Selection
7. Software Design
8. Computer-Aided Design (CAD)
9. Design for Testing
10. Built-in Test
11. Configuration Control

12. Design Reviews

13. Design Releases

In addition to the above, unstable and ill-defined requirements are signs of trouble, thus getting a good mission profile is essential. When the Army dropped out of the V-22 program, it caused some requirements to change. Requirements changes lead to design changes, which lead to cost and schedule changes.

Many design risks are associated with design processes and the maturity of that design. As the design progresses from concept to preliminary design and detailed design, then the systems engineering process and the integrated product team must be working closely together to ensure that all design considerations are well thought out and that the design matures on a predictable schedule.

Integration of sub-systems and components and between is another critical task with prime contractors and their subs and vendors working together to ensure that design considerations are integrated and managed to optimize the system level design.

Finally, the producibility of the design is key and critical to achieving an end item that is affordable and performs as expected. Producibility of the design should include life cycle considerations that would mostly impact the users and maintainers.

When Assessed : The initial concept, through detailed design to final design.

Ways to Reduce Risk : Capturing requirements is a difficult task and one that is best performed using proven tools and best practices.

Best Practice : The following have been identified as best practices:

- Quality Function Deployment (see Chapter 5) is a best practice tool for capturing requirements.
- The PDR and CDR are the systems engineering technical reviews that are used to measure design maturity. By CDR, the design should be mature, stable and with few engineering changes.
- Producibility Engineering Program is a best practice for ensuring that the design is producible and affordable.

11.5.3 Test

Area of Risk : Testing, like production, begins very early in a program and matures as the program matures. In Technology Development contractors might be building a breadboard in a lab environment and testing it to evaluate a design approach and identify the best design approaches to carry forward. Then as the technology, design, and production mature then the testing matures and moves into mover rigorous environments. The testing transitions from the lab to a relevant environment, then to a representative environment, and finally to an operational environment. The critical path templates identifies eight lower levels of templates that are areas of risk.

1. Integrated Test
2. Failure Reporting System
3. Uniform Test Report
4. Software Test
5. Design Limit
6. Life
7. Test, Analyze and Fix (TAAF)
8. Filed Feedback

When Assessed : Testing begins very early in the life cycle of a program, even prior to Milestone A. These tests could be at government, prime contractor or at subcontractor facilities. Government testing includes developmental testing, operational testing and follow-on testing. Contractor testing includes development testing, qualification testing, and acceptance testing.

Ways to Reduce Risk : The best risk reduction tool is a well developed and integrated Test and Evaluation Master Plan (TEMP) that has traceability back to the defined requirements.

Best Practice : A recent OSD Study of Commercial Industry Best Practices in T&E included:

- Recognize that testing is a way to identify and solve problems early in the process in order to control time, cost and schedule late in the process.
- Develop consistent processes to ensure consistent products. Understand the value and cost of T&E.
- Increase T&E to assure product quality rather than reduce it to save T&E cost.
- Gain early commitment by all stakeholders on required T&E resources.
- Ensure early determination of the investment costs to acquire new capability for program support.
- Ensure cohesive (year-to-year) investment plans.
- Charge the cost of test investment to the program.
- Involve testers and evaluators very early.
- Capture test costs at program initiation.
- Use measurements and metrics.
- Integrate Master Test Plans and test execution with program resources and milestones.
- Charge the full cost of testing to the program.
- Establish measures of effectiveness.
- Train the in-house test workforce in test engineering disciplines.

11.5.4 Production

Area of Risk : The critical path templates identifies eight lower levels of templates that are areas of risk.

1. Manufacturing Plan
2. Qualify Manufacturing Plan
3. Piece Part Control
4. Defect Control
5. Tool Planning
6. Special Test Equipment (STE)
7. Computer-Aided Manufacturing (CAM)
8. Manufacturing Screening

When Assessed : Manufacturing should be assessed throughout the life of the program. Early in the program, you will be assessing an item that is produced in a laboratory environment. It may be a component, a coupon or a brassboard. But it will not be a full up system with all of the design and production requirements identified. Now is the time to assess production risks and plan for production, knowing that there are common risks to watch out for. According to the Program Managers Toolkit these common risk include:

- Unstable requirements/engineering changes;
- Unstable production rates and quantities;
- Insufficient process proofing;
- Insufficient materials characterization;
- Changes in proven materials, processes, subcontractors, vendors or components;
- Producibility;
- Configuration management;
- Subcontractor management;
- Special tooling; and
- Special test equipment.

Ways to Reduce Risk : First is to plan out the manufacturing strategy and ensure that strategy gets into the acquisition documents and contracts. Next would be to work with engineering to ensure that the design is producible. A great factory can never overcome a bad design. Third is execute the manufacturing plan. Know what needs to be controlled and then manage and control it.

Best Practice : The adoption of various maturity measures (technology, design, manufacturing and sustainment) as a risk identification tool has become a best practice. Lean and Six Sigma activities are ways to greatly improve the production processes and help ensure that the cost of quality is low. Software tools, both shop floor and in the front office can help to manage all of the manufacturing and quality data and knowledge requirements. This includes MRP/ERP systems, CAD/CAM, software tools to help manage the quality control requirements. Finally, subcontractor quality programs are essential in a world in which 80 percent of the product comes from vendors and suppliers.

11.5.5 Facilities

Area of Risk : The critical path templates identifies three lower levels of templates that are areas of risk.

1. Facility Modernization
2. Factory Improvements
3. Productivity Center

When Assessed : The planning for new, or modernized facilities can begin early in a program. The F-22, for example, began planning for a new facility during the DemVal Phase (now Technology Development Phase) with construction of the facility starting at the beginning of EMD.

Ways to Reduce Risk : The production of today's sophisticated weapon systems often requires state-of-the-art manufacturing equipment and facilities. Factory modernization is often key to achieving cost-effective production techniques. A great example is the F-35 Joint Strike Fighter. Originally the F-35's inlet ducts were drilled out by hand. This process was extremely difficult from an ergonomics perspective, required excessive tooling, was very labor intensive and costly, had a very long cycle time and quality was not what it needed to be. Through a modernization effort under Air Force ManTech, the Air Force invested $6.2M. This investment resulted in $40M in savings, reduced tooling, floor space, and manpower cost. Cycle time was reduced from 50 to 12 hours per duct. Most importantly, the JSF can now meet full rate production targets, which it could not meet before the modernization efforts.

Figure 11- 10 JSF Hole Drilling Modernization

Best Practice : Best practices include early risk identification and planning for modernization. Contracts should be structured to encourage factory modernization in order to achieve target cost, rate and quality targets. Capital investments should be based on long-term benefits.

11.5.6 Logistics

Area of Risk : The critical path templates identifies six areas of risk.

1. Logistics Support Analysis
2. Manpower and Personnel
3. Support and Test Equipment
4. Training and Material Equipment
5. Spares
6. Technical Manuals

When Assessed : The primary purpose of the acquisition process is to field weapon systems and equipment that performs their intended functions, and to do so over and over again without unplanned maintenance and logistics efforts. The logistics templates indicate that planning begins early and continues throughout the life of a program, even through disposal. Disposal has become a major consideration as today's programs face increasing world-wide scrutiny for environmental considerations.

Ways to Reduce Risk : The reduction of risk begins with risk identification and logistics planning and planning is rooted in the logistics support analysis. Initial planning begins in the Material Solution Analysis Phase with an "Alternative Maintenance & Sustainment Concept of

Operations." This will lead to a comprehensive "Product Support Strategy" that gets reviewed and updated on a regular basis.

Best Practice : The Product Support Managers Guide should be used as a best practice. It outlines six major tasks for the Product Support Manager (PSM):

1. Develop and implement a comprehensive Product Support Strategy (PSS)
2. Conduct cost analysis to validate the PSS
3. Develop and implement appropriate product support arrangements
4. Adjust performance requirements and resource allocations to optimize implementation of the PSS
5. Periodically review the product support arrangements to ensure arrangements are consistent with the PSS
6. Periodically review and revalidate any business case analysis performed in support of the PSS

11.5.7 Management

Area of Risk : The critical path templates identifies five lower levels of templates that are areas of risk.

1. Manufacturing Strategy
2. Personnel Requirements
3. Data Requirements
4. Technical Risk Assessment
5. Production Breaks

When Assessed : Management is the first activity or practice that is developed and assessed and is the last activity accomplished with the closing of a program or project. Having the right people at the right time with the right skills and experience is critical to the successful transition from development to production and beyond. The Defense Acquisition Workforce Improvement Act (DAWIA) was enacted to establish standards for education and training of acquisition professionals. However, the Federal Acquisition Streamlining Act of 1994 significantly overhauled federal procurement law and the oversight process. As a result many production, quality, and manufacturing (PQM) professionals migrated out of their career field leaving many organizations with few personnel that really can manage the functions mentioned above.

Ways to Reduce Risk : Training of personnel is key along with having experience in the relevant areas of management. The workforce needs to be rebuilt through training and experience. Programs need to capture lessons learned and develop tools and techniques that can be used to help establish better manufacturing strategies.

Best Practice : The best practice here is still to get DAWIA certified in the Production, Quality and Manufacturing (PQM) career field. In addition, joining the PQM Community of Practice (CoP) will provide you access to hundreds of resources in that you can use to assist you in your daily functions.

11.6 Transition Plan

The fundamental purpose of the transition plan is to provide the integration methodology that will tie together the application of the templates within the context of the industrial process. This process begins with a complete understanding of the technical requirements of the product, then using that knowledge, preparing a transition plan. The transition plan should outline the risks and ways for reducing risks in each of the critical path templates.

The systems engineering activities outlined in the Defense Acquisition Guide, Chapter 4, offer an opportunity for the program manager along with their Integrated Product Team (IPT) to assess risk and the completeness of their transition planning efforts for each stage of development and transition. Several documents are key to this process and are outlined below.

11.6.1 Technology Development Strategy/Acquisition Strategy

The Technology Development Strategy (TDS) is approved at Milestone A to guide the conduct of the Technology Development (TD) phase. The TDS contains a preliminary description of how the potential acquisition program will be divided into increments based on mature technologies; a preliminary program strategy to include overall cost, schedule, and performance goals; specific cost, schedule, and performance goals, including exit criteria, for the TD phase. The TDS eventually becomes the Acquisition Strategy (AS). However the construction of a TDS or AS without due consideration to the manufacturing elements is a sure way to introduce unnecessary risk. Risk that:

- The industrial base may not have the capability of meeting the schedule, performance, and quality desired of the end item.
- The facilities and tooling may not be built in time to support production.
- The funding for many of the factory floor innovations might not be available.
- The personnel with the right skills, training and certifications might not be available.
- The manufacturing processes planned for production might not be proven.
- The ability to achieve targeted quality and reliability levels might not recognized.
- The suppliers might not have had an opportunity to integrate their manufacturing/QA capabilities with those of the prime contractor.

Manufacturing planning within the TDS should include transition considerations that may be impacted by:

- Funding constraints and phasing of money;
- Design considerations, goals and risks;
- Test and evaluation methods and approaches along with success criteria;
- Production processes, methods, personnel, facilities, equipment and capabilities;
- Life cycle logistics and sustainment criteria, approach and goals; and
- Management approach to transition risks.

The challenge of program management is to find the practical middle ground between producing systems based on prototype designs and emerging technologies and extensive development and testing to prove out those prototype designs. Key program office guidelines to follow are:

- Select an acquisition strategy and risk management plan in context with the unique aspects of the program and the risks associated with that development and production effort.
- Enter Engineering and Manufacturing Development (EMD) only with a mature technology base, stable product design and proven manufacturing processes that are stable and under control.
- Plan for transition to production starting at program initiation.
- Avoid gaps in production.

11.6.2 Systems Engineering Plan

The systems engineering plan (SEP) is the blueprint for the execution, management, and control of the technical aspects of an acquisition program from conception to disposal. The SEP outlines how the systems engineering process is applied and tailored to meet objectives for each acquisition phase. The SEP is a "living" document that captures a program's current and evolving systems engineering strategy and its relationship with the overall program management effort. The SEP is updated as needed to reflect technical progress achieved to date and to reflect changes in the technical approaches stemming from the findings and results of the technical reviews, program reviews, acquisition milestones, or other program decision points. The SEP should include transition considerations to include:

- Producibility Assessment and integration with other design activities;
- Identification of key and critical manufacturing assembly and test processes to be evaluated and matured;
- Assessments of risks (technology, manufacturing, software development, and sustainment);
- Development of metrics and data to assess, monitor, manage and control the transition process; and
- Integration of manufacturing risks in cost and manpower estimates.

11.6.3 Production/Manufacturing Plan

Manufacturing plans are not stand-alone documents; rather they should be integrated into other program management documents. Early planning focusing on the specifics of the manufacturing practices and processes required to build the end item should be initiated while the design is fluid, and completed before the start of rate production. A manufacturing plan should be a comprehensive document, provide guidelines for action, identify and give visibility to high risk factors, and then provide direction by which risk can be minimized. The report cited earlier, "Solving the Risk Equation in Transitioning from Development to Production," lists the essential elements of a manufacturing plan which will significantly reduce the risk of transitioning a program from development to production. These criteria include the following:

- Master delivery schedule which identifies by each major subassembly the time spans, need dates, and who is responsible;
- Hard tooling requirements to meet increased production rates as the program progresses;
- Special tools;
- Special test equipment;
- Assembly flow charts;
- Receiving inspection requirements and yield thresholds;
- Production yield thresholds;
- Producibility studies;
- Design improvements;
- Production control;
- Critical processes;
- Cost/schedule reports;
- Trend reports;
- Product assurance;
- Fabrication plan; and
- Engineering release plan.

The creation of a manufacturing plan requires a systematic process for answering questions such as:

- What is the product to be produced?
- How will the components be assembled?
- What assemblies/parts/components compose the final product?
- Who will manufacture the components?
- What equipment/operations are required?
- Where will the components be made?
- What type of labor is involved?
- How long does it take to produce the components/assemblies?
- What raw materials are required?
- How much of each component/assembly must be produced?
- How should the product flow through the plant?
- What should the lot sizes be?

The role of manufacturing is to:

- Influence the design,
- Prepare for production (plan), and
- Execute the manufacturing plan.

One way of verifying that the manufacturing plan was adequate in planning for the transition to production is to conduct a production readiness review (PRR). The chart below shows the various critical path templates activities that should have been concluded by Milestone C, which is the start of low rate initial production (LRIP), and the PRR team can structure the review using the templates of DOD 4245.7M. The chart indicates a stable, mature design release, accompanied by manufacturing processes that have qualified for production, which illustrates smooth transition from design to production. However, for many programs the transition continues for both design and production up through Full Rate Production.

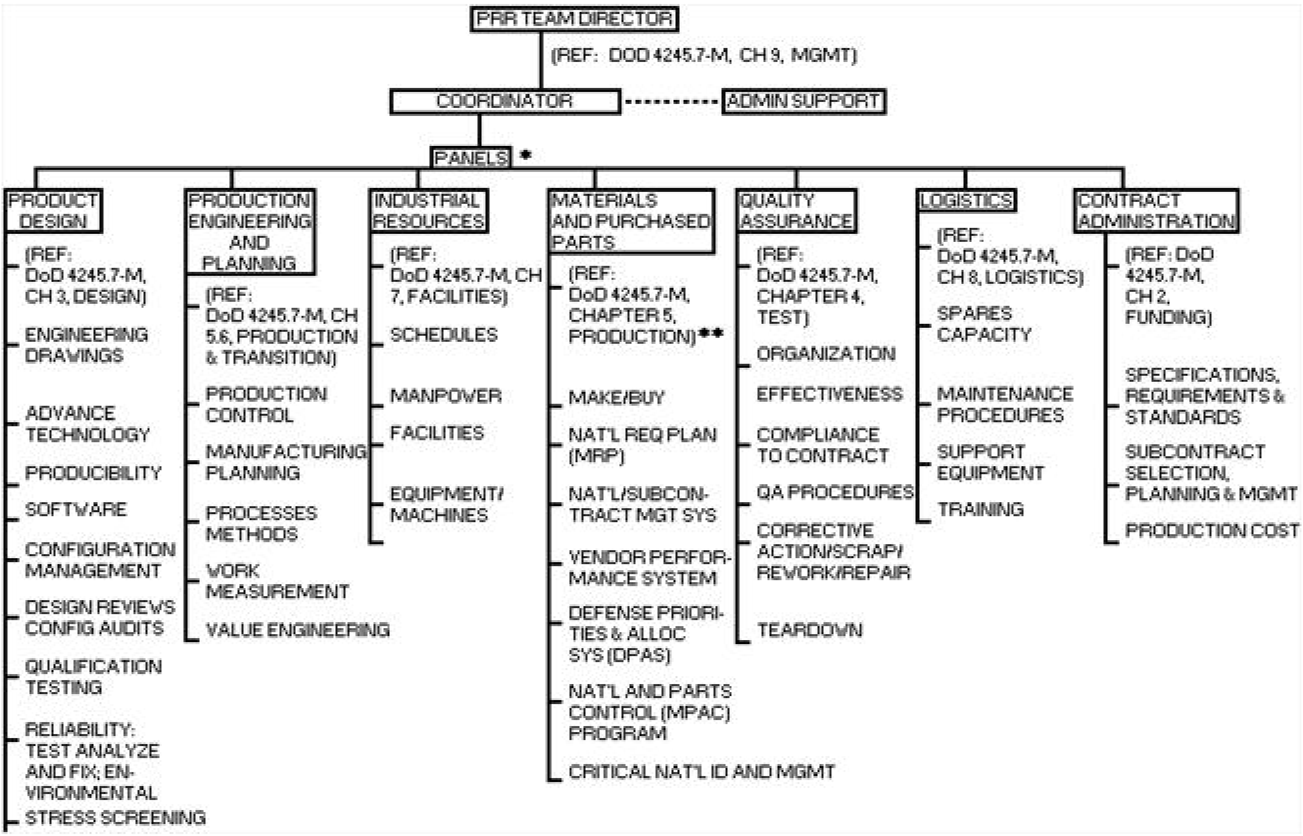


Figure 11-11 PRR Template Relationship

11.7 Transition Challenges

The challenge of program management is development and implementation of a program acquisition strategy that results in the on-time delivery of a quality product that meets cost and performance objectives. A program manager should recognize that system acquisition demands an understanding of the transition process and its control mechanisms. The transition process is very board and it is impacted by the activities that occur, or fail to occur, from the early design phase of a program to the production phase. The control mechanisms of the transition process are called templates and are outlined in DOD 4245.7M "Transition From Development to Production." There are certain factors and events that present challenges to the successful implementation of the transition process. In some cases these challenges are addressed directly by the transition templates; in others they are not. This section addresses some of those challenges not directly addressed in DOD 4245.7-M.

11.7.1 Producibility

The lack of up-front producibility engineering is a very real problem. If the design is so intricate and detailed that it cannot be made by other than expensive model-shop processes when the requirements are for production-line quantities, then affordability becomes an issue. If the item is overly complex, it introduces more opportunities for failures during the manufacturing process, and during operations, thus greatly decreasing reliability and increasing maintenance complexity and costs. If you have not used producibility engineering to reduce the number and types of parts, then you have added to the cost for manufacturing the end item. More parts to manage, more parts to assemble, more parts to fail.

11.7.2 Design Maturity

A design is not mature unless it is stable and can be produced, tested, function to requirements, and be supported properly in the field. Before these requirements can be met, the necessary communication must take place during the design phase between the functional elements of design engineering, test engineering, production, logistics, and procurement.

In order to achieve design maturity, producibility and testability must be designed into the product. If a design is so complicated that it cannot be tested, then there is also an excellent chance that it cannot be manufactured; if the design cannot be manufactured, then probably cannot be maintained and it is not a mature design.

Design maturity is closely linked with producibility. As the design matures, there should be a decline, in the number of formal engineering change notices (ECN) being processed. In addition, a formal producibility assessment will provide the program manager with the confidence that the design is producible and able to achieve its lowest cost potential.

11.7.3 Quality Assurance and Quality Control Planning

Many people use Quality Assurance (QA) and Quality Control (QC) interchangeably, but they are in fact different. QA is concerned with the business processes and practices put into place to make sure that the right things are being done the right way. QC is concerned with the business processes and practices that are put into place to make sure the right results are achieved. QA is process focused and QC is product focused.

Quality Assurance (QA) is the planned and systematic activities implemented in a quality system so that the quality requirements for a product or service are fulfilled. QA focuses on the entire quality system including suppliers and ultimate consumers of the product or service. It includes all activities designed to produce products and services of appropriate quality. QA begins before a product is made or before a project is even started.

Quality Control (QC) refers to the activities used during the production of a product that are designed to verify that the product meets the customer's requirement. QC focuses on the process of producing the product or service with the intent of eliminating problems that might result in defects. QC begins as the product is being produced.

QA planning and control however, is an extremely wide requirement and should be present throughout the acquisition life cycle, and should include a focus on Advanced Quality Systems/Total Quality Management as a central tenet of program management. In the early stages of acquisition, quality is focused on planning. As the program progresses through the acquisition life cycle, the program begins to focus on implementation of the quality assurance and quality control systems. Later the main focus is on assessing the product for conformance, and overlaying the entire process is or should be a system of continuous improvement.

11.7.4 Variability Reduction/Continuous Process Improvement

Modern engineering design, manufacturing engineering and quality assurance, embrace variability reduction as a primary means of improving product performance and reducing product defects. In many firms today, a primary goal of engineering efforts is the continuous and systematic reduction of variability in key product features and manufacturing processes. Variation reduction efforts should be applied only to those features and processes defined as key or critical based on human safety and/or mission essential performance.

Variation may be defined as any unwanted condition or as the difference between a current and a desired end-state. Both product performance and manufacturing processes exhibit variation. To manage and reduce variation, the variation must be traced back to its source. Variation occurs in all natural and man-made processes. If variation cannot be measured, it is only because the measurement systems are of insufficient precision and accuracy.

The traditional situation depends on production to make the product and on quality control to inspect the final product and screen out defects. This is a strategy of detection. It is wasteful, because it allows time and materials to be invested in products or services that are not always usable. 100 percent inspection is limited in usefulness because it cannot contribute to defect prevention and productivity improvements. Inspection activities are always limited to reacting to the past, and can find defective parts only after they have been produced. Decreases in variability will eventually result in greater product performance, fewer defects and lower manufacturing cost, but a system of prevention needs to be implemented in order to achieve reductions.

Continuous Process Improvement or CPI is an integrated system of improvement that focuses on doing the right things right and in reducing variation. CPI is also an enterprise-wide "way of thinking" for achieving lower cost, shorter lead and cycle times, and higher quality. CPI has a focus on enhancing the satisfaction of the customer, often the warfighter, by improving the processes that are used to develop and deliver the product or service.

The implementation of a Failure Reporting and Corrective Action System (FRACAS) is one tool for fostering continuous process improvement. A Failure Reporting System is central and critical to the identification of problems. A failure reporting system is necessary for the timely dissemination of accurate failure information in order that remedial actions may be taken promptly to prevent the recurrence of the failure. By the implementation of FRACAS those requirements can be met. FRACAS is a closed-loop system that initiates failure reports, analyzes the failures, and provides corrective actions for those failures back into the design, manufacturing, and test processes in order to prevent that same type of failure from happening again.

Without an effective QA planning and defect prevention program the cost of rework and repair would be excessive; the "hidden factory" would become larger and larger. Consequently, for a QA and defect prevention program to be effective, it cannot be localized to just one or two templates, but it must extend to all concerned areas, or in this case, templates. Those "concerned areas" are the three primary manufacturing risk areas of Design, Test. and Production, and each of these templates is supported by templates that share an ultimate goal to improve quality, and prevent defects.

11.7.5 Production Cost Analysis

Production cost and production cost estimates change over time. In the early acquisition phases, cost estimating is probably based on analogy. That is, you compare the cost of the proposed new system with that of a similar system that you have experience with and have cost information on. At this point the estimate is not very accurate as the basis of the estimate is may only resemble the final product and much may change as you develop the new system thus driving changes in the cost model. Then as the program matures and moves through the acquisition life cycle, more and more is learned about the final product to the point you may move from analogy to parametric cost estimating. Parametric cost estimating uses a statistical analysis of two or more similar systems to develop cost estimating relationships. Again, as the program matures and more is known about the system as it transitions from development towards production, the cost estimating methodology moves towards engineering estimates. Engineering estimates are derived by summing detailed cost estimates of the individual work packages and adding appropriate burdens. Engineering estimates are usually determined by a contractor's industrial engineers, price analysts, and cost accountants. The final and most accurate cost estimating technique is the use of actuals. Actual cost estimating method uses the actual cost of the previous production lot adjusted for inflation, labor saving, material cost, technology changes and other factors. It generally comes at the end of the developmental cycle. An actual cost is a cost sustained in fact, on the basis of costs actually incurred and recorded in accomplishing the work performed within a given time period, as distinguished from forecasted or estimated costs.

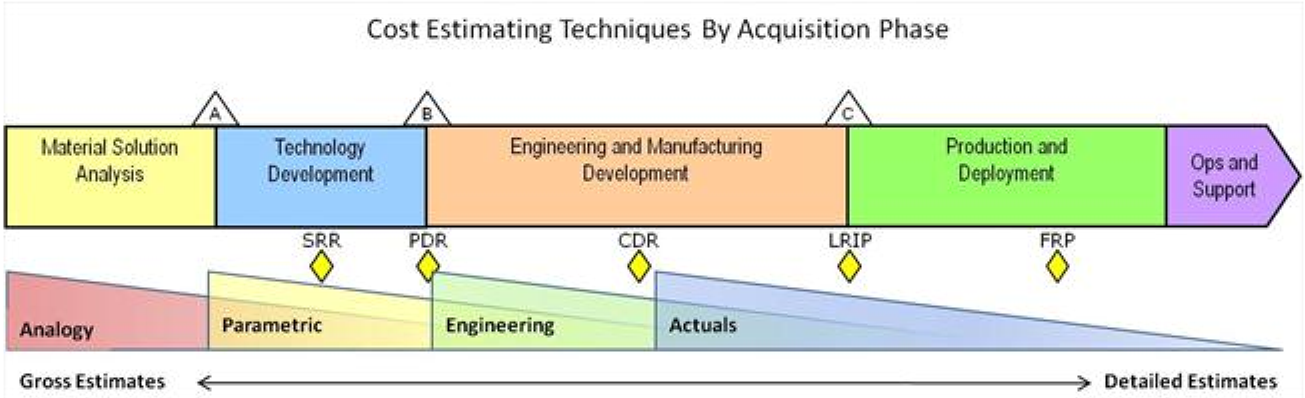


Figure 11-12 Cost Estimating Techniques

One of the major issues to be addressed in the development of the manufacturing plan and cost estimates is determining the rate of production. Unstable production rates are a significant factor in driving programs to becomming unaffordable. Conversely if you want to encourage or drive affordability then it is important to identify and maintain a stable production rate. The demands of the warfighter must be balanced against the capabilities of the industrial base to produce the items and affordability considerations.

Finally, production cost can and will change depending on where you are in the acquisition life cycle and what production environment you are in. For example, early in the program the production environment is probably a laboratory. The production personnel may be highly skilled engineers, and the production lot size may be one. This is a very expensive environment. Even though you may not need production tooling, you have higher costs as you are producing one of a kind. Then as you move forward and transition from the lab to a relevant environment, you move out of the expensive lab with the high cost engineers performing the production tasks to an environment that is beginning to resemble a production environment. Now instead of engineers building the product, you may be using some craftsmen or highly trained technicians. You may begin to use develop some work instructions, soft tooling, and may be building several prototypes. In either case, the unit cost to produce should be going down. Then as you transition from a relevant environment to a production representative environment your unit production costs may once again go down. Like Henry Ford, as he moved from the craft environment that most automobile manufacturers used in his day to his assembly line and then moving assembly line, today's DOD contractors gain significant cost savings moving forward. The final savings comes as the program moves from the production representative environment to a pilot line, and then to Low Rate Initial Production and finally to Full Rate Production.

11.7.6 Production Planning

A successful, thorough production planning activity must be in place in order for a program to successfully transition from development to production. Production planning is an element that comprises activities that are critical to a disciplined program and its transition to production. These activities, along with the template to which they relate, are shown in Table 11-2.

Activity	Template
• Policies and Procedures	• Management Strategy • Quality Manufacturing Process
• Master Phasing Schedule	• Manufacturing Plan
• Manufacturing Lead Times	• Manufacturing Plan
• Critical Component Identification/ Control	• Manufacturing Plan
• Production Schedule/Control	• Manufacturing Plan • Quality Manufacturing Process
• Bottlenecks & Work-Arounds	• Manufacturing Plan
• Manufacturing Job Sheet	• Quality Manufacturing Process
• Design Release Risk Analysis	• Quality Manufacturing Process
• Machine/Plant/Loading Capacity	• Manufacturing Plan
• Make or Buy Plans	• Manufacturing Plan

Table 11-2 Production Planning - Template Relationship

The production planning is usually based on documented procedures that maintain consistency in planning from one project to the other. Although there are other critical elements comprising production planning, one of the most critical is the Master Phasing Schedule. This is used during the initial production planning and depicts a logical time - phasing of program milestones established in order to comply with the program schedule from contract initiation to product delivery. The Master Phasing Schedule serves as a basis for establishment of the Manufacturing Plan.

Another example of inter-dependency between Production Planning and the templates is that the manufacturing job sheets, which are an integral part of production planning, cannot be prepared until after the template activities of Design Release and Qualify Manufacturing Process have taken place.

Planning for resource availability must take place during the very early phases of a program; and the transition templates of Facilities, and Management assist the PM to accomplish this. The Facilities template is supported by three templates: Modernization, Factory Improvements, and Producibility Center, all of which Impact Resource Availability. The Personnel Requirements template supporting the Management template helps the PM plan to ensure personnel availability when it will be needed. In summary, the templates to assist the PM to plan for resource availability are available.

11.7.7 Production Design Change Introduction

Introduction of a design change after the production phase of a program has started is always a cause for concern and caution. This is something that should be avoided if at all possible. When a design change is introduced after production has started, any chance for a smooth transition from Development to Production that may have existed is significantly reduced, if not eliminated.

A Production Readiness Review (PRR) is conducted prior to the approval for the contractor to start the production phase of the program. At that time, the status of the program design is evaluated. If the design is to be mature, it must be considered qualified and ready for production; if the design is not considered to be mature, the program should not be allowed to go into the production phase. Theoretically, it is reasonable to assume that if a design change is introduced after production has started, the design was not really mature at the time of the PRR. By the time that a program starts production, the manufacturing process has been qualified and tooling built. Consequently, any design change introduced after the start of production could require changes in process, new tooling, personnel retraining and a number of other impacts, all of which can be very costly, both from a financial and a schedule standpoint.

So how do programs avoid this undesirable activity? PMs avoid it by using the two templates of Design Release, and Qualify Manufacturing Process. These templates provide the PM with tools by which to avoid an undesirable production design change introduction. The templates, when used in conjunction with each other, can do much toward the assurance of a smooth transition from Development to Production.

11.8 Transition to Production Tools

Since the original Manufacturing Guide was written several new risk assessment tools have been developed. These include:

- Technology Maturity Levels (TRLs),
- Manufacturing Readiness Levels (MRLs), and
- Sustainment Maturity Levels (SMLS).

11.8.1 Technology Maturity Levels (TRLs)

TRLs provide a systematic metric/measurement system to assess the maturity of a particular technology. TRLs enable a consistent comparison of maturity between different types of technologies. The TRL approach has been used for many years in the National Aeronautics and Space Administration (NASA) and is now being used on most DOD programs where new technologies are being developed. TRLs have been divided into nine (9) maturity levels as follows:

- TRL 1: Basic Principles observed and noted.
- TRL 2: Technology concept or application formulated.
- TRL 3: Experimental and analytical critical function and characteristic proof of concept.

- TRL 4: Component or breadboard validation in a laboratory environment.
- TRL 5: Component or breadboard validation in a relevant environment.
- TRL 6: System or subsystem model or prototype demonstrated in a relevant environment.
- TRL 7: System prototype demonstration in an operational environment.
- TRL 8: Actual system completed and "flight qualified" through test and demonstration.
- TRL 9: Actual system "flight proven" through successful mission operations.

11.8.2 Manufacturing Readiness Levels (MRLs)

Manufacturing Readiness Levels (MRLs) and assessments of manufacturing readiness have been designed to manage manufacturing risk in acquisition while increasing the ability of the S&T projects to transition new technology to weapon system applications. MRL definitions create a measurement scale and vocabulary for assessing and discussing manufacturing maturity, risk and readiness. Using the MRL definitions, an assessment of manufacturing readiness is a structured evaluation of a technology, component, manufacturing process, weapon system or subsystem. It is performed to:

- Define current level of manufacturing maturity;
- Identify maturity shortfalls and associated costs and risks; and
- Provide the basis for manufacturing maturation and risk management.

There are ten (10) MRLs that are correlated to the nine TRLs currently in use. The final level (MRL 10) is used to measure and foster Lean practices and continuous improvement for systems in production. The MRLs are defined as follows:

- MRL 1: Basic manufacturing implications identified.
- MRL 2: Manufacturing concepts identified.
- MRL 3: Manufacturing proof of concept developed.
- MRL 4: Capability to produce the technology in a laboratory environment.
- MRL 5: Capability to produce prototype components in a production relevant environment.
- MRL 6: Capability to produce a prototype system or subsystem in a production relevant environment.
- MRL 7: Capability to produce systems, or subsystems, or components in a production representative environment.
- MRL 8: Pilot line capability demonstrated; ready to begin low rate initial production.
- MRL 9: Low rate production demonstrated; capability in place to begin full rate production.
- MRL 10: Full rate production demonstrated and lean production practices in place.

11.8.3 Sustainment (Logistics) Maturity Levels (SMLs)

The Sustainment Maturity Level (SML) concept was established to help the Product Support Manager (PSM) identify the appropriate level of maturity the support plan should achieve at each milestone and the extent to which a program's product support implementation efforts are "likely to result in the timely delivery of a level of capability to the Warfighter. The SMLs provide a uniform metric to measure and communicate the expected life cycle sustainment maturity as well as provide the basis for root cause analysis when risks are identified and support OSD's governance responsibilities during MDAP program reviews. There are twelve (12) SMLs as follows:

- SML 1: Supportability and sustainment options identified.
- SML 2: Notional product support and maintenance concept identified.
- SML 3: Notional product support, sustainment and supportability requirements defined and documented to support the notional concept.
- SML 4: Supportability objectives and KPP/KSA requirements defined. New or better technology required for system or supply chain identified.
- SML 5: Supportability design features required to achieve KPP/KSA incorporated in design requirements.
- SML 6: Maintenance concepts and sustainment strategy complete. Life cycle sustainment plan approved.
- SML 7: Supportability features embedded in design. Supportability and subsystem maintenance task analysis complete.
- SML 8: Product support capabilities demonstrated and supply chain management approach validated.
- SML 9: Product support package demonstrated in an operational environment.
- SML 10: Initial product support package fielded at operational sites. Performance measured against availability, reliability and cost metrics.
- SML 11: Sustainment performance measured against operational needs. Product support improved through continual process improvement.
- SML 12: Product support package fully in place including depot repair capability.

The following figure depicts the three maturity models against the acquisition framework chart.

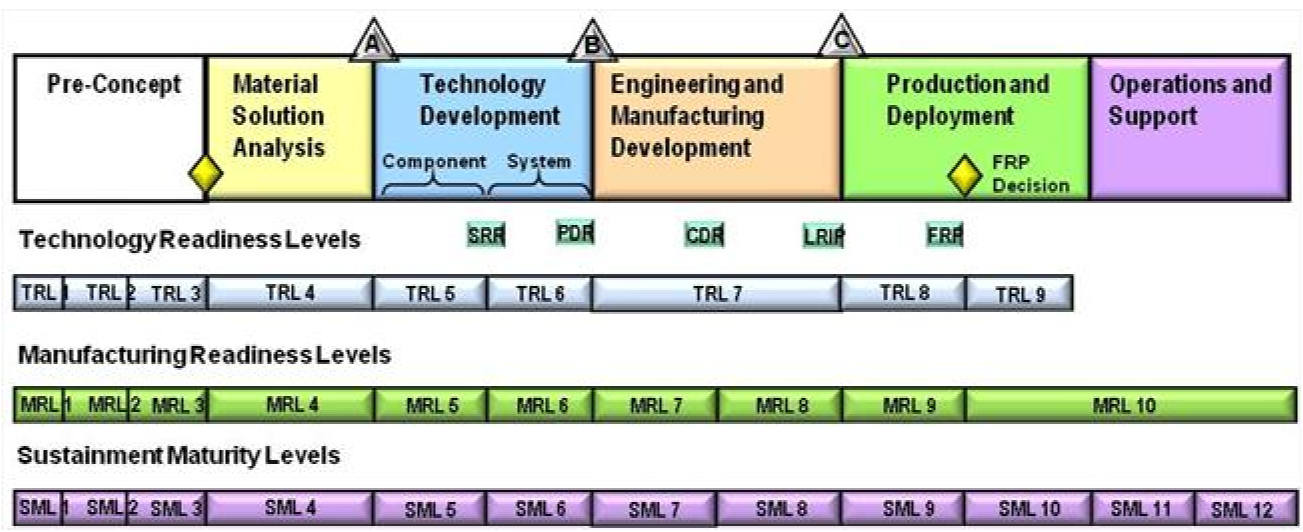


Figure 11-13 TRLs/MRLs/SMLs in the Acquisition Framework Chart

11.8.4 Producibility Engineering Planning (PEP)

The purpose of PEP is to ensure that product designs reflect good producibility considerations prior to release for manufacturing. Although there is no commonly accepted starting point for PEP, it is prudent to anticipate production system requirements as early in the program as in the material solution analysis phase, when only a small percentage of the total expected program life cycle costs has been incurred.

PEP involves the engineering tasks necessary to ensure timely, efficient and economic production of essential material. It includes efforts related to development of the Technical Data Package (TDP), Quality Assurance (QA) procedures, and evaluation of special production processes through trade studies. Also included are development of unique processes essential to the design and manufacture of the material and details of performance ratings; dimension and tolerance data; manufacturing methods; sequences; assembly; schematics; physical characteristics including form, fit and function; inspection test and evaluation requirements; calibration information and quality control procedures.

PEP is, in effect, a qualification process that will confirm the adequacy of the production planning, tool design, manufacturing process, and procedures before rate production begins.

It is DOD policy that factors affecting producibility and supportability shall be fully integrated during EMD. The design and test cycle shall be structured to provide a continuum in development for production, as opposed to discrete phases that cause iterative and redundant activities. The PEP program should be defined contractually and contain specific tasks and measurable performance that will support an orderly transition. PEP progress should be tracked by means of production readiness reviews required before initial or full production decisions. The objective of a transition plan is to provide visibility of how well each activity is being executed. Progress should be regularly compared against the transition plan.

11.8.4.1 Integrate Initial Production Facilities with Producibility Engineering and Planning

Only minimum manufacturing tools are required in the development phase to build and assemble prototype or test articles to be used for testing and evaluation of the engineering design. Off-the-shelf tools are utilized as much as possible and often prototype articles are, for all practical purposes, hand assembled. At some point in the development phase, consideration must be given to production tooling requirements. The Initial Production Facilities (IPF) effort is performed during the initiation of the Production Phase and provides the special tooling and test equipment needed to enter the production phase. The design and supporting documents for special tooling and test equipment are provided under Producibility Engineering & Planning. IPF translates these designs into a functioning production facility. Specific tasks include:

- Fabrication and validation of special manufacturing equipment;
- Fabrication and validation of Special Acceptance and Inspection Equipment (SAIE);
- and other special inspection equipment and gages;
- Initial set-up manufacturing of the line, if appropriate; and
- Maintenance of special equipment.

11.8.4.2 Integrate Long Lead Items with Producibility Engineering and Planning

Manufacturing documentation is prepared as a part of the PEP effort, and includes the master tooling plan, the manufacturing line layout and identification of long lead time items. Product design specifications should be relatively mature, at least with regard to special or scarce material requirement, major production equipment and special purpose production tooling which has to be ordered well in advance of start-up time. The early stages of development characteristically produce many Engineering Change Proposals (ECPs) and the PM must ascertain that the contractor is doing the necessary planning for manufacturing with special consideration for the long lead items.

11.9 Prodcution Risk Reduction Strategies

There are several strategies that PMs can use to reduce transition to production risks. These include:

- Competitive Prototyping,
- Pilot Line Production,
- Low Rate Initial Production, and
- Full Rate Production .

11.9.1 Competitive Prototyping

Competitive prototyping occurs when industry teams develop competing prototypes of a required system. Competitive prototyping is a decision-making strategy for reducing technical and economic risks while preserving the PM's freedom of action. The goal of competitive prototyping is to mature the design before committing substantial resources to its factors of production. Prototypes are usually handmade by design engineers and skilled technicians using general purpose machine tools. Production engineers should be heavily involved in the design of the prototype to ensure that the product can be produced within the cost targets. Then as the design matures and testing validates the engineering approach, the production engineers should prepare for an orderly transition to production by refining their production plans (factory layout, machine tools, production skills, subcontractor relationships, etc.). The Advanced Tactical Fighter (ATF) program is a good example of competitive prototyping. Two contractor teams came up with designs and prototypes for a replacement to the F-15. The Lockheed Martin team designed and produced the YF-22 while the Northrop team designed and produced the YF-23. The Air Force selected the YF-22 for further development and production.

11.9.2 Pilot Line Production

When a program moves into Engineering and Manufacturing Development (EMD) the production environment often moves to one of a pilot line. As the design is being matured and test articles are being produced, there is a continuing inflow of design change which must be fed into the fabrication facility. The goal is to develop affordable and executable manufacturing processes that are becoming increasingly more documented. The manufacturing processes that were used during Technology Development may evolve to different processes and those processes should be matured on the pilot line. For example, during TD you may have made a composite part using hand layup, but now in preparation for Low Rate Initial Production (LRIP) you may be moving to an automated tape layup machine and are using the pilot line to proof the process.

11.9.3 Initial Low Rate Production (LRIP)

At the completion of the development process, a review is normally held to determine if the system is ready to enter the production phase of the program. Approval to proceed into the production phase is based upon:

- Assurance that risks have been resolved, including the threat;
- Cost, schedule, and performance estimates/requirements for production phase are credible and acceptable; and
- Determination that: a practical engineering design has been completed, tradeoffs have optimized production, maintenance, and operating costs and contractual aspects are sound.

Evaluating the production readiness of a weapon system prior to a production decision point is an important element of the DOD weapon system acquisition process. Production readiness is assessed by means of a Production Readiness Review (PRR). The objective of a PRR is to verify that the production design, planning and associated preparations for a system have progressed to the point where a production commitment can be made without incurring unacceptable risks of breaching thresholds of schedule, performance, cost, or other established criteria. The Production Readiness Review is discussed in detail in Chapter 12 of this guide.

Low rate Initial production (LRIP) is a term used to describe the initial production effort needed to reduce the government's exposure on transitioning from development to Full Rate Production (FRP). LRIP is intended to result in the completion of manufacturing development in order to ensure adequate and efficient manufacturing capability exists to produce the minimum quantity necessary to:

- Provide production or production-representative articles for Initial Operational Test and Evaluation (IOT&E);
- Establish an initial production base for the system; and
- Permit an orderly increase in the production rate for the system, sufficient to lead to full-rate production (FRP) upon successful completion of operational testing.

Low rate initial production usually begins at the end of the EMD phase and often transitions from a pilot line to an LRIP production capability. By this time the new technologies should have been matured and ready to transition into the production units. Detailed system design should be complete with few engineering changes, and none that impact form, fit or function. All manufacturing processes should be capable and under statistical control, and there should be no producibility risks. There needs to be a complete definition of the fabrication and assembly tasks and the transfer of those tasks to the general factory work force. Work instructions need to be more detailed and a closely controlled system for changes to the documents used in the factory, such as drawings and process specifications. Extensive documentation required for production planning must be based on a stable design, quantity requirements and delivery schedule. The amount and timing of engineering changes must be controlled to minimize disruption to production documentation and planned manufacturing schedules.

Contractors often need to make basic changes in the manufacturing planning and control systems reflecting a change from small lots of parts with relatively dynamic design, to economical lots with fixed design for quantity production. The measures of effectiveness of the manufacturing function also may change to reflect the efficiencies which would be expected in repetitive production and the balancing of work flow through the facility. The program manager should assure that the contractor has evaluated the planning and control systems used in the factory to determine the need for changes to reflect the difference in the fundamental objectives of development and production. Where change is required, an attainable plan for the system transition should be defined by the contractor.

11.9.4 Full Rate Production (FRP)

Full rate production (FRP) is the highest level of production readiness. Technologies should have matured to TRL 9. This level of manufacturing is normally associated with the Production or Sustainment phases of the acquisition life cycle. Engineering/design changes are few and generally limited to quality and cost improvements. System, components or items are in full rate production and meet all engineering, performance, quality and reliability requirements. Manufacturing process capability is at the appropriate quality level. All materials, tooling, inspection and test equipment, facilities and manpower are in place and have met full rate production requirements. Rate production unit costs meet goals, and funding is sufficient for production at required rates. Lean practices are well established and continuous process improvements are ongoing. At this point of the transition process there should be "no significant manufacturing risks." If production quantities are large enough, then the manufacturing processes should be under statistical control.

11.10 Summary

Many people think that the transition to production begins late in the EMD phase. But that is far from the truth. The transition process is a very broad and is dependent upon certain activities to take place throughout the acquisition life cycle in order for the program to have a smooth, orderly progression. This chapter highlighted how two different programs approached the transition to production (Ford's Model T and Lockheed's F-22). The chapter addresses transition to production activities that should be implemented during each acquisition phase through production. It addressed the importance of planning and the planning documents that should contain provisions for the transition process. The chapter looked at various transition to production challenges and tools for reducing transition risks. Finally, it discussed several production risk reduction strategies. Taken together, this body of knowledge should be used to help implement a transition to production success strategy.

11.11 Related Links and Resources

Numerous reference documents impact the manufacturing management function throughout the acquisition process. These documents originate from many sources and range across academic disciplines, functional activities, and job specialties.

The following is a reference list of DOD Directives (D), Instructions (I) Manuals (M), Pamphlets (P), Military Standards (MS), and other documents. The documents listed contain DOD policy guidance applicable to the manufacturing management function. They are listed as sources of DOD manufacturing management information.

Note: Many of the documents listed are no longer required (due to acquisition reform), but still contain some very valuable information.

Number	Title
DOD 4245.7-M	Transition from Development to Production
NAVSOP P-6071	Best Practices: How to Avoid Surprises in the Worlds Most Complicated Technical Process
	IPPD for S&T Quick Reference
	Acquisition Strategy
	Technology Development Strategy
	Systems Engineering Plan
	Production/Manufacturing Plan

Defense Manufacturing Management Guide for Program Managers
Chapter 12 - Technical Reviews and Audits

12.1 Objective

According to DODD 5000.01 the Program Manager (PM) has the responsibility for providing knowledge about key aspects of a system at key points in the acquisition process (E1.1.14 Knowledge-Based Acquisition). Technical reviews and audits are conducted at key points in the acquisition process and can provide critical knowledge to the program manager about the progress of their program. The material in this chapter is directed towards describing the nature and purpose of the various technical reviews and audits which are required during the life of a defense program and the elements of planning and execution which are required in order to perform the surveys with a focus on the manufacturing aspects of those reviews.

This chapter addresses the following topics and learning objectives:

- Identify role of manufacturing;
- Describe the various technical reviews and audits;
- Outline the various roles and responsibilities for technical reviews;
- Identify the gaps in knowledge of program technical risk; and
- Identify guidance for surveys and reviews.

12.2 Background

The Global Positioning System Block IIIA satellite program completed its Critical Design Review (CDR) at Lockheed-Martin Newtown, Pa., on August 19, 2010, two months ahead of schedule. The CDR ensured that the satellite requirements and detailed design were complete and under configuration control, and that the satellite, support equipment, and production lines were ready to start manufacturing. The CDR was attended by more than 350 people representing 46 different organizations, civilian agencies and the Pentagon. The GPS III program was built on a "back to basics" foundation which emphasized:

- Stable personnel,
- Stable requirements,
- Stable funding, and
- Rigorous systems engineering.

This singular event (CDR) signified the completion of the final design and was the culmination of 63 lower level CDRs that were conducted over a period of twelve months. These series of reviews provided key and critical information leading to an initial system product baseline. Manufacturing support for the CDR is critical since a majority of all manufacturing drawings should have been validated prior to the CDR and any critical manufacturing processes should have been matured by this point.

12.3 Introduction

Technical reviews are an integral part of the systems engineering (SE) process and are consistent with existing and emerging commercial/industrial standards and best practices. As a part of the overall SE process, technical reviews enable an independent assessment of emerging designs against plans, processes and key knowledge points in the development process. Typically members of the program office integrated product team (IPT) and subject matter experts (SMEs) conduct these reviews. Engineering rigor, interdisciplinary communications, and competency insight are applied to the various technical processes in the assessment of requirements traceability, product metrics, and decision rationale. These reviews bring to bear additional knowledge to the program design/development process in an effort to ensure program success. Overarching objectives of these reviews are a well-managed engineering effort leading to a satisfactory technical evaluation, which will meet all of the required technical and programmatic specifications. This, in turn, will ensure a satisfactory Operational Evaluation (OPEVAL), and the fielding of an effective and suitable system for the warfighter.

12.4 The Role of Manufacturing

Manufacturing has three major roles in the acquisition process.

1. The first is to influence the design process so that the design is producible. That is, the design is efficient and can be manufactured using existing facilities, tools, equipment and people.

2. The second role is to prepare for production or plan for production.

3. The final role is to execute the manufacturing plan. Execute the plan in a way that reflects the design intent while ensuring repeatable processes and focusing on continuous improvement.

The goal of manufacturing is to deliver uniform, defect-free product, with consistent performance, and that is affordable (see figure 12-1). Manufacturing personnel support the conduct of technical reviews and audits in order to effect the achievement of those roles and goals. Technical reviews and audits provide a mechanism for manufacturing managers to assess performance towards achieving these goals.

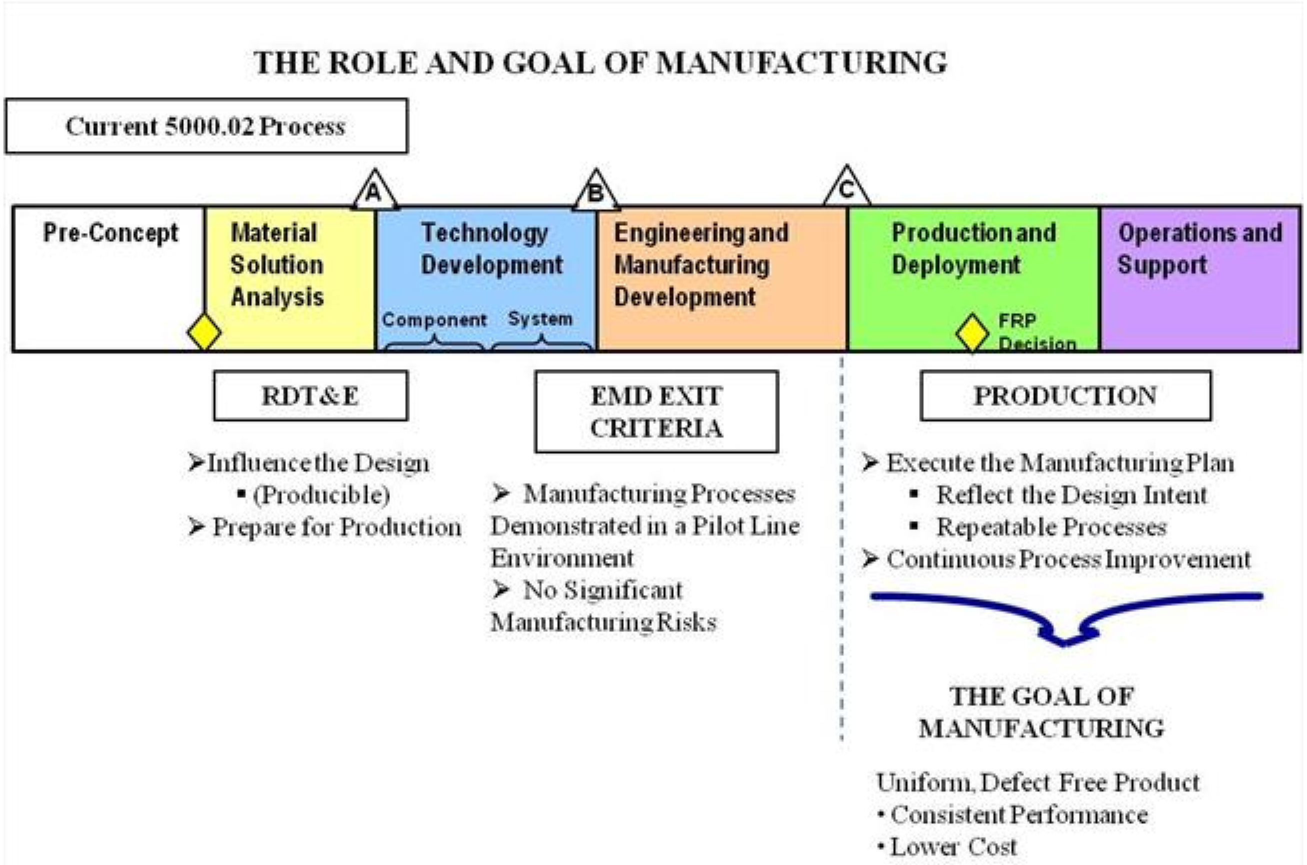


Figure 12-1 The Role of Manufacturing

12.4.1 Manufacturing Surveys

Manufacturing surveys are conducted to assess the capability of defense contractors to perform the manufacturing tasks and to develop estimates of the production risk inherent in the design and the proposed manufacturing approaches. These reviews assess the physical, managerial and financial capability of the contractors to accomplish the work required.

12.4.2 Historical Role of Manufacturing Surveys

Manufacturing surveys have been around for a very long time. MIL-STD-1528, *Manufacturing Management Program* , identified three major reviews that were used to assess manufacturing risks:

1. Manufacturing Feasibility and Capability Assessment;
2. Manufacturing Management/Production Capability Review (MM/PCR); and
3. Production Readiness Review (PRR).

Other reviews that can be used to support Manufacturing and Quality Assurance assessments include:

- Pre-award Surveys,
- Quality Assurance Surveys,
- Producibility Reviews, and
- In-Process Reviews.

12.4.2.1 Manufacturing Feasibility and Capability Assessment

The Manufacturing Feasibility and Capability Assessment is an assessment conducted to identify potential manufacturing constraints and risks and the capability of the contractor to execute the manufacturing efforts. This is typically the first and lowest level of manufacturing risk assessment aimed at understanding if it is even possible to build the end item. Feasibility and capability assessments were usually conducted early in the program's life cycle during the Material Solution Analysis or Technology Development Phase.

12.4.2.2 Manufacturing Management/Production Capability Review (MM/PCR)

The Manufacturing Management/Production Capability Review (MM/PCR) is an investigation conducted at the prospective contractor facilities during the source selection process. The reviews are conducted to evaluate each competing contractor's capability to meet all immediate and future production requirements of proposed systems by considering the contractor's current and projected business. The review includes an assessment of the potential impact on cost risk due to inadequate manufacturing facilities. MM/PCRs were usually conducted during the Technology Development Phase or early in the Engineering and Manufacturing Development phase.

12.4.2.3 Production Readiness Review (PRR)

The Production Readiness Review (PRR) is a formal examination of a program to determine if the design is ready for manufacturing, if manufacturing problems have been resolved, and if the contractor has adequately planned for the production phase. The review may be conducted incrementally, and are usually conducted during the Engineering and Manufacturing Development or Production and Deployment phase.

Manufacturing managers need to be concerned with the contractor's systems for planning, executing and controlling the business and technical function. The specific contractor systems (engineering, test, production, etc.) used are unique to that company's business objectives, size, product mix and operating style. The focus on these types of reviews should be on the capability of the management system to effectively support the current and planned levels of design, test and manufacturing operations.

To make this determination, the review team needs to ensure that the system is structured, defined and communicated to the individuals within the company who are charged with making it work. It is also necessary to make a determination that the system is, in fact, functioning as it is described. A company often has a structured system which, unfortunately, is not used by its personnel. There is always a need to determine contractor compliance with their internal requirements as well as with contract requirements.

12.4.2.4 Pre-Award Surveys

The Defense Contract Management Agency (DCMA) conducts nearly all preaward surveys required by government buying activities. The process begins with a buying activity's request for a survey and concludes with a procuring contracting officer's (PCO) decision based on a recommendation by a DCMA Contract Management Office (CMO) survey team.

A pre-award survey can focus on virtually every facet of the contractors business operations-from technical capability to financial stability, from quality assurance to plant safety. In a sense, the survey process is the contractor’s opportunity to provide evidence (i.e., Plan of Performance) that they can successfully fulfill the terms of the contract. Listed below are some of the factors that are often the focus of pre-award surveys.

• Technical Capability • Production Capability • Quality Assurance • Finance • Accounting • Government Property Control	• Transportation and Packaging • Security • Plant Safety • Environmental/Energy Compliance • Flight Operations/Safety

Table 12-1 Pre-Award Survey Factors

12.4.2.5 Quality Assurance Surveys/Audits

Quality surveys or audits are assessments of the contractor's systems and processes for assuring that product and services meet the terms and conditions of the contract. These reviews and audits have four focus areas:

1. Process Quality (adherence to ISO or some other quality standard),
2. Product Quality,
3. Supplier Quality, and
4. Continuous Improvement.

12.4.2.6 Producibility Reviews

A producibility review is a review of the design of a specific hardware item or system to determine the relative ease of producing it using available production technology considering the elements of fabrication, assembly, inspection, and test. The review includes a comparison of alternative design materials, processes, and manufacturing techniques to determine the most economical manufacturing processes and materials to produce a product while meeting performance specifications and required production n rates.

12.4.2.7 In-Process Reviews

The IPR is a generic term that simply refers to a program review to determine on-going status, or to provide information to the decision maker(s), or to IPT members. The in-process review can be called for at any time in the acquisition life cycle. These reviews could be used to focus on the following manufacturing concerns:

- The review should explore the production implications of the design.
- Given the details of the design, how can it be built?
- What are the limitations on the productive processes?
- What process limits the production capacity?
- What kind of fabrication approaches can be used?
- What will it cost to do it?
- Given a pre-existing unit production cost goal and a breakdown of that goal through the work breakdown structure, the current subsystem and part estimates can be compared to the goals and an engineering trade-off study can be conducted.
- If the design is not acceptable from either a cost and/or performance standpoint, it will be necessary to go back and look at alternative designs.
- What design alternatives might yield the same or improvement performance?
- The design needs to be evaluated in terms of the three basic parameters of cost, schedule and quality.
- After this evaluation, there is a need to define actions such as design changes or process changes.
- The design cannot be forced to meet the constraints of a specific contractor's production environment nor can the government force this production environment to meet a nonproducible design.
- Often trades must be made, so both the design and the production process selection must be somewhat flexible during the design evolution.
- The survey team should see evidence of contractor trade studies which compare alternative approaches to the fabrication and production tasks.

12.5 Technical Reviews and Audits

Technical reviews and audits are a systems engineering tool that provide a way to assess progress and maturity of the product as it moves through the various phases of the acquisition life cycle. These reviews and audits are consistent with existing DOD and commercial best practices and form the backbone for effective systems engineering planning. All reviews are or should be multi-disciplined that ensure all of the members of the integrated product team (IPT) have an opportunity to review the product and documentation in order to assess progress in their functional area towards achievement of phase goals. These reviews provide a systematic process for assessing risk and easing the transition from development to production and beyond by:

- Assessing the maturity of the design/development effort;
- Clarifying design requirements;

- Challenging the design and related processes;
- Checking proposed design configuration against technical requirements, customer needs, and system requirement;
- Evaluating the system configuration at different stages;
- Providing a forum for communication, coordination, and integration across all disciplines and IPTs;
- Establishing a common configuration baseline from which to proceed to the next level of design and production; and
- Recording technical decisions and rational in the decision database.

Reviews are an important oversight tool that the program manager can use to review and evaluate the state of the system and the program, re-directing activity if necessary. Figure 12-2 shows the relative timing of each of the technical reviews, technically oriented program reviews, and technology readiness assessments.

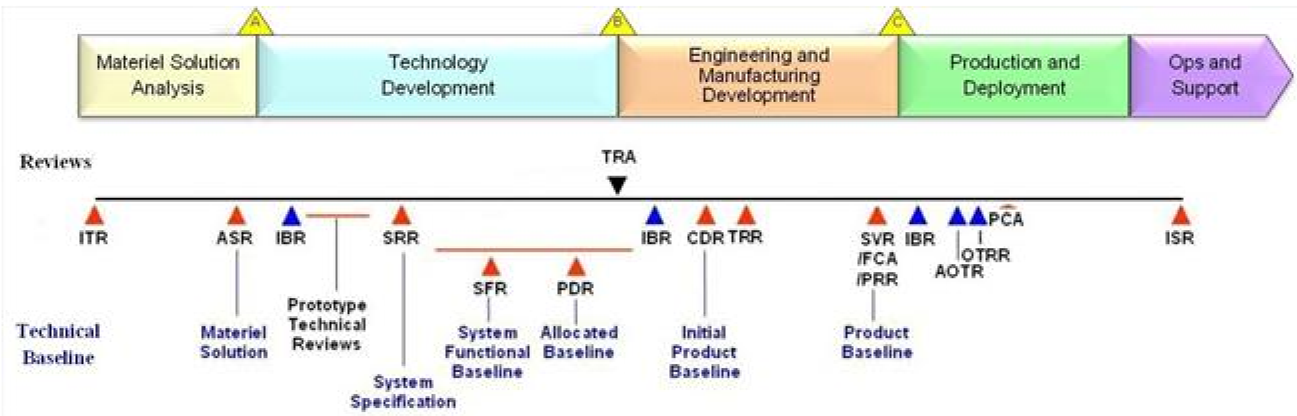


Figure 12-2 Systems Engineering Technical Review Timing

The following business and technical reviews are held for most programs:

- Initial Technical Review (ITR),
- Alternative Systems Review (ASR),
- System Requirements Review (SRR),
- Technology Readiness Assessment (TRA),
- Integrated Baseline Review (IBR),
- System Functional Review (SFR),
- Preliminary Design Review (PDR),
- Critical Design Review (CDR),
- Test Readiness Review (TRR),
- System Verification Review (SVR),
- Functional Configuration Audit (FCA),
- Production Readiness Review (PRR),
- Operational Test Readiness Review (OTRR),
- Physical Configuration Audit (PCA), and
- In-Service Review (ISR).

OSD has developed a checklist for each of technical reviews. The checklist structure for many of the reviews is shown below and includes twelve focus areas to include the PQM community. Questions can be segregated by focus area by enabling the macros and selecting PQM. This will provide only those questions that have been identified as an interest area for that focus area. These checklists are available on the Systems Engineering Community of Practice (CoP) at the Defense Acquisition University (DAU).

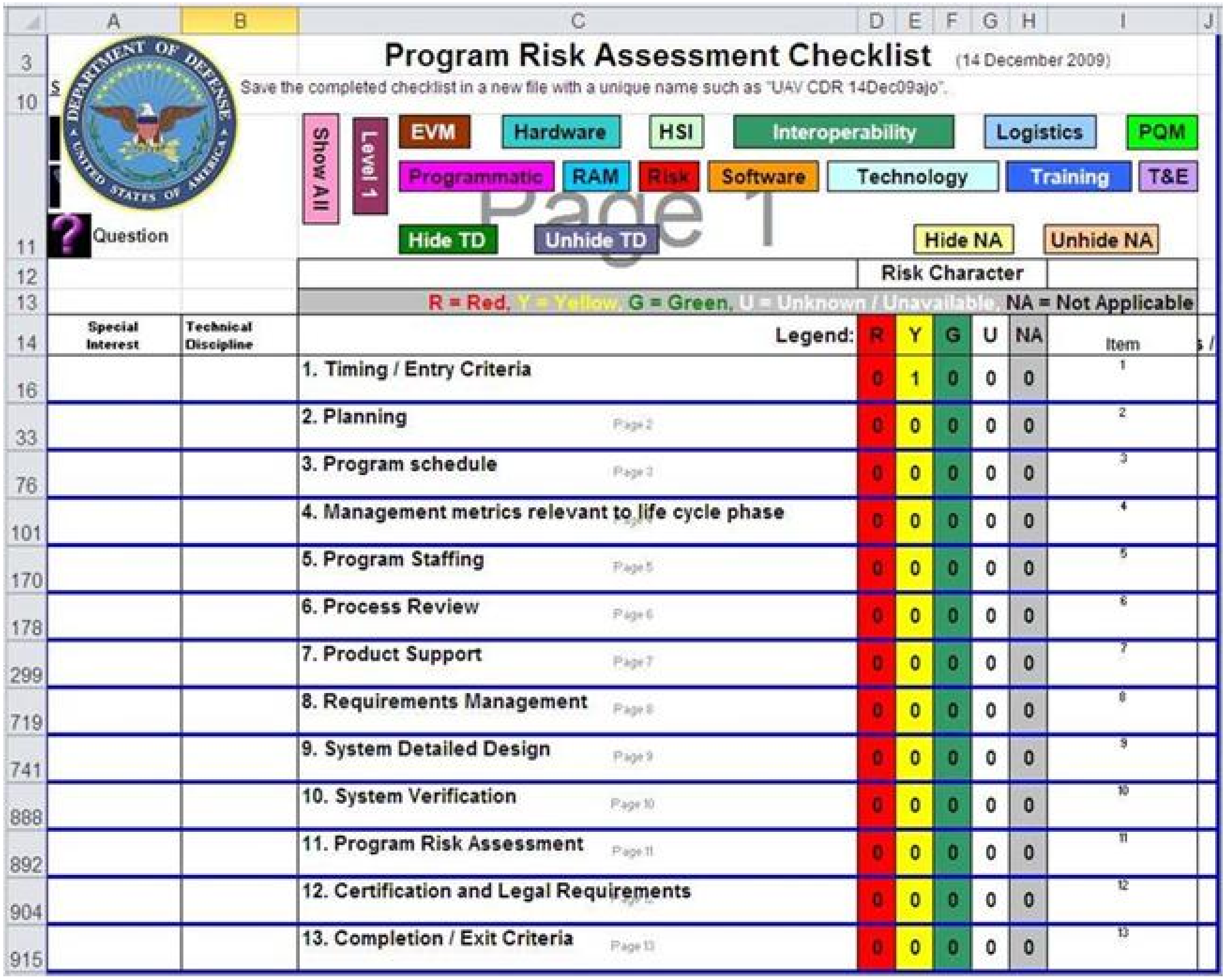


Figure 12-3 Typical Format for a Technical Review

A note of caution . The current DOD checklist contains questions that are relevant for personnel in the Production, Quality and Manufacturing (PQM) career field. However, those questions need to be reviewed carefully for appropriateness. Often there are more questions centered on Diminishing Manufacturing Sources and Material Shortages (DMSMS) than there are for Manufacturing, Quality and Environmental considerations combined. For this reason it is recommended that PQM'ers review the Manufacturing Readiness Level questions to augment PQM questions in the existing technical reviews and audits.

12.5.1 Initial Technical Review (ITR)

The ITR is a multi-disciplined technical review to support a program's initial Program Objective Memorandum submission. This review ensures a program's technical baseline is sufficiently rigorous to support a valid cost estimate (with acceptable cost risk) and enable an independent assessment of that estimate by cost, technical, and program management subject matter experts (SMEs). The ITR assesses the capability needs and Materiel Solution approach of a proposed program and verifies that the requisite research, development, test and evaluation, engineering, ***manufacturing*** , logistics, and programmatic bases for the program reflect the complete spectrum of technical challenges and risks. Additionally, the ITR ensures the historical and prospective drivers of system life-cycle cost have been quantified to the maximum extent and that the range of uncertainty in these parameters has been captured and reflected in the program cost estimates.

12.5.2 Alternative System Review (ASR)

The ASR is a multi-disciplined technical review to ensure the resulting set of requirements agrees with the customers' needs and expectations and then the system under review can proceed into the Technology Development phase. The ASR should be completed prior to, and provide information for, Milestone A. Generally, this review assesses the preliminary materiel solutions that have been evaluated during the Materiel Solution Analysis phase, and ensures that the one or more proposed materiel solution(s) have the best potential to be cost effective, affordable, operationally effective and suitable, and can be developed to provide a timely solution to a need at an acceptable level of risk. Of critical importance to this review is the understanding of available system concepts to meet the capabilities described in the Initial Capabilities Document (ICD) and to meet the affordability, operational effectiveness, technology risk, and suitability goals inherent in each alternative concept.

12.5.3 System Requirements Review (SRR)

The SRR is a multi-disciplined technical review to ensure that the system under review can proceed into initial systems development, and that all system requirements and performance requirements derived from the Initial Capabilities Document or draft Capability Development Document are defined and testable, and are consistent with cost, schedule, risk, technology readiness, and other system constraints. Generally this review assesses the system requirements as captured in the system specification, and ensures that the system requirements are consistent with the approved materiel solution (including its support concept) as well as available technologies resulting from the prototyping effort.

12.5.4 System Functional Review (SFR)

The SFR is a multi-disciplined technical review to ensure that the system's functional baseline is established and has a reasonable expectation of satisfying the requirements of the Initial Capabilities Document or draft Capability Development Document within the currently allocated budget and schedule. It completes the process of defining the items or elements below system level. This review assesses the decomposition of the system specification to system functional specifications, ideally derived from use case analysis. A critical component of this review is the development of representative operational use cases for the system. System performance and the anticipated functional requirements for operations maintenance, and sustainment are assigned to sub-systems, hardware, software, or support after detailed analysis of the architecture and the environment in which it will be employed. The SFR determines whether the system's functional definition is fully decomposed to its lower level, and that Integrated Product Teams (IPTs) are prepared to start preliminary design.

12.5.5 Preliminary Design Review (PDR)

The PDR is a technical assessment establishing the physically allocated baseline to ensure that the system under review has a reasonable expectation of being judged operationally effective and suitable. This review assesses the allocated design documented in subsystem product specifications for each configuration item in the system and ensures that each function, in the functional baseline, has been allocated to one or more system configuration items. The PDR establishes the allocated baseline (hardware, software, human/support systems) and underlying architectures to ensure that the system under review has a reasonable expectation of satisfying the requirements within the currently allocated budget and schedule.

12.5.6 Technology Readiness Assessment (TRA)

The TRA is a regulatory information requirement for all acquisition programs. The TRA is a systematic, metrics-based process that assesses the maturity of critical technology elements (CTEs), including sustainment drivers. The TRA should be conducted concurrently with other Technical Reviews, specifically the Alternative Systems Review (ASR), System Requirements Review (SRR), or the Production Readiness Review (PRR). If a platform or system depends on specific technologies to meet system operational threshold requirements in development, production, or operation, and if the technology or its application is either new or novel, then that technology is considered a CTE.

12.5.7 Critical Design Review (CDR)

The CDR is a key point within the Engineering and Manufacturing Development (EMD) phase. The CDR is a multi-disciplined technical review establishing the initial product baseline to ensure that the system under review has a reasonable expectation of satisfying the requirements of the Capability Development Document within the currently allocated budget and schedule. Incremental CDRs are held for each Configuration Item culminating with a system level CDR. This review assesses the final design as captured in product specifications for each Configuration Item in the system and ensures that each product specification has been captured in detailed design documentation. Configuration Items may consist of hardware and software elements, and include items such as airframe/hull, avionics, weapons, crew systems, engines, trainers/training, support equipment, etc. Product specifications for hardware enable the fabrication of configuration items, and include production drawings. Product specifications for software enable coding of the Computer Software Configuration Item. The CDR evaluates the proposed Baseline ("Build To" documentation) to determine if the system design documentation (Initial Product

Baseline, including Item Detail Specs, Material Specs, Process Specs) is satisfactory to start initial manufacturing.

12.5.8 Test Readiness Review (TRR)

The TRR is a multi-disciplined technical review designed to ensure that the subsystem or system under review is ready to proceed into formal test. The TRR assesses test objectives, test methods and procedures, scope of tests, and safety and confirms that required test resources have been properly identified and coordinated to support planned tests. The TRR verifies the traceability of planned tests to program requirements and user needs. It determines the completeness of test procedures and their compliance with test plans and descriptions. The TRR also assesses the system under review for development maturity, cost/ schedule effectiveness, and risk to determine readiness to proceed to formal testing.

12.5.9 System Verification Review (SVR)

The SVR is a multi-disciplined product and process assessment to ensure the system under review can proceed into Low-Rate Initial Production and full-rate production within cost (program budget), schedule (program schedule), risk, and other system constraints. Generally this review is an audit trail from the System Functional Review. It assesses the system functionality, and determines if it meets the functional requirements (derived from the Capability Development Document and draft Capability Production Document) documented in the functional baseline. The SVR establishes and verifies final product performance. It provides inputs to the Capability Production Document. In some organizations the SVR is conducted concurrently with the Production Readiness Review.

12.5.10 Functional Configuration Audit (FCA)

The FCA is the formal examination of the as tested characteristics of a configuration item (hardware and software) with the objective of verifying that actual performance complies with design and interface requirements in the functional baseline. It is essentially a review of the configuration item's test/analysis data, including software unit test results, to validate the intended function or performance stated in its specification is met. For the overall system, this would be the system performance specification. For large systems, audits may be conducted on lower level configuration items for specific functional areas and address non-adjudicated discrepancies as part of the FCA for the entire system. A successful FCA typically demonstrates that Engineering and Manufacturing Development product is sufficiently mature for entrance into Low-Rate Initial Production.

12.5.11 Production Readiness Review (PRR)

The PRR examines a program to determine if the design is ready for production and if the prime contractor and major subcontractors have accomplished adequate production planning without incurring unacceptable risks that will breach thresholds of schedule, performance, cost, or other established criteria. The review examines risk; it determines if production or production preparations identify unacceptable risks that might breach thresholds of schedule, performance, cost, or other established criteria. The review evaluates the full, production-configured system to determine if it correctly and completely implements all system requirements. The review determines whether the traceability of final system requirements to the final production system is maintained.

At this review, the Integrated Product Team (IPT) should examine the readiness of the manufacturing processes, the quality management system, and the production planning (i.e., facilities, tooling and test equipment capacity, personnel development and certification, process documentation, inventory management, supplier management, etc.). A successful review is predicated on the IPT's determination that the system requirements are fully met in the final production configuration, and that production capability forms a satisfactory basis for proceeding into Low-Rate Initial Production (LRIP) and Full-rate production.

Typically performed incrementally, PRRs determine if production preparation for the system, subsystems, and configuration items is complete, comprehensive, and coordinated. A PRR formally examines producibility of the design, the control over the projected production processes, and adequacy of resources necessary to execute production.

12.5.12 Operational Test Readiness Review (OTRR)

The OTRR is a multi-disciplined product and process assessment to ensure that the system can proceed into Initial Operational Test and Evaluation with a high probability of success, and that the system is effective and suitable for service introduction. The Full-Rate Production Decision may hinge on this successful determination. The understanding of available system performance in the operational environment to meet the Capability Production Document is important to the OTRR. Consequently, it is important the test addresses and verifies system reliability, maintainability, and supportability performance and determines if the hazards and ESOH residual risks are manageable within the planned testing operations. The OTRR is complete when the Service Acquisition Executive evaluates and determines materiel system readiness for Initial Operational Test and Evaluation.

12.5.13 Physical Configuration Audit (PCA)

The PCA is conducted around the time of the Full-Rate Production Decision. The PCA examines the actual configuration of an item being produced. It verifies that the related design documentation matches the item as specified in the contract. In addition to the standard practice of assuring product verification, the PCA confirms that the manufacturing processes, quality control system, measurement and test equipment, and training are adequately planned, tracked, and controlled. The PCA validates many of the supporting processes used by the contractor in the production of the item and verifies other elements of the item that may have been impacted/redesigned after completion of the System Verification Review . A PCA is normally conducted when the government plans to control the detail design of the item it is acquiring via the Technical Data Package. When the government does not plan to exercise such control or purchase the item's Technical Data Package (e.g., performance based procurement), the contractor should conduct an internal PCA to define the starting point for controlling the detail design of the item and establishing a product baseline. The PCA is complete when the design and manufacturing documentation match the item as specified in the contract. If the PCA was not conducted before the Full-Rate Production Decision, it should be performed as soon as production systems are available.

12.5.14 In-Service Review (ISR)

The ISR is a multi-disciplined product and process assessment to ensure that the system under review is operationally employed with well-understood and managed risk. This review is intended to characterize the in-service health of the deployed system. It provides an assessment of risk, readiness, technical status, and trends in a measurable form. These assessments substantiate in-service support budget priorities. The consistent application of sound programmatic, systems engineering, and logistics management plans, processes, and sub-tier in-service stakeholder reviews will help achieve the ISR objectives. Example support groups include the System Safety Working Group and the Integrated Logistics Management Team. A good supporting method is the effective use of available government and commercial data sources. In-service safety and readiness issues are grouped by priority to form an integrated picture of in-service health, operational system risk, system readiness, and future in-service support requirements.

12.6 Managing the Technical Review Process

Technical reviews should be conducted at both the system level and at lower levels (e.g., sub-system and below, possibly down to the configuration item). A well-defined and stable Work Break-Down Structure (WBS) will to help focus the technical review. Lower-level technical reviews may be thought of as events that resolve issues at the lowest levels and support and prepare for the system-level reviews. Obviously in a well run program, sub-system reviews will precede systems-level reviews. It is important that reviews be held at appropriate event-driven points in program development and that both the contractor and government have common expectations regarding the content and outcomes.

12.6.1 Technical Review Objectives

Technical reviews provide the PEOs, and program managers with sound analytical basis for the system's acquisition and confidence that the system will satisfy its Joint Capability requirements. These reviews provide the program managers with an integrated technical (e.g., logistics, engineering, manufacturing, test and evaluation (T&E), in-service support) baseline evaluation, and confidence that the technical baseline is mature enough for the next stage of development. This is accomplished via a multi-disciplined, engineering assessment of the program's progress towards demonstrating and confirming completion of required accomplishments as defined in the program's Systems Engineering Plan (SEP). These reviews include an overall technical assessment of cost, schedule, and performance risk, which forms the basis for an independent cost estimate. End products of these reviews include a capability assessment, technical baseline assessment, an independent review of risk assessments and mitigation options, Request for Action (RFA) forms, and minutes.

12.6.2 Government Roles and Responsibilities

The government is responsible for assuring that the appropriate technical review or audit is put on contract and that the technical review is conducted in accordance with established policy and guidance. Technical reviews, and manufacturing reviews in particular are a "contact sport." You cannot evaluate a factory environment from the comfort of a conference room. You cannot learn from a briefing what you can learn by walking around a plant floor observing operations and asking questions. A typical technical review follows the activities outlined in Figure 12-4.

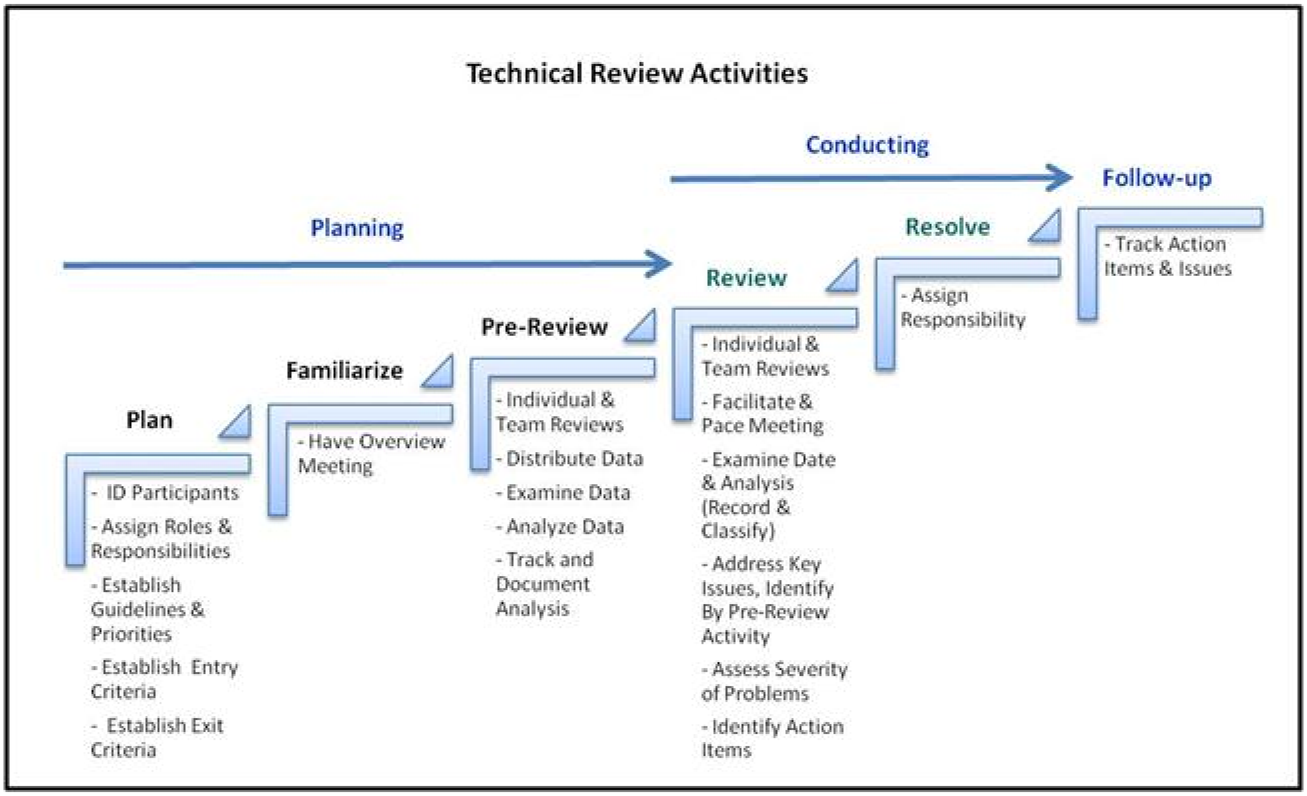


Figure 12- 4 Technical Review Activities

12.6.2.1 Planning

Technical reviews must be an extensive and an "up-front and- early" effort. Important by-products of such a planning effort include the following:

- Timely attention and visibility into the activities preparing for the review;
- Identification and allocation of resources necessary for the total review effort;
- Tailoring consistent with program risk levels;
- Scheduling consistent with availability of appropriate data;
- Establishing and tailoring event-driven entry and exit criteria;
- Where appropriate, use of incremental Technical Reviews; and
- Implementation and participation by IPTs.

Maturity of end products should be assessed along with their associated enabling products. Reviews should also consider the lifecycle issues testability, producibility, manufacturing, quality, training, and supportability for the system, subsystem or configuration items, being assessed.

The depth of the review is a function of the complexity of the system, subsystem, or configuration item being reviewed. For instance, where design is pushing state-of-the-art technology, the review should require a greater depth than if it is for a commercial off the- shelf item. Items which are complex or an application of new or novel technology will require even more detailed scrutiny.

12.6.2.2 Conducting the Review

Technical reviews should be event-driven, meaning that they are to be conducted when the progress of the product under development merits review in terms of technical review entry criteria. Forcing a review (simply based on a calendar based schedule) will jeopardize the overall review's legitimacy. The necessary work effort should be completed ahead of the review event. Outcomes of technical reviews must be a confirmation of completed effort. The data necessary to determine if the exit criteria are satisfied should be distributed, analyzed, and analysis coordinated prior to the review.

Technical reviews should be brief, not involve a "cast of thousands" and follow a prepared agenda based on the pre-review analysis and assessment of where attention is needed. Participants should include representation from all appropriate government activities, contractor, subcontractors, vendors and suppliers.

Action items resulting from the review are documented and tracked. These items, identified by specific nomenclature and due dates, are prepared and distributed as soon as possible after the review. The action taken is tracked and results distributed as items are completed.

Ten Tenants of Technical Reviews:

- Do not make them problem solving sessions.
- Do not make them training sessions.
- Do not make them dog and pony shows.
- Do not surprise anyone.
- Have a plan for the meeting (review).
- Come to the review prepared.
- Reviews should be event driven.
- Have exit criteria.
- Record action items.
- Tailor reviews.

12.6.3 Contractor Roles and Repsonsibilities

The contractors are responsible for establishing the time, place and agenda for each of the reviews in accordance with contract requirements and the master program schedule. Most reviews should be conducted at the prime contractor facilities. Subcontractor reviews should be led by the prime contractor and conducted at the subcontractors facilities.

The contractor is required to provide the appropriate materials, resources and documentation required in support of the review. The following is a partial list of what might be included or required by contract:

- Meeting agenda and plans;
- Conference rooms and breakout rooms (if necessary);
- Applicable business and technical data (drawings, specifications, schedules, costs, test data, productions schedules, make/buy plans, etc.);
- Studies and analysis;
- Risk assessments and reports;
- Hardware and related production or test articles;
- Test methods and data; and
- Meeting minutes.

12.6.4 DCMA Roles and Responsibilities

The Defense Contract Management Agency (DCMA) can make a significant contribution to most, if not all, of the reviews and surveys which are accomplished during the life cycle of a system acquisition. DCMA often has a continuing and on-going involvement with the specific contractors, and thus can make major contributions to the successful accomplishment of any review.

The Program Manager can expect DCMA personnel to be on-site and ready to assist the survey team when it arrives. He can expect an in-briefing from the assigned DCMA functional managers and engineers on the strengths and weaknesses of the contractor involved. The DCMA Engineers, Industrial Specialists and Quality Assurance Specialists will be prepared to answer questions pertaining to the topics listed below.

- Plant Resources/Facilities
  - Adequacy for Production (LRIP and FRP)
  - Timely Acquisition/Installation
  - Automated Production Techniques

- Contractor Personnel
  - Personnel Levels
  - Skills Development/Training
  - Certification

- Manufacturing Planning and Control
  - Schedule Compatibility
  - Cost Reduction
  - Alternative Capabilities
  - Configuration Management

- Handling of Engineering Changes
  - Information Systems Assessments

- Materials/Purchased Parts
  - Long Lead Items
  - Procurement Plan Selection of Subcontractors
  - Visibility of Subcontractors

- Quality Assurance
  - Quality System Review
  - Integration with Production Planning
  - Corrective Action

- Contract Administration
  - Pre-Award Assessment
  - Post Award Support and Oversight
  - Contract Closeout Support

Table 12- 2 DMCA Expertise

In most cases, the personnel assigned to DCMA are highly trained and experienced professionals. They constitute a considerable body of technical expertise familiar with the capacity and capability of the contractors involved in acquisition programs. They represent a substantial resource to program managers which should be utilized to get the most effective use of our limited defense budget. In many cases, these resources can be used to offset the problems of finding sufficient numbers of qualified personnel at the PM or buying activity.

When utilizing DCMA personnel, it is incumbent on the PM to provide to the DCMA personnel an understanding of the specific objectives and risks inherent in the acquisition program. This will provide the necessary "program focus" to the review. It should also be noted that the DCMA personnel can provide significant value in the post review time period. Since they continue in residence at the contractor's facility, they can make major contributions to the surveillance of status on action items and periodic reporting of contractor progress.

12.6.5 Contracting for the Review

Contractor cost associated with supporting any technical review must be a consideration, therefore it is important to ensure that appropriate requirements are included in the Statement of Work (SOW) covering support of the proposed review. The specific SOW terms need to be tailored to reflect the program objectives, the funds available for accomplishing the task, the level of risk, and the prime and subcontract structure of the program. The language should be as specific as possible to minimize future conflict in the understanding of the requirement. Whenever possible, the types of contractor preparation required for team visits, the team size, number of planned visits and their duration should be specified to include reviews at subcontractor facilities.

12.6.5.1 Suggested Contract Language is outlined below

The effort to be performed under this contract includes a series of technical reviews as outlined in [insert the complete title, date, and contract attachment number for the SOO, SOW, Spec or other applicable reference]. The parties agree that the fundamental purpose of these systems engineering technical reviews (SETRs) is to review the design/development to date of the [insert program name] system and in so doing to assess the progress to date towards meeting the technical and/or performance requirements set forth in this contract. As such, each review will be tailored to ensure that the emerging design/development of the [insert program name] system is ready to enter the next phase towards completion of this contract. The parties further agree that Government approval of any particular technical review does not eliminate nor modify the Contractor's responsibility to perform in accordance with the terms and conditions of this contract. In that regard, unless expressly directed in writing by the Procuring Contracting Officer, the Contractor is free to adopt or reject any recommendations or advice offered by the Government during the conduct of any of the required SETRs. Moreover, in the event the Contractor is expressly directed in writing by the Contracting Officer to implement a change(s) to the design/development of the [insert program name] system, this clause shall remain in full force and effect unless the Contractor provides written notice to the Contracting Officer requesting relief from the requirements of this clause. Such written request shall provide detailed rationale to support and justify the Contractor's request for relief. In addition, such written request shall be made not later than five (5) days after being directed in writing by the Contracting Officer to implement said change and the Contractor waives any and all entitlements to relief from the requirements of this clause by failing to make a timely written request to the Contracting Officer .

12.7 Gaps in Knowledge

Numerous GAO reports on " *Assessments of Selected Weapon Systems* ," have cited the lack of product knowledge a key decision points as a major factor in programs that overrun costs, are behind schedule and do not deliver the performance as promised. After nine reports, the GAO continues to find that newer programs are beginning to demonstrate higher levels of knowledge at key decision points, but most are still not fully adhering to a knowledge-based acquisition approach. Good acquisition outcomes require the use of a knowledge-based approach to product development that demonstrates knowledge ***before*** significant commitments are made. On the basis of their studies the GAO has identified three key knowledge points:

- **Knowledge Point 1** : Resources and Requirements Match.
- **Knowledge Point 2** : Product Design is Stable.
- **Knowledge Point 3** : Manufacturing Processes are Mature.

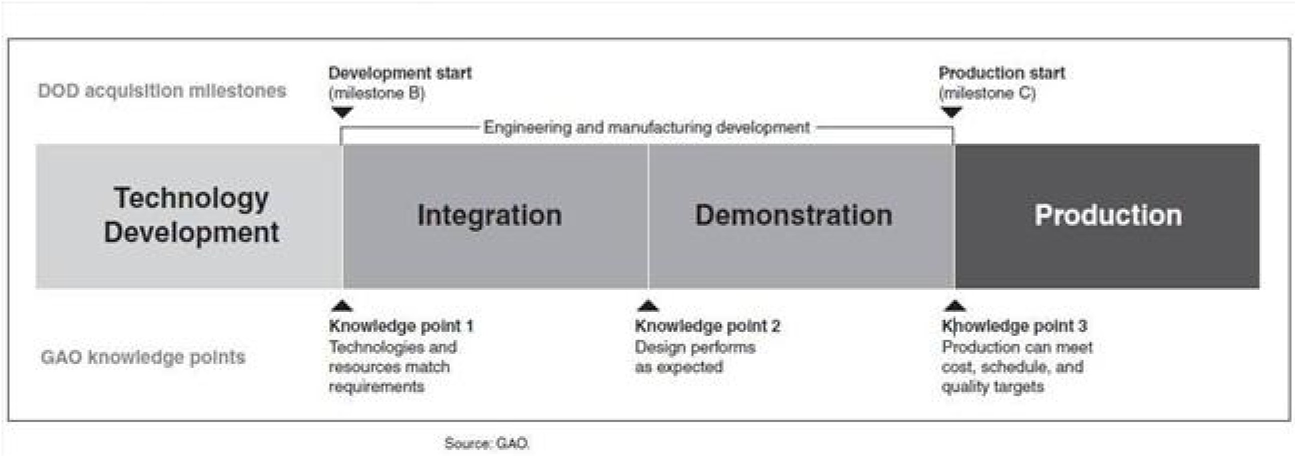


Figure 12- 5 GAO Identified Knowledge Points

Each of these knowledge points can be measured during the acquisition life cycle and using the technical reviews and audits as a knowledge assessment tool makes a lot of sense.

12.7.1 Knowledge Point 1: Resources and Requirements Match

Achieving a high level of technology maturity by the start of system development is an important indicator of whether this match has been made. This means that the technologies needed to meet essential product requirements that have been demonstrated to work in their intended environment. In addition, the developer has completed a preliminary design of the product that shows the design is feasible.

12.7.2 Knowledge Point 2: Product Design is Stable

This point occurs when a program determines that a product's design will meet customer requirements, as well as cost, schedule, and reliability targets. A best practice is to achieve design stability at the system-level critical design review, usually held midway through system development. Completion of at least 90 percent of engineering drawings at this point or 100 percent of the 3D product models for ships at fabrication start provides tangible evidence that the product's design is stable, and a prototype demonstration shows that the design is capable of meeting performance requirements.

12.7.3 Knowledge Point 3: Manufacturing Processes Are Mature

This point is achieved when it has been demonstrated that the developer can manufacture the product within cost, schedule, and quality targets. A best practice is to ensure that all critical manufacturing processes are in statistical control - that is, they are repeatable, sustainable, and capable of consistently producing parts within the product's quality tolerances and standards - at the start of production.

12.8 Survey/Review Guidance

Technical reviews of program progress shall be event-driven and conducted when the system under development meets the review entrance criteria as documented in the Systems Engineering Plan (SEP). They shall include participation by subject matter experts who are independent of the program (i.e., peer review), unless specifically waived by the SEP approval authority as documented in the SEP. The conduct of any review can be an expensive and time consuming activity therefore there are certain general rules or guidelines to follow.

12.8.1 Types and Numbers of Reviews

In identifying the specific areas to be evaluated, the focus should be on those areas which could have the maximum impact on readiness. Developing this focus can be started with identification of the high value or critical items. in most cases, a large portion of the cost and risk is in a small percentage of the items. These are the items on which to focus effort. One way to identify "where" to conduct a review is to use a WBS Risk chart as seen below.

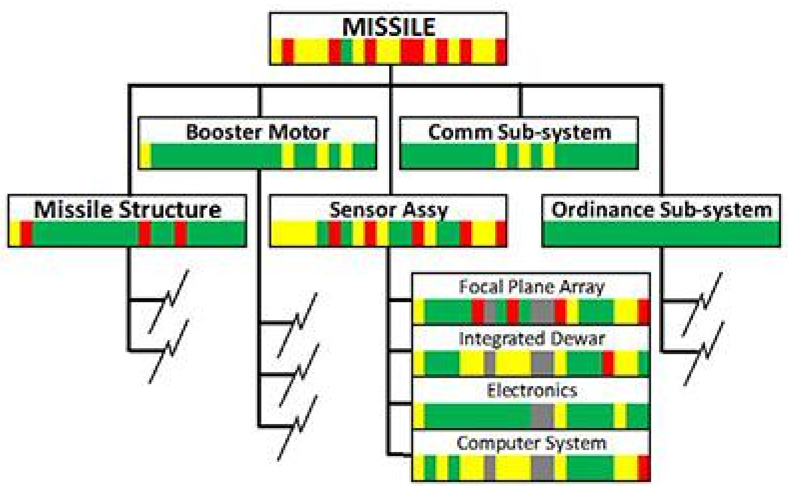


Figure 12-6 Missile Risk Chart

12.8.2 Participants in Reviews

The review should include a broad cross-section of program office participants representing key functional disciplines. These folks are often referred to as Subject Matter Experts (SMEs). Reviews should or could include DCMA personnel, customers, sponsors and end users.

12.8.3 Objectives of the Reviews

The general objectives of any review should include:

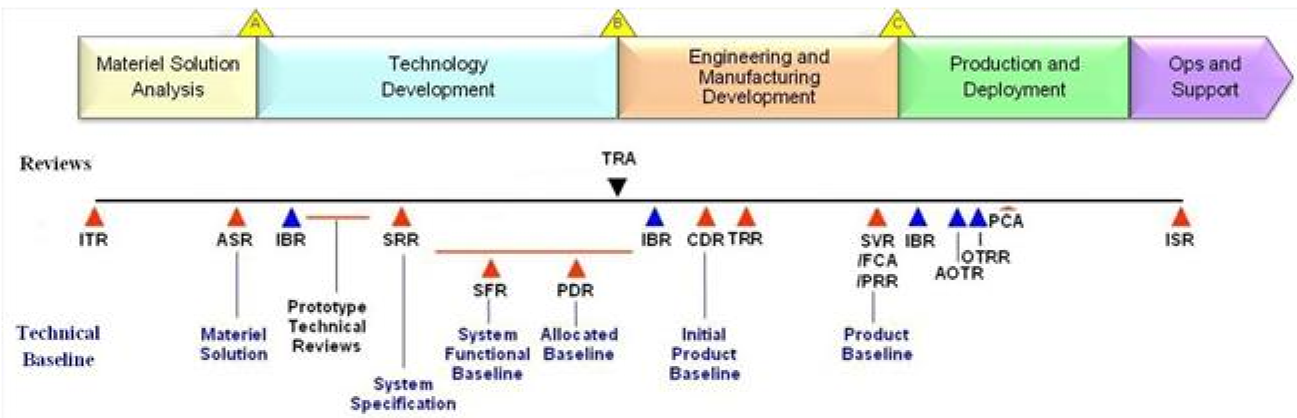
- The demonstration of progress towards specific goals;

- The identification of risks and assignment of responsibilities for follow-up;
- Verification of the expected maturity (technology, design, manufacturing, and sustainment); and
- Agreement for a path forward to assure that risk are managed.

12.9 Summary

This chapter addresses the following topics and learning objectives:

- Identifies the role of manufacturing (influence the design, plan for production, and execute the production plan).
- Describes the various technical reviews and audits.
- Outlines the various roles and responsibilities for technical reviews (Government, contractor and DCMA).
- Identifies the gaps in knowledge of program technical risk:
  - Knowledge Point 1: Resources and Requirements Match,
  - Knowledge Point 2: Product Design is Stable, and
  - Knowledge Point 3: Manufacturing Processes are Mature.
- Identifies survey guidance.



12.10 Related Links and Resources

Numerous reference documents impact the manufacturing management function throughout the acquisition process. These documents originate from many sources and range across academic disciplines, functional activities, and job specialties.

The following is a reference list of DOD Directives (D), Instructions (I) Manuals (M), Pamphlets (P), Military Standards (MS), and other documents. The documents listed contain DOD policy guidance applicable to the manufacturing management function. They are listed as sources of DOD manufacturing management information.

Note: Many of the documents listed are no longer required (due to acquisition reform), but still contain some very valuable information.

Number	Title
	Technical Reviews: A Summary
DAG Chapter 4.5.9	Summary of Technical Reviews
	Initial Technical Review (ITR) Checklist
	Alternative System Review (ASR) Checklist
	System Requirements Review (SRR) Checklist
	System Functional Review (SFR) Checklist
	Preliminary Design Review (PDR) Checklist
	Technology Readiness Assessment (TRA) Checklist
	Critical Design Review (CDR) Checklist
	Test Readiness Review (TRR) Checklist
	System Verification Review (SVR) Checklist
	Functional Configuration Audit (FCA) Checklist
	Production Readiness Review (PRR) Checklist
	Operational Test Readiness Review (OTRR) Checklist
	Physical Configuration Audit (PCA) Checklist
	In-Service Review (ISR) Checklist

Defense Manufacturing Management Guide for Program Managers
Chapter 13 - Manufacturing Controls

13.1 Objective

Manufacturing resources (Figure 13-1) consist of facilities, materials, machines, manpower, methods, measurement systems, and capital that are used to convert or transform raw materials and component parts into end products. Contractors must have an effective combination of people and systems in order to plan for, monitor, and control these manufacturing resources. The government, in recognition of this objective, requires contractors to implement proven manufacturing ***control systems*** which, when properly implemented and managed, lead to successful manufacturing management.

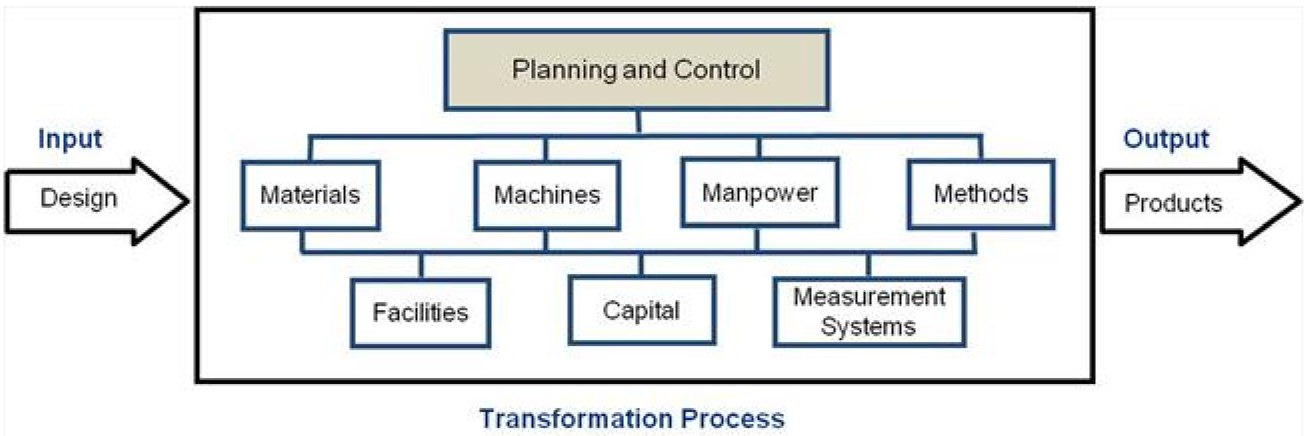


Figure 13-1 Planning and Control over Manufacturing

Throughout this guide, the manufacturing management functions are discussed within the context of the defense systems acquisition process. This chapter concentrates on the manufacturing controls necessary to ensure that manufacturing operations are properly managed and problems do not disrupt the acquisition program. These controls include:

- Performance Evaluation,
- Configuration Management,
- Measures of Contractor Effectiveness,
- Work Measurement,
- Cost/Schedule Control System Criteria (C/SCSC),
- Line of Balance, and
- Earned Value Management.

13.2 Background

In a 2008 GAO report, *Requirements and Oversight Needed to Improve DOD's Acquisition Environment and Weapon System Quality (GAO-08-294)* , they noted that "Problems related to quality have resulted in major impacts to the 11 DOD weapon systems GAO reviewed-billions in cost overruns, years-long delays, and decreased capabilities for the warfighter. For example, quality problems with the Expeditionary Fighting Vehicle program were so significant that DOD extended development 4 years at a cost of $750 million, and the F-22A fighter aircraft experienced cracks in the plane's canopy that grounded the flight test aircraft. GAO's analysis illustrated that defense contractors' use of immature designs, inadequate testing, defective parts, and inadequate manufacturing controls led to many of the problems that GAO found.

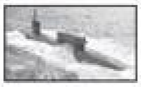
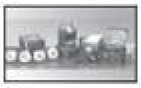
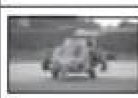
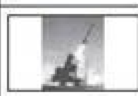
		Source of quality problem			Impact of quality problem	
System		Systems engineering	Manufacturing	Supplier quality	Cost (dollars in millions)	Schedule
Advanced SEAL Delivery System[a]		✓		✓	$87	Program halted
Advanced Threat Infrared Countermeasure/ Common Missile Warning System		✓	✓		$117	5-year delay
Expeditionary Fighting Vehicle		✓			$750	4-year extension to system development
F-22A		✓	✓	✓	$400	No schedule impact to program
Global Hawk[a]		✓		✓	$239	4-month production slip for sensor suite
Joint Air-to-Surface Standoff Missile			✓	✓	$39	Program deferred
LPD 17 Amphibious Transport Dock[a]		✓	✓	✓	$846	3-year delay
MH-60s Fleet Combat Support Helicopter			✓		No cost impact to program	6-month production slip
Patriot Advanced Capability-3		✓	✓	✓	$26	6-month delay

Figure 13-2 Programs with Problems

13.3 Introduction

The Joint Strike Fighter (JSF) is just one example of a very complex weapon system. The JSF program is in reality a family of aircraft including a conventional take-off and landing variant, a carrier-based variant, and a short take-off vertical-landing variant. Numerous countries are providing funding for the JSF and are participating in the development and production of the aircraft. Well over $3 billion in contracts have been awarded to companies in the United Kingdom, Italy, Netherlands, Turkey and other NATO countries that are supporting this effort. In addition, over 2,500 contracts have been awarded to small businesses contracts. All of these resources need to be managed and controlled if this program is to be successful.

13.4 Manufacturing Management System Evaluation

One role of manufacturing (Figure 13-3) is to:

- Influence the design process so that the design is producible;
- Prepare for production or plan for production; and
- Execute the manufacturing plan.

Execute the plan in a way that reflects the design intent while ensuring repeatable processes and focusing on continuous improvement. Executing the plan includes many control functions.

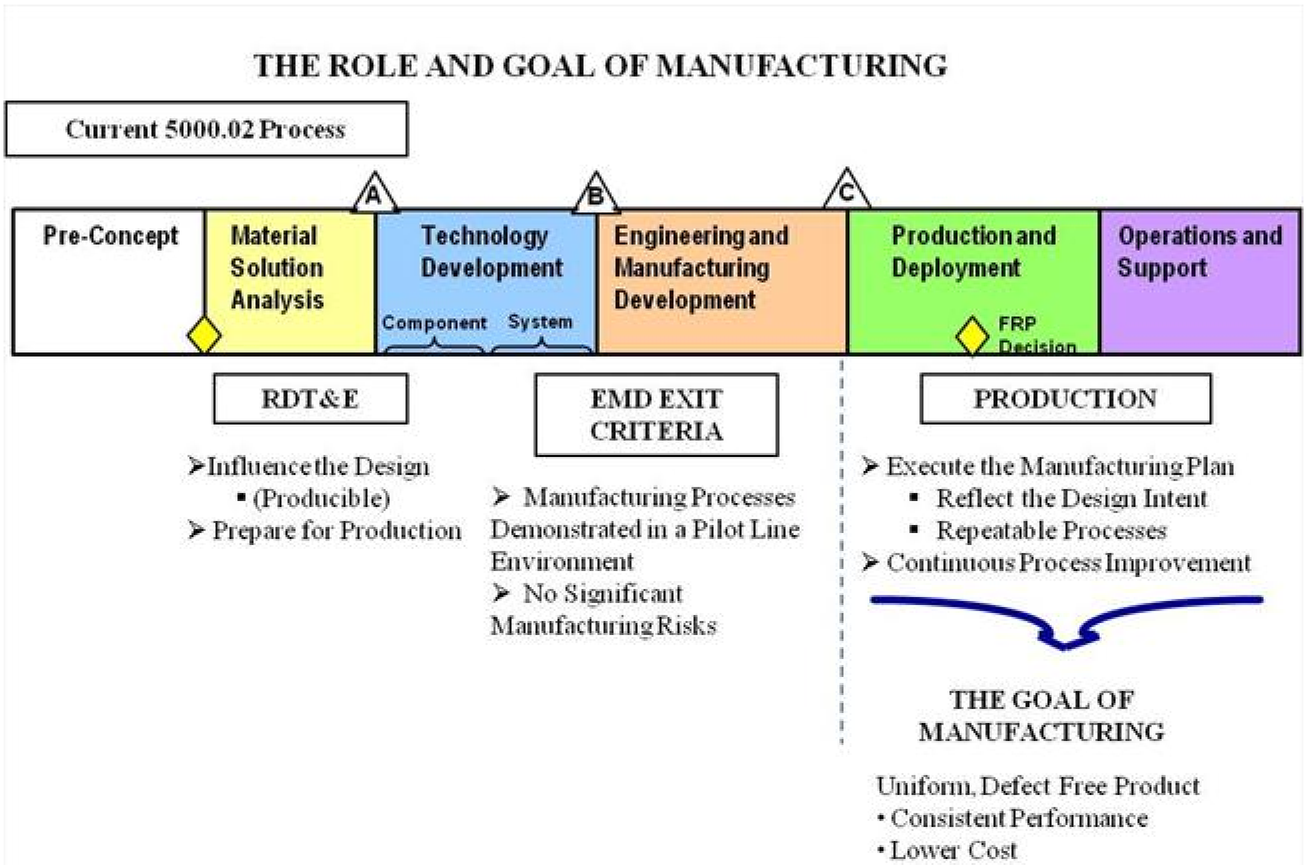


Figure 13-3 The Role and Goal of Manufacturing

Control of the manufacturing system is critical to ensuring that quality products are produced on-time, within budget and delivering the expected performance. A well-defined management system needs to be established and implemented within the factory and supporting organizations that can provide managers with insight into the contractor's performance. As the manufacturing system is accomplishing the production task, control systems must exist to identify variances from plans or targeted performance. These variances alert management to take action to correct the causes of the problems before major program impact results.

13.4.1 Manufacturing Scope

Manufacturing management and control pertains to all operations and functions between receiving and shipping. If manufacturing costs increase, then the budget constraint will cause a reduction in the number of systems acquired, which results in less operational capability. Manufacturing inefficiency reduces the capability of the industrial base to respond to basic DOD needs as well as to surge and mobilization. Regardless of the type of contract involved, the manufacturing management effort including program office, contract administration, and contractor involvement, must be structured to meet defined program objectives related to manufacturing efficiency, capacity and capability.

Most program managers get concerned about manufacturing management during the later stages of the Engineering and Manufacturing Development (EMD) phase and beyond. But, there is a need to manage and control the emerging manufacturing and production risks that begin to appear in the early acquisition phases. For example:

- **Material Solution Analysis (MSA) Phase** : The MSA phase is usually concerned with advancing of the state of knowledge. Planning focuses on the technologies being evaluated. Measuring progress is possible if the technical objective is clearly expressed, if the technical risk can be identified; experimental procedures and skills determined; and work plan developed with subtasks identified. Technical maturity and progress are the main measures of program success in R&D.
- **Technology Development (TD) Phase** : The TD phase matures technologies, determines the appropriate set of technologies to be matured, conducts competitive prototyping, refines requirements, and develops the functional and allocated baselines of the system configuration. Progress is often hard to gauge. Objective scheduling criteria may be minimal; technical parameters may be broad and flexible. Researchers may encounter technological setbacks that cause schedule slippage. Monitoring progress consists largely of evaluation of the technical aspects of a program along with planned schedules. Financial progress involves monitoring costs incurred and the contractor's level of effort and accomplishment.
- **Engineering and Manufacturing Development (EMD) Phase** : Progress measurement becomes easier. Though the design is not completed, much of the indefiniteness of R&D is gone. Manufacturing is moving out of the laboratory and into a production representative environment or pilot line. Monitoring and control of manufacturing functions is becoming increasingly important. Data systems need to provide managers with the right information at the right time in order to support management activities and successful transition to production.
- **Production and Deployment (P&D) Phase** : Progress measurement for the production contract should be a daily activity. The end item design should be firm or at least reasonably firm. The manufacturing processes and associated costs and schedule should have been established at the outset of the procurement. The emphasis has now shifted from technical evaluations to production control and financial status data.
- **Operations and Support (O&S) Phase** : Progress monitoring and program controls need to remain in place for many contracts as the program moves from typical

operational builds to building spares, for foreign military sales, and for modifications to the original designs.

13.4.2 Manufacturing Functions

Manufacturing management involves planning for, controlling and executing a wide spectrum of manufacturing functions, processes and operations. Some of these activities require manufacturing managers to work with a company's front office functions:

- Working with sales to establish workload requirements tied to sales forecast.
- Working with procurement to establish delivery dates for supplies.
- Working with distribution managers to establish delivery dates for finished goods.

Accomplishing manufacturing objectives requires that the contractor establish basic manufacturing policies, implement those policies through manufacturing procedures, and develop detailed work instructions. These activities also require manufacturing mangers to work with a wide spectrum of personnel to include:

- Manufacturing and Quality Engineers;
- Industrial and Process Engineers;
- Production and Quality Specialists;
- Production Planners and Schedulers;
- Facilities Engineering; and
- Tooling Engineers and Tool Makers.

Government manufacturing engineers and industrial specialists are the individuals primarily concerned with surveillance of the contractor's accomplishment of the manufacturing objectives and with the efficiency and economy of manufacturing operations. This requires the consideration of a wide range of issues involving manufacturing planning and control, personnel and equipment scheduling and loading, production equipment maintenance, in-process inventory control, analysis of manufacturing operations, scrap prevention, and manufacturing management techniques.

One current issue is the shortage of manufacturing talent. According to a 2011 survey by Deloitte and The Manufacturing Institute they found that 67 percent of manufacturers are facing a shortage of manufacturing workers in many skills categories. This shortage amounts to as many as 600,000 skilled positions were unfilled in the 2011 timeframe in the U.S. alone, making the challenges of producing complex DOD weapon systems that much riskier.

In evaluating the contractor's ability to attain a program's manufacturing objectives, the following questions can serve as a basis for the DOD evaluation:

- Are the contractor's manufacturing objectives and assignment of responsibilities satisfactorily described in policies and implementing procedures?
- Does the contractor have a system for establishing functional performance goals, measuring performance against goals and identifying causes for failures to achieve goals?

- Are manufacturing plans and procedures designed so that personnel requirements can be determined by number, skills, and training?
- Are the contractor's internal audit practices and procedures designed to identify manufacturing management deficiencies and is there a requirement for prompt corrective action?

It must be emphasized that manufacturing management evaluation is system oriented. While each of the parts comprising the manufacturing operations system may be individually acceptable, contractor integration of the parts is critical to overall success.

13.5 Performance Evaluation

Production surveillance and reporting is a requirement of the Federal Acquisition Regulation (FAR Subpart 42.11): *"Production surveillance is a function of contract administration used to determine contractor progress and to identify any factors that may delay performance. Production surveillance involves Government review and analysis of* --

(a) Contractor performance plans, schedules, controls, and industrial processes; and

(b) The contractor's actual performance under them."

Performance evaluation includes the periodic examination of the contractor's efforts to perform to the contract; appraisal of the extent to which these efforts have moved forward toward completion of the total effort; and a judgment of the probability of the total effort being completed as required by the contract. Surveillance and oversight is often focused on two areas:

1. Production progress, and

2. Financial progress.

The evaluator must determine the importance of the contract activities being evaluated in order to arrive at an order of magnitude of surveillance effort and the priority of that effort. This decision should be influenced by:

- The size of the program in terms of:
    - Length of time,
    - Estimated cost, and
    - Extent of the effort involved.
- The significance of the effort in relation to overall organization objectives.
- The nature and complexity of the work.
- The type of contractual relationship.

The kind and degree of surveillance and evaluation will also depend upon the degree of certainty or uncertainty associated with the extent of the contract work. If the program is highly complex or is immature then a greater degree of management control will be required. These factors in turn directly impact both cost and the capability to deliver on time. Associated with this is the confidence that the government and the contractor have in the estimate the amount of effort that is necessary to accomplish the contract task within the time and technical constraints.

13.5.1 Production Progress

The purpose of monitoring production progress is to obtain the information about the contractor's performance from a technical and schedule perspective. Monitoring may disclose problems in the contractor's manufacturing system or show the need for monitoring subcontract performance. Monitoring provides a variety of information serving many purposes:

- Providing up-to-date delivery information;
- Helping determine the adequacy of the contractor's own monitoring system;Helping to identify and isolate contractor performance problems;
- Generating data on cost of specific areas of performance (these data are often needed for cost analysis of change orders, or approval of progress payments in certain types of contracts);
- Identifying the need to allocate government property to various programs requiring it;
- Help in making decisions about when to incorporate new components in major equipment;
- Determining the government's rights under the contract (e.g. when questions of default arise);
- Determining future funding requirements by comparing actual cost with accomplishments.

Progress information comes from many sources; however, the primary ones are: schedules, monthly cumulative progress reports, material inspection and receiving reports, special progress reports, and cost performance reports or cost/schedule status reports.

The contractor may be required to submit a phased schedule for review by the government. This requirement appears in the Statement of Work and the Contract Data Requirements List (CDRL). These schedules usually show the time required to perform the entire fabrication cycle from planning, to purchasing, plant rearrangements, tooling, component manufacture, subassembly and final assembly, testing, and finally to shipping. The degree to which each function is subdivided depends on considerations of the nature of the end item, the type of fabrication process, the size and complexity of the contractor's organization, and the established schedule. The approved schedule serves as a basis for reporting and measuring contract performance.

Contractors provide performance progress information via their monthly reports. These reports show actual and forecast deliveries and compares it with the contract schedule. These data are shown in terms of scheduled and estimated starting and completion dates and percentage of completion. The report form should also contain narrative sections to explain any difficulties, or delay factors, action taken or proposed to overcome these difficulties, and any assistance required from the government.

13.5.2 Financial Progress

Monitoring financial progress is critical, especially given today's budget constraints and focus on affordability. Effective program management depends on receiving cost information and ensuring that the contractor's system is capable of generating timely and accurate cost information. On 29 April, 1993, the Secretary of Defense Les Aspin fired three Air Force general officers and one senior civilian for mismanagement of the C-17 cargo aircraft with over $1.5 billion in cost overruns. The C-17 was begun in the late 1970's as a low risk, low cost venture with McDonnell Douglas as the prime contractor. Unfortunately, by the 1990's Douglas was in trouble. In addition to the C-17, Douglas had two other large fixed price contracts with the Navy for the T-45 trainer and A-12 attack aircraft and both were over budget and behind schedule. In addition, Douglas had two large commercial efforts going on at the same time, the MD-80 and MD-11 and both of those aircraft programs were experiencing difficulties leading to significant schedule slippages. How could the Air Force mismanage programs that were in obvious trouble? One problem, as noted in a 1993 Defense Science Board review was that the "MDC *business systems are struggling to provide the management visibility and control needed to properly support the C-17 program* ."

The financial data furnished by the contractor normally includes: cumulative expenditures on the contract, forecasts of future expenditures and commitments, and an estimate of the total costs at contract completion. This information helps in forecasting cost underruns or overruns on cost reimbursement and fixed-price-incentive contracts. The Earned Value Management (EVM) report (formerly known as the cost performance report) and the Cost/Schedule Status Report (C/SSR) provide the basis for measuring the contractor's overall performance on the contract.

13.6 Configuration Management (CM)

Configuration management (CM) is about control. If the configuration is controlled then there is some hope of controlling the costs. If the configuration is not controlled, then the cost will also not be in control. CM helps to ensure that the configuration of items is known throughout their life. CM controls the important aspects of a weapon system that might have a negative impact if not controlled and the change allowed rippling through the system. For example, an aircraft subcontractor makes a design change to a jet engine that improves performance, but that change ripples through several subsystems. That one change could:

- Impact a sensor on the engine;
- Cause a reading to change in the cockpit;
- Force the pilot to react differently in certain situations;
- Cause a change to a technical order and to a maintenance procedure;
- Impact the reliability of the weapon system and cause a change to provisioning requirements;
- Cause a change to the training program and to the flight simulation programs;
- Cause a change to the supply or vendor base; and/or
- Require a change to software code that monitors engine performance.

Configuration management is a management process for establishing and maintaining consistency of a product's performance, functional, and physical attributes with its requirements, design and operational information throughout its life. These simple words describe a complex process essential to the successful management of a production program and highlight five major areas of effort as outlined below:

1. **Planning and Management -** Provides total life-cycle configuration management planning for the program/project and manages the implementation of that planning.

2. **Identification** - Establishes configuration information and documentation of functional and physical characteristics of each configuration items. Documents agreed-to configuration baselines and changes to those configurations that occur over time.

3. **Change Management** - Ensures that changes to a configuration baseline are properly identified, recorded, evaluated, approved or disapproved, and incorporated and verified, as appropriate. A common change method is the Engineering Change Proposal.

4. **Status Accounting -** Manages the capture and maintenance of product configuration information necessary to account for the configuration of a product throughout the product life cycle.

5. **Verification and Audit** - Establishes that the performance and functional requirements defined in the technical baseline are achieved by the design and that the design is accurately documented in the technical baseline.

The configuration management (CM) discipline spans the product life cycle and contributes toward ensuring sustained system performance, minimizing the effects of design changes functional or physical reducing the incidence of system incompatibility, and avoiding the procurement of obsolete spare parts during the provisioning process. Figure 13-4 shows the relationship between configuration management and the product development cycle. As the program move through the acquisition phases the configuration of the product becomes increasingly clearer and more complex.

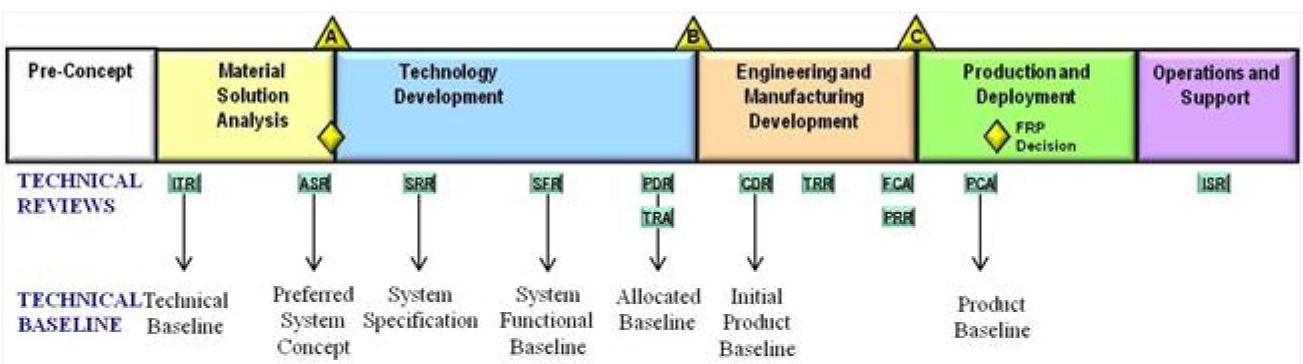


Figure 13-4 Configuration Management Technical Baselines

The **technical baseline** is the authorized and documented technical description specifying the functional and physical characteristics of a system/component.

- Functional characteristics describe the performance requirements the item is expected to meet.
- Physical characteristics relate to the material composition and dimensions of the end item.

Baseline management deals with defining and documenting the system requirements and the requirements for each configuration item (CI). These baselines reflect the development status and are intended to control the implementation of system changes while retaining design and development flexibility. The translation of technical requirements in a baseline management function permits contracting for needed engineering and production support (producibility, risk analyses, process development, tool design, testing, inspection) in a clearly definable, priceable and manageable progression. Three baselines are generally considered in configuration management. These are outlined below:

- **Functional Baseline** : This baseline is derived from the Capability Development Document (CDD) and documented in the system or subsystem specification. The functional baseline describes the functional, interoperability and interface characteristics of a system and it identifies the verification required to demonstrate achievement of the specified characteristics. The functional baseline is normally established and put under configuration control at the System Functional Review. It is usually verified with a System Verification Review and/or a Functional Configuration Audit (FCA).
- **Allocated Baseline** : The allocated baseline describes those functional, interoperability and interface characteristics allocated from a higher level that is the level above it. The allocated baseline is usually established and put under configuration control at each configuration item's (hardware and software) Preliminary Design Review (PDR), culminating in a system allocated baseline established at the system-level PDR.
- **Product Baseline** : The Product Baseline describes the product once it has been completely developed. The initial product baseline includes "build-to" specifications for hardware (product, process, material specifications, engineering drawings, and other related data) and software. The initial product baseline is usually established and put under configuration control at each configuration item's Critical Design Review (CDR), culminating in an initial system product baseline established at the system-level CDR.

13.6.1 Configuration Identification

Configuration Identification consists of documentation of formally approved baselines and specifications, including:

- Selection of the CIs;
- Determination of the types of configuration documentation required for each CI;
- Documenting the functional and physical characteristics of each CI;
- Establishing interface management procedures, organization, and documentation;

- Issuance of numbers and other identifiers associated with the system/CI configuration structure, including internal and external interfaces; and
- Distribution of CI identification and related configuration documentation.

Typically the top tier of CIs directly relate to the line items of a contract and the work breakdown structure (WBS). Determining what to designate as CIs is normally simple and straight forward as asking, "Would a change here cause a significant impact here or somewhere else?" Some of the primary reasons for designating separate CIs are:

- Critical, new or modified design;
- Independent end use functions;
- Sub-assembly factors such as the need for separate configuration control or a separate address for the effectivity of changes;
- Components common to several systems;
- Interface with other systems, equipment or software;
- Level at which interchangeability must be maintained;
- Separate delivery or installation requirement;
- Separate definition of performance and test requirements; and
- High risk and critical components.

This breakdown of CIs is critical to successful application of the configuration management discipline and impacts performance and functional compatibility of the weapon system sub-elements from the prime contractor down through the supply chain. Specifications must be prepared to document the characteristics of each CI; design reviews and audits must be performed for each CI; engineering change proposals are prepared individually for each CI; and status accounting tracks the implementation of changes to each CI.

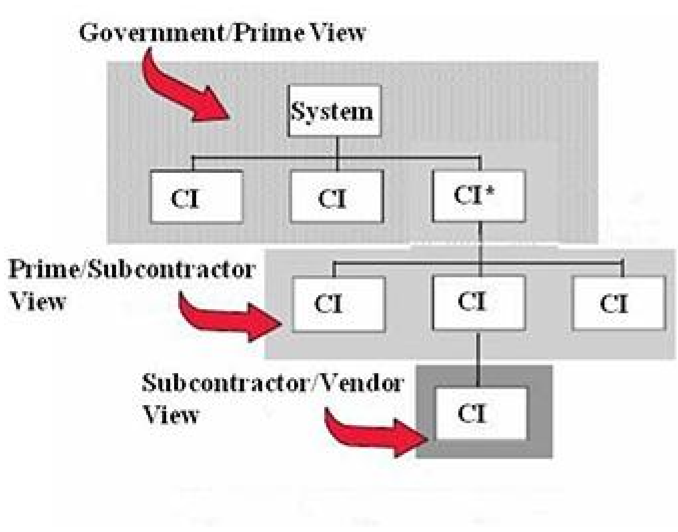


Figure 13-5 Configuration Items

13.6.2 Configuration Control

Configuration control is the systematic evaluation, coordination, approval, and implementation or disapproval of all changes in the configuration of a system or end product after formal establishment of its configuration identification. Configuration control maintains the functional, allocated, and product CI baselines and regulates all changes. Change control prevents unnecessary or marginal engineering changes while expediting the approval and implementation of those that are necessary or offer significant benefits.

Configuration control is perhaps the most visible element of configuration management. It is the process used by contractors and government program offices to manage preparation, justification, evaluation, coordination, disposition, and implementation of proposed engineering changes and deviations to effected Configuration Items (CIs) and baselined configuration documentation.

The primary objective of configuration control is to establish and maintain a systematic change management process that regulates life-cycle costs, and:

- Allows optimum design and development latitude with the appropriate degree, and depth of configuration change control procedures during the life cycle of a system/CI.
- Provides efficient processing and implementation of configuration changes that maintain or enhance operational readiness, supportability, interchangeability and interoperability
- Ensures complete, accurate and timely changes to configuration documentation maintained under appropriate configuration control authority.
- Eliminates unnecessary change proliferation.

Configuration control begins for the government once the first configuration document is approved and baselined. This normally occurs when the functional configuration baseline is established for a system or configuration item. At that point, government and contractor change management procedures are employed to systematically evaluate each proposed engineering change or requested deviation to baselined documentation, to assess the total change impact (including costs) through coordination with affected functional activities, to disposition the change or deviation and provide timely approval or disapproval, and to assure timely implementation of approved changes by both parties. Configuration control is an essential discipline throughout the program life cycle.

13.6.3 Configuration Status Accounting

Configuration status accounting is defined as the recording and reporting of the information that is needed to manage configuration effectively, including:

- A listing of the approved configuration identification;
- The status of proposed changes to configuration; and
- The implementation status of approved changes.

Configuration status accounting represents the process of recording the documented changes to an approved baseline and results in the maintaining of a continuous record of the configuration status of the individual CIs comprising the system. Additionally, valuable management information concerning both required and completed actions resulting from approved engineering changes is provided. Status accounting information includes an index consisting of the approved configuration and a status report detailing the current configuration. All items of the initially approved configuration are identified and tracked as authorized changes to the baseline occur.

13.6.4 Configuration Audits

Configuration Audits are used to verify a system and its components' conformance to their configuration documentation. Audits are key milestones in the development of the system and do not stand alone.

Functional Configuration Audits (FCA) and the System Verification Review (SVR) are performed in the Production Readiness and LRIP stage of the Production and Development Phase. The FCA is used to verify that actual performance of the configuration item meets specification requirements. The SVR serves as system-level audit after FCAs have been conducted.

The Physical Configuration Audit (PCA) is normally held during Rate Production and Development stage as a formal examination of a production representative unit against the draft technical data package (product baseline documentation).

Successful completion of verification and audit activities results in a verified System/CI(s) and a documentation set that may be confidently considered a Product Baseline. It also results in a validated process to maintain the continuing consistency of product to documentation.

13.7 Measures of Contractor Effectiveness

During the production phase of the product life cycle, some measures of the effectiveness of the manufacturing organization should be established. The objective of this phase is to produce, in a timely fashion, systems and equipment which conform to the technical documentation at a minimum cost. Measures of effectiveness for each of these areas should be established, and performance tracked against the measure to identify opportunities for improvement for the manufacturing organization. These measures fall into three general categories:

- Time
- Conformance
- Cost

Some of the measures can be used to provide insight into cost and schedule or conformance and cost. Several measures of contractor effectiveness will be discussed in the ensuing paragraphs.

13.7.1 Time Measures (Schedules)

In most DOD acquisitions, the delivery schedule is integrated with deployment, training, testing and other schedules. Failure of the manufacturing organization to achieve and maintain schedule can have significant impact on many other factors such as cost or operational readiness. Schedule attainment also tends to be a rather visible program element and is often used as a measure of program status by the DOD and Service and Agency Headquarters as well as Congress and the public. The PM should establish, or have the contractor establish, a data collection system which will support the development of schedule projections that could be used to highlight potential problems or risks. This provides an opportunity to take actions to minimize the impact of delays on the deployment process.

13.7.2 Conformance Measures

Conformance measures often fall under the purview of the Quality department. When systems, subsystems or materials are presented to the government for customer acceptance, it is now up to the government to verify that the items meet government contract requirements. Throughout the manufacturing and assembly process, the contractor is required to document inspection and test points and results. Government production and quality assurance personnel should be on-site verifying these inspections and tests. The reality is that items often get presented to the government accompanied by waiver and/or deviation requests (or approved waivers or deviations). There are also departures from technical documentation below the level of the government's configuration control which are handled by Material Review Board (MRB) action. Reducing the number of these occurrences is a basic element of a strong Quality Management program.

13.7.3 Cost Measures

Manufacturing cost estimates for the production phase are normally based on the assumption that the design is complete, that the manufacturing processes are known, and manufacturing operations will be accomplished as planned. Any deviation from these assumptions could cause a growth in cost. As such, time and conformance measures can give some indication of potential or real cost aberrations since there is normally a direct correlation between late delivery or conformance problems and cost. In addition, the following measures may also indicate the existence of cost problems:

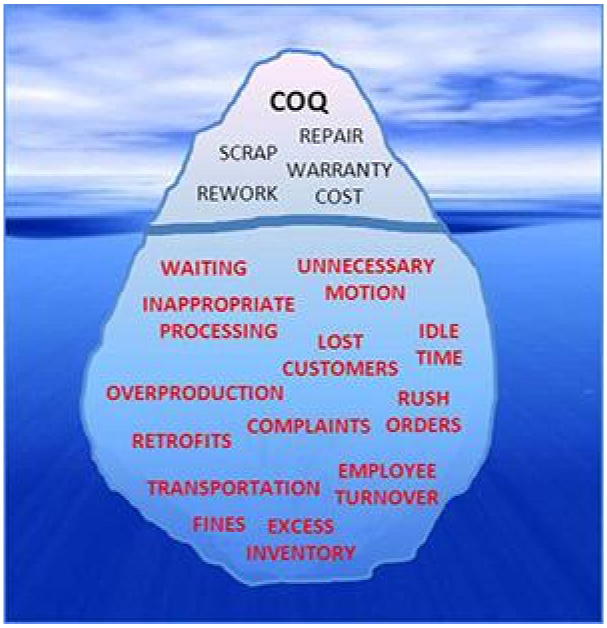


Figure 13-6 Cost of Quality

- Scrap and rework rates,
- Percentage of out-of-station work,
- Supplier quality problems,
- Engineering change volume,
- Yield rates on manufacturing operations, and
- Reliability growth profiles.

Estimating cost is a requirement in all the phases. One of the problems with estimating costs is the need to understand all of the "hidden costs." Those cost that are not readily visible but none the less are still there. Those in the field of manufacturing and quality assurance understand the "hidden factory." That part of the factory where there is waste and non-value added activities. The hidden factory is often called the "cost of quality (COQ)" or the "cost of poor quality (COPQ)."

These indicators do not replace normal management control systems but can be used as supplementary information or aids in predicting and isolating causative factors. They are also valuable measures in assessing the effectiveness of the contractor's quality program.

13.8 Work Measurement

Work measurement, like many other performance measurement tools is a major element of scientific management or Taylorism. It's roots come from time (Frederick Taylor) and motion (Frank and Lillian Gilbreth) studies that sprang up in the early days of the industrial revolution as managers attempted to understand, measure, and improve factory floor performance. Time studies looked at establishing standard times for work activities. Motion studies looked at the processes or motions used to conduct work methods. These two techniques eventually became integrated into time and motion studies.

A Work Measurement System evolved from time and motion studies and is an industrial engineering term used to describe a technique for establishing how much time it should take to complete a task or series of tasks that has well defined work content. Work measurement is designed to:

- Analyze the touch labor content of an operation;
- Establish labor standards for that operation;
- Measure and analyze variances from those standards; and
- Continuously improve both the operation and the labor standards used in that operation.

Work measurement and the reporting of labor performance are not considered ends in themselves, but a means to more effective management. When properly understood and used by management, the benefits described in Table 13-1 typically accrue from an effective WMS.

- Greater output from a given amount of resources
- Lower unit costs because production is more efficient at all levels
- Reducing wasted time in performing operations
- Continued attention to methods and process analysis because of the necessity for achieving improved performance
- Improved budgeting and cost estimating
- Improved basis for planning for long-term personnel, equipment, and capital requirements
- Continual control activities and delivery time estimates
- Help in solving layout and material handling problems by providing accurate figures for planning and utilization of equipment

Table 13-1 Benefits of Work Measurement

13.8.1 Work Measurement Within the DOD

Work measurement within the DOD is a system often used to measure and control the time required to perform production tasks at contractor facilities or maintenance, repair and overhaul tasks at depots. Work measurement is an important tool which can be of great value in cost estimating, production planning, and contract management. A work measurement system uses one of two types of labor standards in most phases of the manufacturing operation (engineered standards and non-engineered standards). A labor standard describes the time allowed for a normally skilled or qualified operator following a prescribed method, working at a normal level of effort, to complete a defined task with acceptable quality.

- An engineered standard is one established using a recognized technique, such as time and motion study, predetermined time system, standard data, or work sampling to derive to least 90 percent of the total time associated with the labor effort covered by the standard.
- Non-engineered standard are those not meeting the above criteria and are usually determined by estimates or based on historical data.

An engineered standard is composed of three components or elements: leveled time; a personal, fatigue, and delay (PF&D) allowance; and any applicable special allowances. Figure 13-7 depicts some of the factors that should be considered in each element of the engineered standard as it is developed.

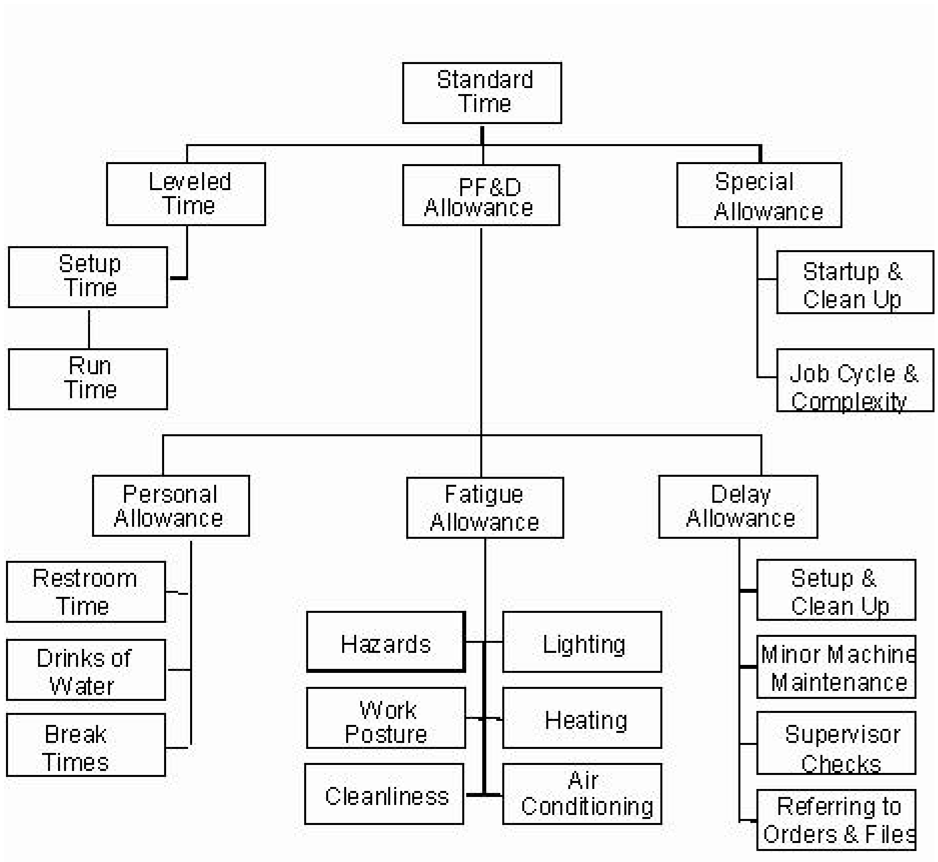


Figure 13-7 Work Measurement Components

Leveled time is the time that a worker of average skill, making an average effort, under average conditions, would take to complete the required task. After the leveled time is developed, estimators must consider a personal, fatigue, and delay (PF&D) allowance. Be careful when contractors use predetermined time systems. Some predetermined time systems include a partial or complete allowance for PF&D. If the contractor uses such standards, additional PF&D consideration may not be appropriate. Any proposed special allowance must be supported by detailed engineering analysis. An appropriate study should be conducted in each shop or functional area to ascertain any requirement for a separate delay allowance. The analyst should assure that there is no duplication between cycle time elements and allowance elements and that the Special Allowance does not become a dumping ground for operation activity that is not an integral part of shop work load.

Standards represent goals for efficient operation. Tasks are rarely completed in the allowed standard time. Work Measurement Systems commonly use realization or efficiency factors to evaluate how the actual time required to complete a task compares with the standard time for that task. Analysts can then use these measures to identify tasks that require special analysis to identify and correct inefficient operations.

13.8.2 Objectives of a Work Measurement System

Work measurement standards provide information on what it should cost to complete an operation or series of operations in product production. Managers can use this information to identify areas requiring particular management emphasis and focus on improvements in productivity. For each standard, offerors should be required to provide information on internal analyses of the variance between the actual time required to complete the work and the standard time to determine the causes for the variance and identify ways of managing performance improvement.

Variance analysis should identify, categorize, and develop plans to control all variances from standard. Plans will typically concentrate on the operations with the largest variances from standard, because these operations present the greatest opportunity for cost reduction.

Contractors should consider the use of labor standards whenever contractor employees will be performing the same tasks repetitively over an extended period of time. Labor standard development requires extensive detailed effort. The time and cost required for standards development are prohibitive unless the task will be performed repetitively. On the other hand, when an operation will be performed repetitively, the cost visibility provided by labor standards permits detailed cost evaluation and control that can result in significant savings to the government. To be of real value, labor standards must be considered in making key management decisions (e.g., budgeting, estimating, production planning, and performance evaluation).

Contractors that have implemented Lean/Six Sigma or other improvement programs should be able to demonstrate continued improvement in realization and efficiency factors. The Acquisition Team can use that same information to identify inefficient operations for close scrutiny during contract negotiations.

13.9 Cost/Schedule Control System Criteria

The Cost/Schedule Control Systems Criteria (C/SCSC) were first developed by DOD and NASA as a PERT/Cost model in 1963. Then in 1967 DOD established the Cost/Schedule Control Systems Criteria or C/SCSC. C/SCSC are a set of criteria which describe the capabilities which must be present for a contractor's cost and schedule control systems to be acceptable for use on contractors for major programs. The objectives of C/SCSC are twofold:

1. For contractors to use effective internal cost and schedule management control systems; and

2. For the Government to be able to rely on timely and auditable data produced by those systems for determining product oriented contract status.

C/SCSC became the DOD adopted approach to identify general criteria that contractor's management control systems must meet. The C/SCSC criteria are intended to be general enough to allow their use in evaluating development, construction and production contracts. Since these contracts differ significantly, it is unwise to specify detailed guidance applicable in every circumstance. Use of the criteria must be based upon common sense and practical interpretations that maintain the capabilities for adequate performance measurement.

Uniform implementation of the criteria will avoid imposing multiple cost and schedule systems on contractors. Application of management control systems acceptable to both the DOD and contractor to contracts at a given contractor's facility will provide a common source of information for all management levels. While C/SCSC is still used it has been overtaken by Earned Value Management or EVM practices.

13.10 Earned Value Management (EVM)

Earned Value Management (EVM) is a program management tool that integrates the technical, cost, and schedule parameters in order to measure contract performance against a baseline plan. EVM is an outgrowth of the work done with Program Evaluation and Review Technique (PERT) and C/SCSC modeling. EVM emerged in the 1980's as a project management control methodology. Then in 1989 the Undersecretary of Defense for Acquisition made EVM a program management requirement and was one of the few government business practices to survive the acquisition reform movement. Ownership of EVM criteria was transferred to industry in the late 90's with the adoption of ANSI/EIA-748 which addressed nine management practices. As such EVM is a cost measure, performance measure and a time measure.

Earned Value Management, or EVM, is a widely accepted industry best practice for project management that is being used across the DOD, the Federal government, and the commercial sector. It is the use of an integrated management system that coordinates the work scope, schedule, and cost goals of a program or contract, and objectively measures progress toward these goals. EVM is a tool used by program managers to:

- Quantify and measure program/contract performance;
- Provide an early warning system for deviation from a baseline;
- Mitigate risks associated with cost and schedule overruns; and
- Provide a means to forecast final cost and schedule outcomes.

EVM has not always been consistently applied or used to manage programs. When PMs use EVM in its proper context as a tool to integrate and control program performance, the underlying EVM system and processes become self-regulating and self-correcting. PMs should lead this effort. The success or failure of EVM and ultimately, the success of the program itself, depends heavily on whether the PM fully embraces EVM and uses it on a daily basis.

13.10.1 EVM and Earned Value

Earned Value can be defined as " *the value of work accomplished against the planned budget over a specified period of time.* "

The contractor's management control system must provide cost, schedule and performance data that:

- Relates time-phased budgets to specific contract tasks;
- Objectively measures work progress;
- Properly relates cost, schedule, and technical accomplishments;
- Allows for informed decision-making and corrective action;
- Is valid, timely, and able to be audited;
- Allows for statistical estimation of future costs;
- Supplies managers with status information at the appropriate level; and
- Is derived from the same management systems used by the contractor to manage the contract.

EVM improves visibility of project management by requiring that work progress be quantified through "earned value," an objective measure of how much work has been accomplished on the contract. EVM requires the contractor to plan, budget, and schedule authorized effort in time phased increments that form a performance measurement baseline (PMB). As work is accomplished, the earned value concept allows comparisons to be made against the plan which identifies schedule and cost variances. The development of a PMB requires the following to be accomplished:

Scope	1. Identify the scope of work 2. Extend scope to control accounts/work package level 3. Arrange the work packages in order
Schedule	4. Schedule the work packages 5. Classify the work 6. Budget the work packages
Budget	7. Spread the budget over time 8. Calculate the cumulative Budget Cost of Work Scheduled (BCWS) 9. Create the PMB

Table 13-2 Performance Measurement Baseline Development Steps

13.10.2 Work Breakdown Structure (WBS)

The task of defining the contract work or scope is accomplished through the use of a work breakdown structure (WBS) which is essentially a "family tree" subdivision of work to successively lower levels of detail. Table 13-3, extracted from MIL-STD-881A, Work Breakdown Structures for Defense Material Items defines three levels of identification. The

PMO, in conjunction with the contractor, determines the upper levels of this WBS, which serve as the summary level for reporting purpose.

Level 1 is the entire defense materiel item; for example, the Joint Strike Fighter system, the Aegis Cruiser system, and the Abrams Tank system.
Level 2 elements are major elements or subsystems of the defense materiel item.
Level 3 elements are subordinate to Level 2 elements.

Table 13-3 Work Breakdown Structure Level Identification

The contractor extends this structure to the cost account and work package levels (Figure 13-8). At that level, organizational elements are actually assigned to do the work. The work package must have discrete starting and completion points (schedule) which are compatible with upper level schedules. The work package must be the responsibility of a single organizational unit.

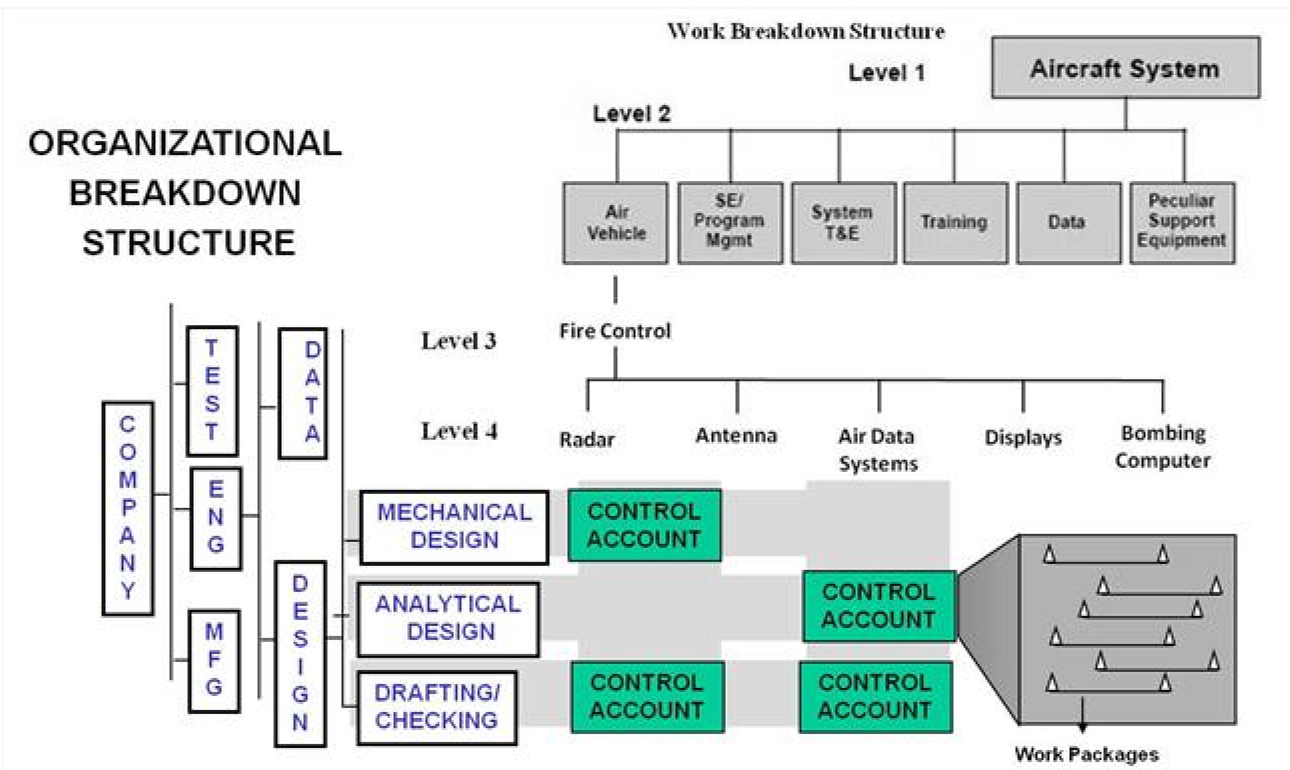


Figure 13-8 Work Breakdown Structure Extended to the Cost Account and Work Package Levels

13.10.3 EVM Process

The EVM process is comprised of the following seven steps:

1. Define the work,
2. Plan the work,
3. Execute the work plan,
4. Collect the performance results (data),
5. Measure performance,
6. Analyze deviations or variance, and
7. Take corrective action (if corrective action is required you need to return to step 2 and manage any changes through change or configuration control procedures).

An important step to understand is Step 6: Analyze Performance. Below are a couple of examples or ways to look at and analyze performance but in order to understand the charts you need to understand some of the EVM terminology used here:

- **BCWS** = Budgeted Cost of Work Scheduled = What you planned to do.
- **BCWP** = Budgeted Cost of Work Performed = What has been accomplished.
- **ACWP** = Actual Cost of Work performed = Actuals.
- **BAC** = Budget at Complete = Total budget (sum of time phased budgets).
- **ETC** = Estimate to Complete = Estimated cost to complete program from now on.
- **EAC** = Estimate at Complete = Projected final cost of program.

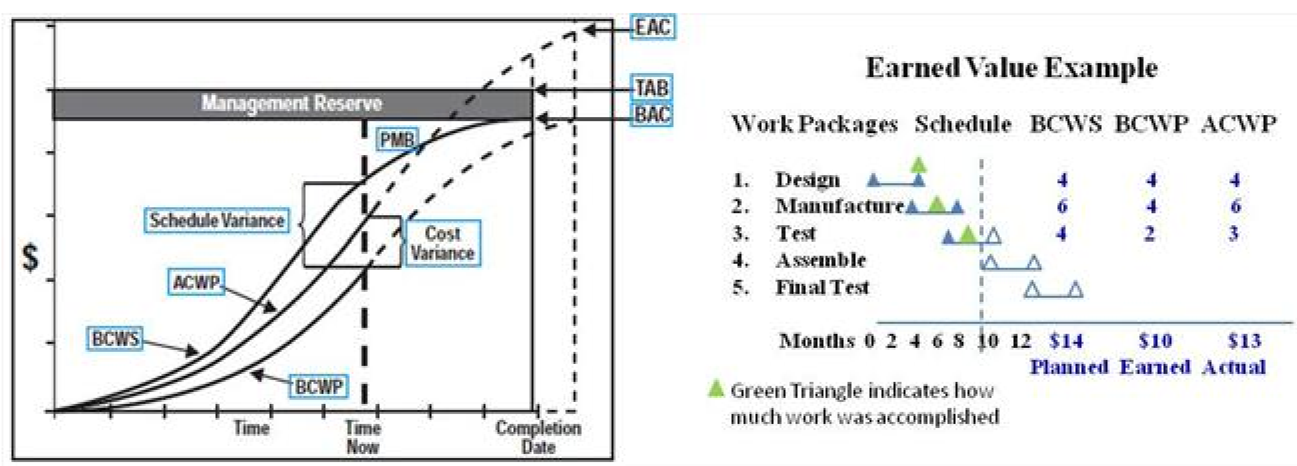


Figure 13-9 Earned Value Management (EVM) Examples

The schedule variance (SV), compares the budgeted value of work accomplished (earned value) to the budgeted value of the work scheduled to be done, i.e., a difference from the plan expressed in budget ($) terms. From the example above you can see that Test was supposed to be completed by the tenth month but as yet has not been completed, thus there is a schedule variance.

The cost variance (CV), compares the earned value against the actual costs generated to do the work, i.e., the amount of cost under or overrun from the plan for the work accomplished. From the example above, to date $14 of work was scheduled, $13 was spent, but only $10 was earned, leaving a negative cost variance.

Planned or scheduled value of work, earned value, and the actual cost of work performed provide an objective measure of performance, thus enabling a performance trend analysis to be done and cost estimates at completion to be developed at various levels of the contract.

EVM provides a static, high-level view of a programs performance based on historical information. Thus the current condition may be better or worse than what the data is showing. Contractors and program managers need to be intimately familiar with all aspects of their program in order to understand current performance.

13.10.4 DOD Policy

The new DOD policy requires EVM on:

Cost/incentive contracts equal to or over $50 million:

- Compliance with ANSI/EIA-748,
- EVM system formally validated and accepted by cognizant contracting officer,
- Contract Performance Report (DI-MGMT-81466A),
- Integrated Master Schedule (DI-MGMT-81650),
- Integrated Baseline Reviews,
- CWBS (DI-MGMT-81334B), and
- CFSR (DI-MGMT-81468).

Cost/incentive contracts equal to or over $50 million:

- Compliance with ANSI/EIA-748,
- No formal EVM system validation
- Contract Performance Report (DI-MGMT-81466A) (tailoring recommended),
- Integrated Master Schedule (DI-MGMT-81650) (tailoring recommended),
- Integrated Baseline Reviews,
- CWBS (DI-MGMT-81334B), and
- CFSR (DI-MGMT-81468).

Cost/incentive contracts under $20 million:

- EVM optional based on risk assessment,
- Requires cost-benefit analysis, and
- Requires program manager approval.

Firm-fixed price contracts:

- EVM discouraged regardless of dollar value,
- Requires business case analysis, and
- Requires milestone decision authority approval.

13.11 Line of Balance

Line of Balance (LOB) is a production control technique which combines features from a critical path scheduling time chart with a required delivery schedule, and presents in graphic form information relating to time and accomplishment of production. It shows the delivery objective, sequence and duration of all activities required to produce a product, a progress chart of the current status of production items, and, from these charts, an LOB to show the relationship of actual component production to schedule.

LOB is most appropriate for assembly operations involving a number of discrete components and has proven most useful in production programs from the point when raw materials or incoming parts arrive, to the shipment of the end product.

Without a computer controlled production process, Line of Balance does not lend itself readily to day-by-day updating, but a weekly or monthly check is usually frequent enough to keep the process on schedule. If the project falls behind schedule, management will know it, and know why, far enough in advance to make smooth adjustments.

Reporting to customers or top management is quick, inexpensive and graphic. The charts used for analysis and troubleshooting are suitable for at-a-glance status reporting. A set of clear, simple charts is easier to understand than a list of facts and figures, and charts are faster and more reliable than oral reports.

A Line of Balance study has four elements:

1. The objectives of the program (Objective Chart);
2. The production plan, and a schedule for achieving it;
3. The current program status; and
4. A comparison between where the program is and when it's supposed to be.

The first step in using LOB is to gather and organize the needed material for the three charts which comprise an LOB report. Once this is done you can "strike the line of balance" whenever necessary to keep track of the program.

13.11.1 Objective Chart

The objective chart is designed to display planned and actual deliveries in cumulative and items per unit of time. In Figure 13-10, for example, the delivery schedule calls for three items in December, five in January, seven more in February and five each month thereafter through June. The delivery schedule should realistically reflect attainable production capability taking into account learning associated with a new product (if this is an initial production activity) anticipated methods improvements, or other factors expected to influence productivity.

The other curve on the Objective Chart shows actual delivery of parts. The horizontal difference shows how far actual deliveries lag behind scheduled deliveries in terms of time, the vertical difference shows the variance, in numbers of units, from schedule.

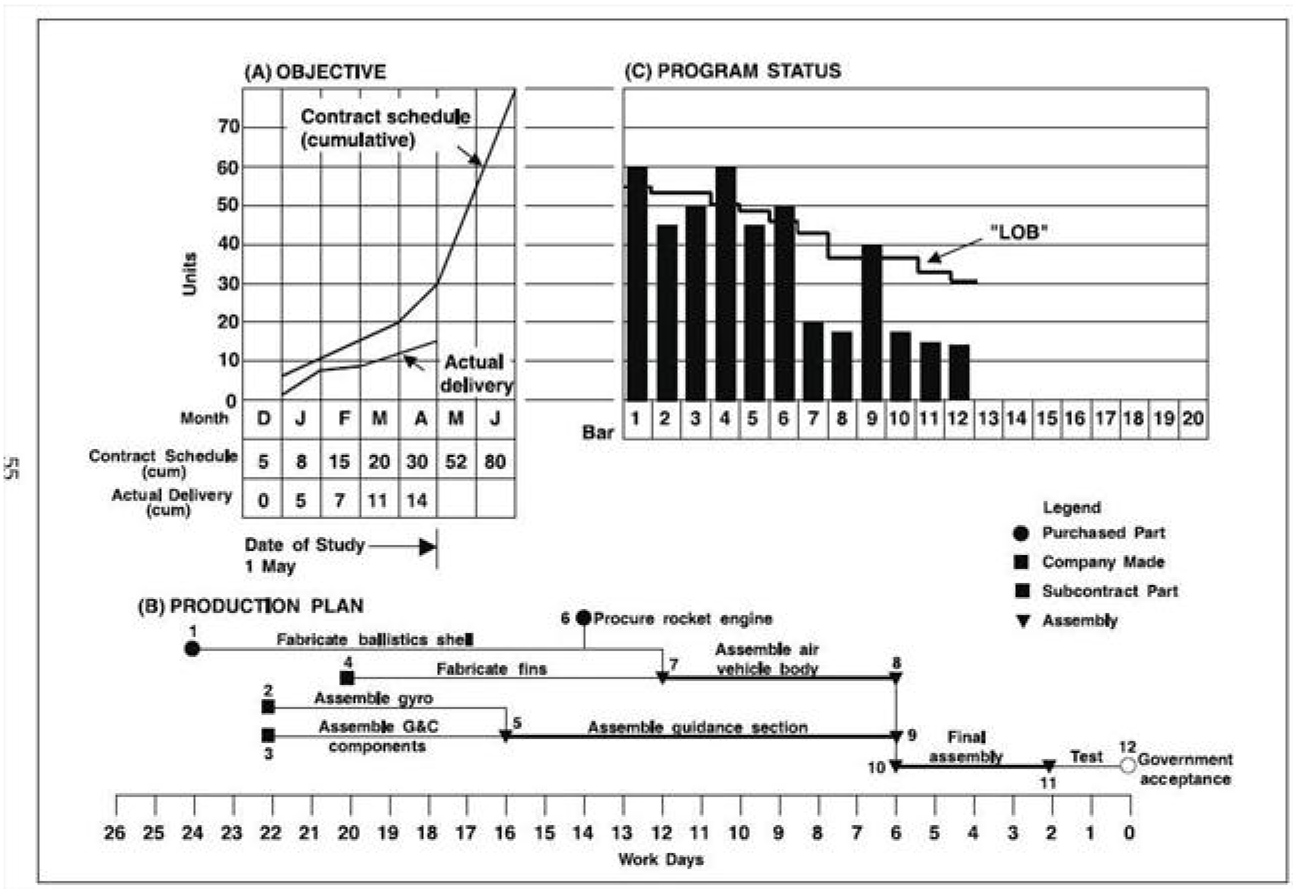


Figure 13-10 Line of Balance Objectives Chart (A), Production Plan (B) and Program Status (C)

13.11.2 The Production Plan

Following the development of the objectives, the second step is to chart the planned process of production. The production plan is a graphic flow chart of the operations required to complete a unit. Selected production activities are plotted against the lead time required before shipment.

For example, Figure 13-10 illustrates the key plant operations in the manufacturing sequence of a rocket.

The production plan is developed by setting down the selected events and operations in their proper sequence, commencing at the point of delivery and moving backward through the entire production process. The control points are numbered from left to right and from top to bottom as shown in Figure 13-10. This will usually result in four or more general sequential phases as follows: the final assembly process, preceded by major subassembly work, proceeded by manufacture of parts, proceeded by acquisition and preparation of raw materials and purchased parts.

In Figure 13-10, the receipt of purchased parts identified as event 1 must start 24 working days in advance of final delivery for that unit. The gyro components must enter the production stream at control point 2 on day 22, as must the guidance and control components at control point 3 in order to assure start of the assembly at the guidance section (event 5) on day 16. If the required material or number of parts is not at each control point or any critical event in the production flow of a unit is not started on time (or completed on schedule), the delay is symptomatic of a problem which should be investigated; corrective action should be taken to forestall continuing delays and late deliveries.

13.11.3 The Program Status or Progress Chart

The progress chart, example shown in Figure 13-10, pertains to the status of actual performance and comprises a bar chart which shows the quantities of materials, parts, and subassemblies available at the control points at a given time. Production progress is depicted in terms of quantities of materials, parts and subassemblies which have passed through the individual check points or control points of the production plan, including those contained in end items already completed. This information is derived from production records or accumulated by a physical inventory for each control point.

13.11.4 Comparison of Program Progress to Objective

Development of the objective chart, the production plan, and program progress chart completes the accumulation of physical information. There remains the task of relating the facts already gathered. This is accomplished by striking a "Line of Balance, (LOB)" which is the basis to be used for comparing the program progress to the objective.

The balance line quantity depicts the quantities of end item sets for each control point which must be available as of the date of the study to support the delivery schedule. In different words, it specifies the quantities of end item sets for each control point which must be available in order for progress on the program to remain in phase with the objective. Figure 13-10 is illustrative of the procedure for striking the LOB.

The balance line quantity depicts the quantities of end item sets for each control point which must be available at the end of the reporting period to support the delivery schedule. The required quantities are then compared with the actual completions by control point. Where the actual completions are less than the required quantity, this would indicate that there is a strong probability that deliveries will not be met at some future point. The timing of the potential delivery shortfall can be determined from the lead time data displayed in the LOB. If the behind schedule control point is 20 weeks flow time prior to final delivery, we would expect to see the impact in 20 weeks if corrective action is not taken.

Two final points should be noted. While the LOB technique offers insight into future delivery problems, the technique shows only where the problem is and does not characterize its nature. It is necessary for contractor or government management action to be taken to identify the causes end initiate appropriate corrective action. The second point deals with manner of presentation of the output products of the technique. For expository purposes we have emphasized the graphic mode utilizing charts. For large acquisitions it is often more appropriate to have the data provided in tabular form (particularly when the contractor utilizes computer analysis for preparation of the data). The key is to find the most cost-effective manner of portraying information for management action.

13.12 Maturity Measures

Since the original Manufacturing Guide was written several new tools have been developed that can be used to measure program progress. These tools tend to focus on measuring maturing in a specific technical area and include the following:

- Technology Maturity Levels (TRLs),
- Manufacturing Readiness Levels (MRLs), and
- Sustainment Maturity Levels (SMLS).

13.12.1 Technology Maturity Levels

TRLs provide a systematic metric/measurement system to assess the maturity of a particular technology. TRLs enable a consistent comparison of maturity between different types of technologies. TRLs have been divided into nine (9) maturity levels as follows:

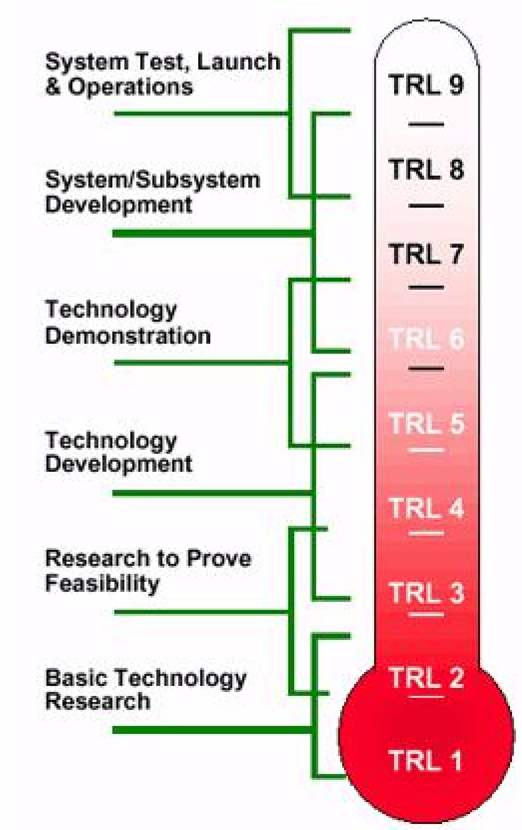


Figure 13-11 Technology Readiness Levels

- TRL 1: Basic Principles observed and noted.
- TRL 2: Technology concept or application formulated.
- TRL 3: Experimental and analytical critical function and characteristic proof of concept.
- TRL 4: Component or breadboard validation in a laboratory environment.
- TRL 5: Component or breadboard validation in a relevant environment.
- TRL 6: System or subsystem model or prototype demonstrated in a relevant environment.
- TRL 7: System prototype demonstration in an operational environment.
- TRL 8: Actual system completed and "flight qualified" through test and demonstration.
- TRL 9: Actual system "flight proven" through successful mission operations.

13.12.2 Manufacturing Readiness Levels

Manufacturing Readiness Levels (MRLs) and assessments of manufacturing readiness have been designed to manage manufacturing risk in acquisition while increasing the ability of the S&T projects to transition new technology to weapon system applications. MRL definitions create a common language and standard for assessing and discussing manufacturing maturity, risk and readiness. Using the MRL definitions, an assessment of manufacturing readiness is a structured evaluation of a technology, component, manufacturing process, weapon system or subsystem. It is performed to:

- Define current level of manufacturing maturity;

- Identify maturity shortfalls and associated costs and risks; and
- Provide the basis for manufacturing maturation and risk management.

There are ten (10) MRLs that are correlated to the nine TRLs currently in use. The final level (MRL 10) is used to measure and foster Lean practices and continuous improvement for systems in production. The MRLs are defined as follows:

- MRL 1: Basic manufacturing implications identified.
- MRL 2: Manufacturing concepts identified.
- MRL 3: Manufacturing proof of concept developed.
- MRL 4: Capability to produce the technology in a laboratory environment.
- MRL 5: Capability to produce prototype components in a production relevant environment.
- MRL 6: Capability to produce a prototype system or subsystem in a production relevant environment.
- MRL 7: Capability to produce systems, or subsystems, or components in a production representative environment.
- MRL 8: Pilot line capability demonstrated; ready to begin low rate initial production.
- MRL 9: Low rate production demonstrated; capability in place to begin full rate production.
- MRL 10: Full rate production demonstrated and lean production practices in place.

Figure 13-12 Manufacturing Readiness Levels

13.12.3 Sustainment Maturity Levels

The Sustainment Maturity Level (SML) model can be used by the Product Support Manager (PSM) to assess and identify the appropriate level of logistics maturity of the program. The SMLs provide a uniform metric to measure and communicate the expected life cycle sustainment maturity as well as provide the basis for root cause analysis when risks are identified and support OSD's governance responsibilities during MDAP program reviews. There are twelve (12) SMLs as follows:

- SML 1: Supportability and sustainment options identified.
- SML 2: Notional product support and maintenance concept identified.
- SML 3: Notional product support, sustainment and supportability requirements defined and documented to support the notional concept.
- SML 4: Supportability objectives and KPP/KSA requirements defined. New or better technology required for system or supply chain identified.
- SML 5: Supportability design features required to achieve KPP/KSA incorporated in design requirements.

- SML 6: Maintenance concepts and sustainment strategy complete. Life cycle sustainment plan approved.
- SML 7: Supportability features embedded in design. Supportability and subsystem maintenance task analysis complete.
- SML 8: Product support capabilities demonstrated and supply chain management approach validated.
- SML 9: Product support package demonstrated in an operational environment.
- SML 10: Initial product support package fielded at operational sites. Performance measured against availability, reliability and cost metrics.
- SML 11: Sustainment performance measured against operational needs. Product support improved through continual process improvement.
- SML 12: Product support package fully in place including depot repair capability.

13.13 Summary

Throughout this guide, the manufacturing management functions are discussed within the context of the defense systems acquisition process. This chapter concentrates on the manufacturing controls necessary to ensure that manufacturing operations are properly managed and problems do not disrupt the acquisition program. These controls include:

- Performance Evaluation,
- Configuration Management,
- Measures of Contractor Effectiveness,
- Work Measurement,
- Cost/Schedule Control System Criteria (C/SCSC),
- Line of Balance, and
- Earned Value Management.

13.14 Related Links and Resources

Numerous reference documents impact the manufacturing management function throughout the acquisition process. These documents originate from many sources and range across academic disciplines, functional activities, and job specialties.

The following is a reference list of DOD Directives (D), Instructions (I) Manuals (M), Pamphlets (P), Military Standards (MS), and other documents. The documents listed contain DOD policy guidance applicable to the manufacturing management function. They are listed as sources of DOD manufacturing management information.

Note: Many of the documents listed are no longer required (due to acquisition reform), but still contain some very valuable information.

Number	Title
Mil-Std-1567A	Work Measurement
	Cost/Schedule Control System Criteria (C/SCSC)
	Earned Value Management

	Line of Balance Technology Readiness Level (TRL) Guidance Manufacturing Readiness Level (MRL) Deskbook Sustainment Maturity Levels (SML)

Defense Manufacturing Management Guide for Program Managers
Chapter 14 - Factory of the Future

14.1 Objective

Production planning is driven by the existing and expected near term (less than 5 years out) factory capabilities. However, improvements in factory capabilities based on advanced technologies and manufacturing practices may require a change in the planning and expected results of production. This is especially true for those programs in the early phases of acquisition and for those programs with a potential for long term production contracts. This chapter describes the environment and major influences operating to change the nature and role of the factory floor and the numerous interconnected activities and organizations that will be used to produce our future weapon systems. The primary areas of change in the factory of the future are described and a brief summary of the current status is discussed to include:

- Trends in technology;
- Emerging changes to the factory floor and the 5Ms (machines, materials, methods, measurements, and manpower);
- Digital engineering and the integration of design and manufacturing; and
- The integrated supply chain.

14.2 Background

Charlie Chaplin played an ordinary man struggling to survive in a depressed economy and an emerging industrialized world in the movie "Modern Times." In one classic scene Charlie's character, the Little Tramp, is seen being fed through massive gears on an assembly line. Today's manufacturing managers might feel in some ways like the Little Tramp as they get caught up in technological change and factory modernization that comes at them at an increasingly faster pace. Increased globalization, modernization and technology are all driving forces in forcing companies to become more:

- Efficient, productive and affordable;
- Reliable, with higher quality;
- Sustainable, using less resources and energy;
- Flexible, agile and able to mass customize;
- Quicker to market, reducing development time;
- Linked in and collaborating with colleagues across the globe.

14.3 Introduction

Figure 14-1 Gorks Digital Factory

The transition from hand crafted products to mechanized assembly line was seen as a significant accomplishment in the early 1900's and later during World War II was instrumental in our being able to field the weapon systems we needed in order to win wars on two fronts. Since then improvements in machines have contributed to higher precision, better quality, faster processing times, and lower cost. Improvements in technology have continued to play a major role in advancing the productivity of our industrial economy. But nowhere has "modernization" had a more dramatic impact then on emerging computer technology as applied to industrial equipment. For example, in the 1980's mechanical tool control devices, such as special cams for automatic lathes, were replaced by direct numerical controls which eliminated the need for a special set of cams for each new part configuration. This innovation not only eliminated a costly tool component but drastically reduced set-up time for each new part. While maintaining the same capability to accurately reproduce many parts, greater freedom for part variation was provided. With machine control centered in a computer program, a relatively minor computer program change is needed to affect a change in part configuration compared to two to three hours previously required to change cams. But that was in the 1980's and the change from cams to numerical controls took many years. Today's improvements are coming at us at an ever increasing pace.

The National Institute of Standards and Technology (NIST) is focusing on manufacturing technology improvements under the Advanced Manufacturing Partnership (AMP) with efforts in the following areas:

- Robotics: NIST is supporting the National Robotics Initiative through the development and deployment of measurement science to increase the versatility, autonomy, and rapid re-tasking of intelligent robots and automation technologies to improve the utilization of robotics in manufacturing. The program addresses major barriers including perception, manipulation, intelligent planning, and safety. Robots that can collaborate with humans and readily handle a wider variety of tasks at lower cost will give all U.S. manufacturers large and small an edge in quality and responsiveness to their customers.

- Nanomanufacturing: NIST is working with partners in academia and industry to develop the measurement tools and instrumentation needed to enable cost-effective in-line measurement techniques for closed-loop process control, required for large-scale production of nanomaterials and devices.
- Advanced Materials Design: As part of the Materials Genome Initiative, NIST is working with partners across the government to develop:
    - computational and validated materials databases, data assessment tools, techniques and standards;
    - reference materials models and simulations;
    - mechanisms for exchange of materials information and best practices;
    - consortia to determine consensus standards for materials data interchange; and
    - teams built through a Center of Excellence for identifying the critical barriers that can be technically overcome to achieve Integrated Computational Materials Engineering.

14.4 Trends in Technology

Thousands of years ago producing things was easy. Craftsmen handed down their secrets to production (methods) by word of mouth. The classroom was the shop floor; the technology was simple hand tools. The materials were what was found in nature, close to where people lived and worked. Measurement was only an approximation for thousands of years until measurement systems began to appear around 3000 B.C. Not much progress was made to many of the 5Ms until the late 1700's when Eli Whitney brought about the system of interchangeable parts laying the groundwork for mass production. Henry Ford of course has been held largely responsible for developing mass production techniques and paving the way for the moving assembly line. By this time workers moved away from the skills required of the craftsman and learned only how to do one or two tasks. The work process and flow (method) became the responsibility of industrial engineers. Materials now came from suppliers, building to spec and shipping parts and materials often from sites a long distance from final assembly. Tools became expensive and difficult to change, and hand tools and measurement systems were taken away from the worker and placed in controlled environments until needed. Automation on the shop floor actually began in the 1950's when tools were fitted with motors that were controlled by punched tapes. The Air Force got involved in the development of numerical controlled machines, along with the Massachusetts Institute of Technology and the Aerospace Industries Association (AIA) to develop a fully capable computer numerically controlled (CNC) machine in the late 1950's. Lean/Six Sigma, while not a technology, was one of the more significant productivity enablers that dramatically changed the factory floor environment. Getting shop floor, front office, back office, suppliers and others all engaged in continuous process improvement. The pace of change is picking up in part due to Moore's Law (the number of transistors on an integrated circuit will double every two years) as his law has been used to explain the doubling of knowledge and computer processing speeds.

The factory of the future (Figure 14-2) is a strange and brave new world. It is a connected world that comes with its own language as people "move (their applications) to the cloud." This section will discuss several emerging technology trends from 2012. Because technology is perhaps the fastest changing area in manufacturing management, it is an area that manufacturing managers need stay abreast of on their own. Below are some trends that impact the factory of the future:

- Industrial/Cyber Security
- Smart/Sustainable Buildings
- Mobile/Connected Workforce
- Wired/Wireless and the Cloud
- Integrated and Traceable Supply Chains
- Integrated Plant Safety
- Machine Vision and Artificial Intelligence
- Predictive Analytics and Self-Learning Machines

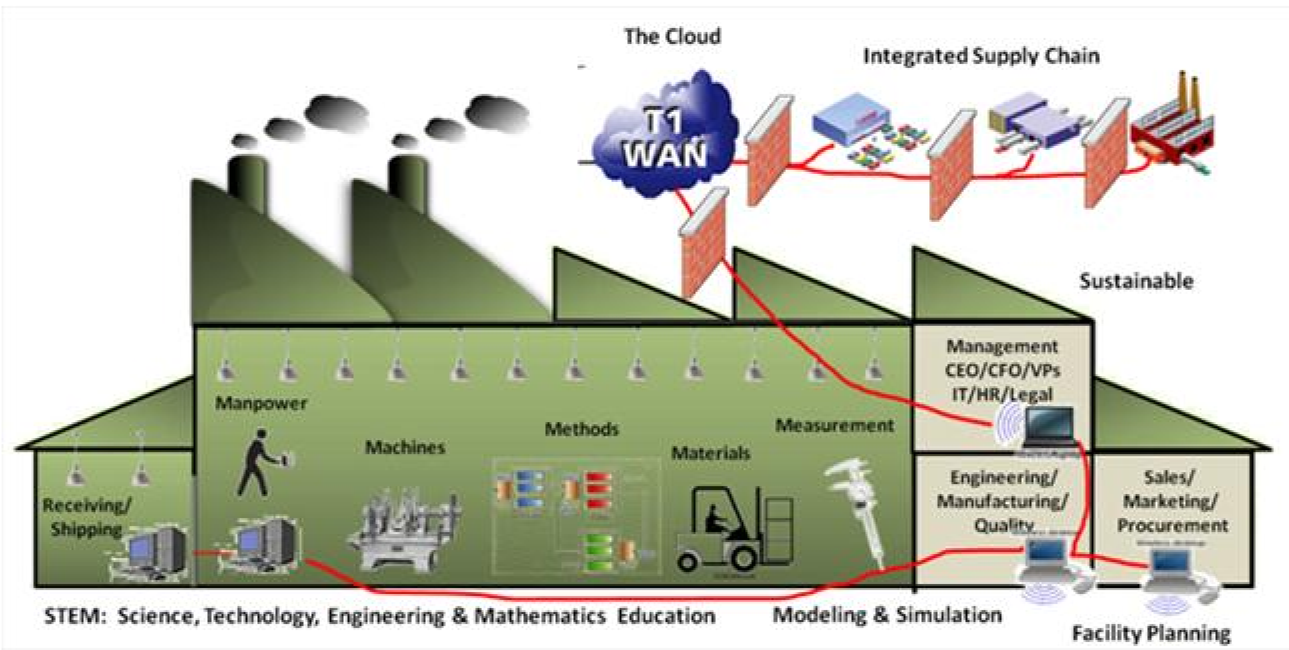


Figure 14-2 The Factory of the Future

14.4.1 Industrial/Cyber Security

The 2011 DOD Cyber Crime Conference featured many speakers addressing the growing threat of cyber crime as it affects the Department of Defense, other federal Agencies and DOD related businesses that provide us with our weapon systems. The conference noted that the growth in the internet, social media, wired and wireless communications, and cloud computing all are being used to exploit vulnerabilities in our systems. The cyber threat can be in the form of a disruption or denial of services, theft of classified, business sensitive information or intellectual property, and in some cases the sharing of this information on a global scale (e.g. Wiki Leaks). Cyber threats have a great potential for becoming a significant component of future military conflicts as today more than thirty nations have created their own military cyber units.

According to a 2010 FBI report, the U.S. is the number one target for cyber crime. Therefore it is no surprise that there has been a big push in the market for cyber security related products and services. Most DOD activities and businesses leaders are opting for a multi-layered defense to ensuring the security of information and that the security is being deployed along the entire communication chain. In response to the growing threat, the 2011 DOD Strategy for Operating in Cyberspace includes five strategic initiatives:

1. Organize, train, and equip so that DoD can take full advantage of cyberspace's potential;

2. Employ new defense operating concepts to protect DoD networks and systems;

3. Partner with other U.S. government departments and agencies and the private sector to enable a whole-of-government cyber security strategy;

4. Build robust relationships with U.S. allies and international partners to strengthen collective cyber security; and

5. Leverage the nation's ingenuity through an exceptional cyber workforce and rapid technological innovation.

14.4.2 Smart/Sustainable Buildings

The DOD is the nation's single largest landlord and energy consumer, operating more than 300,000 facilities and approximately one-fourth of these buildings do not meet Executive Order 13514s mandate for sustainable buildings. Historically, approximately $30 billion is spent annually on acquiring or renovating Federal facilities, and about $7 billion is spent on energy for Federal facilities. This footprint represents an enormous opportunity to transfer sustainable technologies and practices on a large scale, thereby helping to transform the marketplace and create a more healthy work environment.

High performance and sustainable buildings integrate advanced materials, environmental and diagnostic sensors, and energy management technologies to measure, monitor, and control building functions. This approach enables facility managers to make informed and strategic decisions about facility operations, indoor environmental quality and comfort, physical security, fire prevention and detection, electric and mechanical fault detection, moisture penetration, and communications. High performance and sustainable buildings are achieved by pursuing Leadership in Energy and Environmental Design (LEED) Green Building standards and certification. LEED has a rating system with a series of metrics that can be applied to all building types. The LEED system rates building construction in five categories:

- Sustainable Sites: Discourages development on undeveloped land; seeks to minimize a building's impact on ecosystems and waterways; encourages regionally appropriate landscaping; rewards smart transportation choices; controls stormwater runoff; and promotes reduction of erosion, light pollution, heat island effect and construction-related pollution.
- Water Efficiency: Encourages smarter use of water. Water reduction is typically achieved through more efficient appliances, fixtures and fittings inside and water-conscious landscaping outside.

- Energy and Atmosphere: Encourages energy-wise strategies: commissioning; energy use monitoring; efficient design and construction; efficient appliances, systems and lighting; the use of renewable and clean sources of energy, generated on-site or off-site; and other innovative measures.
- Materials and Resources: Encourages energy-wise strategies: commissioning; energy use monitoring; efficient design and construction; efficient appliances, systems and lighting; the use of renewable and clean sources of energy, generated on-site or off-site; and other innovative measures.
- Indoor Environmental Quality: Promotes strategies that improve indoor air as well as those that provide access to natural daylight and views and improve acoustics.

14.4.3 Mobile/Connected Workforce

Figure 14-3 Global Connectivity

Today's workforce, Generation "Y," is a highly mobile and connected workforce. And they are rapidly replacing the baby boomers of the 60's as they approach retirement age. And according to many researchers, they come to work with a new attitude. They are often the early adapters, embracing change, new technologies, and in love with social media sites. They tend to stay connected from the time they awake in the morning until the time they go to bed at night. They connect internally at work and externally with a global network of friends, co-workers and other collaborators that they may only know in a virtual world. Knowledge is power and they know how to access and leverage this power.

The Defense Acquisition University (DAU) is one of the world's leaders in knowledge management and knowledge sharing. DAU provides a far reaching community tools for sharing knowledge and for collaborating in space, in real time. Collaboration is an opportunity to share knowledge, solve problems, engage with customers, partners and suppliers, and for serving customers and communities. Today's knowledge workers know how to tap into the resources of the internet and the millions of people and organizations connected to it.

Technology companies are increasingly aware of how knowledge workers collaborate and connect and are constantly developing and offering new features and functions on the technologies that they provide. Today's technologies for collaboration include smart phones, iPods and tablets of all sorts, laptops, webcams, live web links and seminars, etc. But who knows what tomorrow's technologies will bring. We can envision that the new technologies with provide more diagnostics and service functions to aid trouble-shooting. In addition, social media is growing rapidly as a source of knowledge. People are connected by Facebook, LinkedIn, MySpace, Twitter, blogs and other media and are sharing information across organizational and corporate boundaries. In addition, many of these social media sites have sites within the sites for specific subgroups. For example, within LinkedIn there is a subgroup for people with an interest in Aerospace, or in manufacturing.

14.4.4 Wired, Wireless and the Cloud

Today's technologies, either in the office or at home, can be wired, wireless or both. Traditionally, many companies and organizations, to include the DOD, tend to use a wired infrastructure due to the security and reliability advantages over wireless solutions. However, there have been many advances in wireless networking. The development of wireless standards along with improved technology and security has allowed companies and organizations to adopt wireless technologies.

One of the newest advances in information sharing is the hosting of services over the internet or Cloud computing. The term comes from the use of the cloud as a symbol to represent the Internet on flowcharts and other diagrams. One of the features of the cloud over traditional hardware solutions is that the cloud is "elastic," that is it is flexible or scalable depending on needs at any given time. This capability is driving data, functions and services to the cloud.

The cloud can be either public, private or a combination of the two. A public cloud is open to anyone and everyone that has access to the internet. Thus sites like DAU's Communities of Practice (CoPs) are open to the public. A private site is, as the name implies, closed to the public and is available only to a select group of individuals. Most corporate sites and government sites have a private and a public sector. The private side is accessible only by people with rights to that data.

The cloud can offer manufacturing productivity tools that were previously unaffordable or impractical for SMEs. Manufacturing Operations Management (MOM) software provides for real-time data about a number of factory operations (labor and materials, job and shop orders, inventory, and shipment information). Many of the traditional manufacturing computing solutions of the past (supply chain management, enterprise resource planning, manufacturing resource planning, customer relationship management, etc.) are migrating to the cloud.

Today's factory environment has virtually everything connected to everything else using either wired or wireless. Computer programs based on standard computer/network architectures are spreading into all corners of the factory floor. Today, many companies are adopting manufacturing execution systems (MES) as a standard set of integrated information technologies. These emerging MES programs can be used to:

- Manage product definitions;
- Manage product recipes;

- Manage scheduling functions;
- Execute production orders and functions;
- Collect production and quality data; and
- Perform production analysis.

14.4.5 Integrated and Traceable Supply Chains

Supply chains exist in all sorts of organizations to include manufacturing, service, operational, and acquisition organizations to name a few. In all of these organizations, the supply chain exists to ensure the flow of products and/or information between members of the supply chain. This requires that the supply chain be integrated and information driven in order to enable cost efficiencies and satisfy customer demands. Customer's today demand that they know where their product is at all times. One pizza chain recently added a feature to their website where customers can track their pizza from the time it is ordered to the time of delivery and will even tell who at that particular store is making the pie.

Recent innovations in technologies have made global track and trace a real capability. Many companies have basic track and trace capabilities through their ERP and EDI systems. But when a crisis hits the information system fails to keep up. For example, when Japan experienced the earthquake and tsunami in 2011 many firms connected to the Toyota supply chain lost connectivity and lost the ability to respond to changing needs. Likewise, when U.S. Army troops outpaced their supply chains as they entered Bagdad they had to resort to capturing supplies (explosives, lubricants, etc.) from enemy stores and warehouses in order to keep the war machine functioning.

The supply chain of the future will be connected, secure and integrated. According to a 2011 Logistics CIO report, supply chain managers are looking for technology solutions that will improve:

- Transportation management;
- Mobile technologies;
- Business intelligence;
- Customer relationship management;
- Electronic data interchange (EDI); and
- Track and trace capabilities.

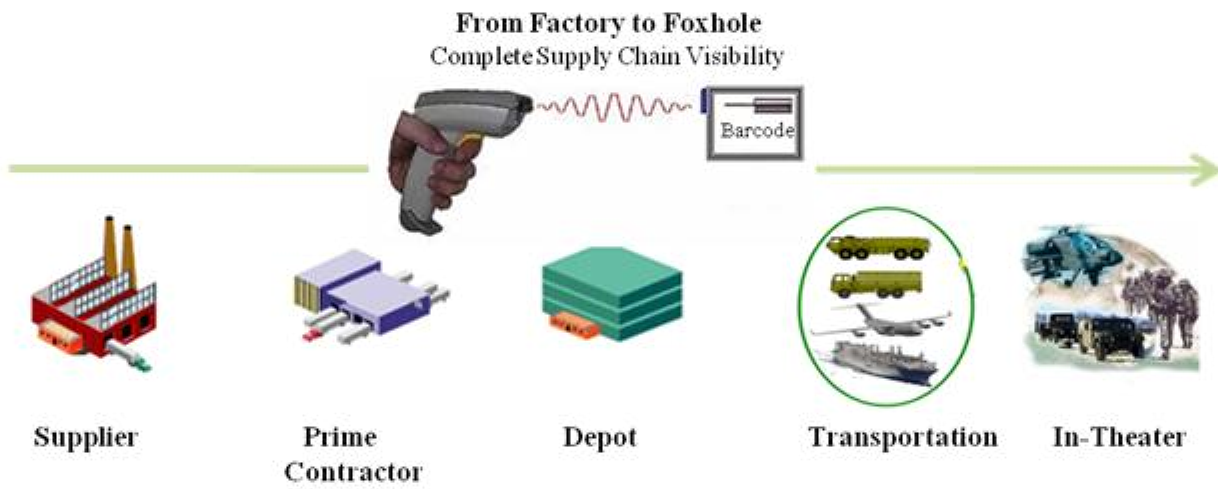


Figure 14-4 From Factory to Foxhole

14.4.6 Integrated Plant Safety and Control

Many manufacturing industries operate their plants with known risks. For example, chemical plants may be taking raw materials and converting them into chemicals for use in other industries. These materials and the end chemicals may be toxic or reactive and require safety protocols. Safety instrumented systems (SIS) are automation and control systems found in plants having hazardous processes and materials which need to be controlled and protected, and can be safely shut down in case of any accidents or incidents. These systems protect people, assets and the environment, and in case of unwanted deviations, failures of the main process control system or equipment, and any other undesirable and unplanned events.

Integrated plant safety and control is a subset of "smart buildings." Global safety standards are changing and manufacturers need to integrate their safety system and plant automation systems if they are to comply. In addition safety is a unique animal in that the only news is bad news. That is, no one hears any news about good safety metrics, but everyone hears and reads about safety disasters. One of the aspects of safety is to maintain a good image with employees, customers, and the local community. This effort will require manufacturers to adopt emerging technologies related to plant safety and control and to adopt a layered approach to safety and plant control. However, plant safety should not be at the expense of productivity. Open protocols can be used to improve the integration and interoperability between facility and safety control systems and often result in increased safety and control and reduced cost, a true win-win. Integration provides manufacturers with better visibility into problems and risks, and their ability to more manage the large amounts of complex safety and control data.

14.4.7 Machine Vision and Artificial Intelligence

Machine vision is the ability to automatically inspect and control a manufacturing process using advanced technologies and methods that rely in part on imaging capabilities. These capabilities often come in the form of a camera, processor and software. These technologies can be used to support a number of manufacturing processes:

- Template matching (recognizing patterns);
- Edge detection (locating the edge of objects);
- Gauging (measuring object dimensions); and
- Bar code recognition (reading bar codes).

The most common output from machine vision systems is a quality decision (go/no go, pass/fail, accept/reject) that is accomplished without contacting the product. However these systems can also be used for pattern recognition, object recognition, object tracking, and human gesture recognition. For example, the pick-and-place machine used to mount components on a printed circuit board is an example of a machine vision system.

Today's machine vision systems can identify and track objects in 3D and advances in sensors and computing power allow these machines to operate faster and with more accuracy. These newer vision systems can better distinguish between objects and have expanded their capabilities to track gestures, body motion, and even facial recognition.

Artificial intelligence (AI) has a growing roll in assisting manufacturing managers become more productive. Toyota for example is using AI to model material flow throughout their manufacturing operations via their Manufacturing Execution System (MES). In one application, Toyota has been able to generate more realistic production schedules which take into account variation inherent on the factory floor. AI frees managers from making the mundane and time consuming day-to-day decisions that can be accomplished by machines with built in rules and constraints. For example, artificial intelligence can be used to monitor and correct in-process quality characteristics that are going out of control. The AI can adjust the machine while work is in-progress and bring the characteristic back in control.

14.4.8 Predictive Analytics

Predictive analytics embodies the use of statistical techniques to study and analyze data (current and historical) for the purpose of making predictions about future behavior. This technique is quite often used in machine learning. Predictive analytics is being applied in several manufacturing areas like maintenance, sales forecasting and quality.

Predictive maintenance (PdM), sometimes called condition-based maintenance, is rapidly replacing time-based maintenance decisions. The goal of PdM is to identify and provide for an opportunity to perform maintenance activities at a time that is optimized, balancing costs against equipment or product loss. The predictive aspect of PdM comes from having the capability to accurately predict when a maintenance activity is required before any failures occur. The analysis of maintenance requirements may come from such sources as oil analysis, vibration analysis, acoustic analysis, and heat analysis (infrared) to name a few.

14.5 The Future of the 5Ms

This section of Chapter 14 will focus on one of the 5Ms (machines, materials, methods, measurements, and manpower) and emerging capabilities that may become standard practices in a few years.

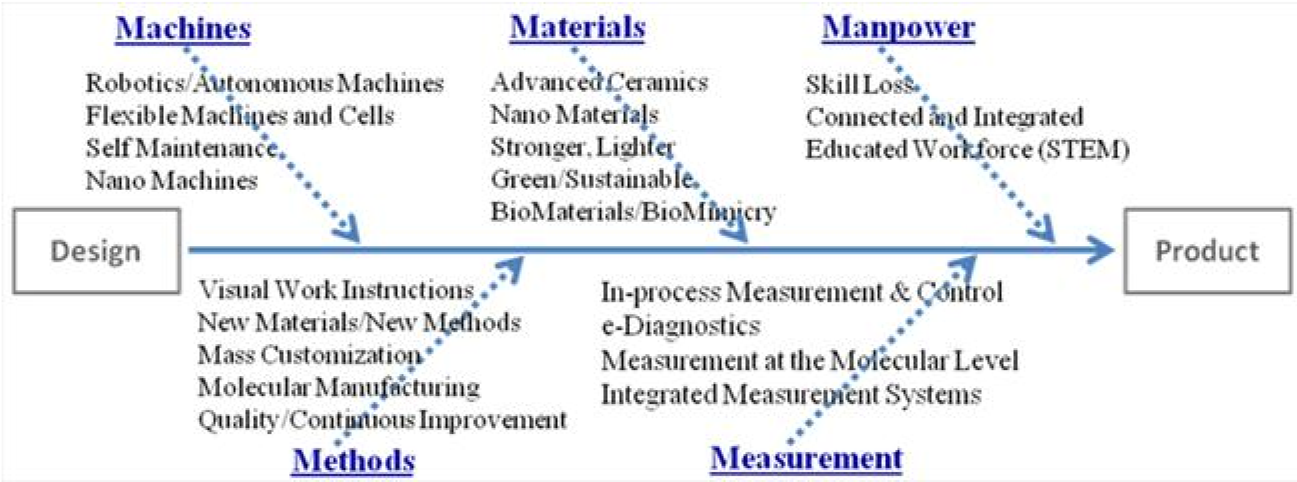


Figure 14-5 Emerging Capabilities and 5Ms

Production accounts for approximately 30% of an acquisition program's typical life cycle costs. This is often three times the cost of the development effort. A great deal of money is spent during a relatively short period of time. Each of these 5Ms contributes to the cost of the program and to its success. Future trends in these five areas can and will have a dramatic impact on current and future costs as programs plan for and prepare to execute their programs in the factories of the future.

14.5.1 The Future of Machines

The 1st Industrial Revolution, late 1700's, was fueled by a series of inventions that dramatically increased productivity and led in part to the building of large manufacturing facilities to take advantage of these innovations. Important inventions included:

- John Wilkinson invented the horizontal boring machine in 1775. This device allowed James Watt to invent the 1st reliable steam engine as it gave Watt the capability to bore closer tolerances in the cylinders.
- First reliable steam engine is credited to James Watt (1776) and was used to power other industrial machines. Steam engines could be used in place of water wheels and animal powered mills.
- The textile industry had several inventions that sparked the textile revolution to include the flying shuttle (John Kay in 1733), the Spinning Jenny (James Hargreaves in 1764), and the spinning mule (Samuel Crompton in 1779) all led to the establishment of large textile mills and all greatly improved different textile processes.

The inventions of the 1st and 2nd Industrial Revolutions allowed people to move from the craft and guild business structures to modern day factories with their moving assembly lines. Machines and improvements to machines will continue to play a significant role in forming the Factories of the Future. Innovations for the future may include:

- Robotics and autonomous machines;
- Flexible machines;
- Learning machines;
- Self-maintenance that goes beyond predictive maintenance; and
- Nano machines.

14.5.1.1 Robotics and Autonomous Machines

Figure 14-6 Robotic Arm

Actually robotics are not totally new, in fact the first robot to appearing on a shop floor was a die-casting application in an automotive facility. The International Standardization Organization (ISO) defines an industrial robot as "an automatically controlled, reprogrammable, multipurpose manipulator programmable in three or more axes." Most robots fall into the category of robotic arms (Figure 14-5). Robots are often used to perform routine and mundane operations that are:

- Dangerous for humans to perform;
- Repetitive tasks that are often difficult to perform;
- Tasks involving heavy lifting or work in confined spaces;
- High precision tasks; and
- Tasks that might be distasteful to humans.

Many of these industrial robots are large, heavy, capital intensive systems that are dependent on specialized components such as servos, sensors, actuators, and other components that enable the robot to complete its tasks. Some future robots will be:

- More integrated, not only to the enterprise as a whole but to humans,
- More flexible, able to handle more tasks, and more complex tasks,

- Smaller, with the ability to work on a micro scale,
- Less expensive, today's industrial robots are mass produced,
- More standardized, today six-axis industrial robots are the norm.

Future robots will have more integration of sensor systems and RFID-tagging to better manage and control processes. Future robots will be more autonomous and have the capability to work within a factory environment with lots of variables. For example, robots in the future will be able to work in a cell environment and be able to deal with several machines and processes at a time, be able to synchronize tasks and activities with humans and other robots. Finally, future robots will be learners. They will be able to learn by evaluating data it collects and develop new strategies for improving productivity. The future development of industrial robots will depend largely on improvements to sensors and intelligence.

14.5.1.2 Flexible Machines

A flexible factory is a factory that is organized to provide a wide range of production operations across many product lines and requires very little time or expense to change over from one product line to the next product line. Flexibility or agility is seen by many companies as a core business strategy. Ford, for example, wanted a "multi-activity vehicle" facility. A facility that would be able to produce vehicles with either electric or conventional powertrains, either large or small sedans, or using either electric, gas or hybrid engines. But flexibility is not free and Ford had to invest over $550 million in its Wayne, Michigan plant to upgrade the facility to make it more agile. Some of those investments were in laying out a flexible line and other investments went into flexible machines.

Flexible machines are machines that can process various production processes with ease. Flexible machines generally fall into one of several categories:

- Product flexibility: The machine has the ability to produce multiple product types and can change the order of manufacturing operations required to produce a product with relative ease.
- Routing flexibility: The machine has the ability to route product through different machines and processes but still get the same results.
- Volume flexibility: The machine has the ability to produce the same or existing part types at different volumes efficiently.

Manufacturing flexibility may be the answer for surviving future market changes as customers demand product now (short lead times), with high quality and reliability (tighter tolerances on key characteristics), lower costs, and continuous improvements in products and performance. Flexible manufacturing systems can help to achieve a balance between cost, schedule, and performance at the product level. Flexibility in the future will come about as a result of improvements in vision sensing systems, integration with other systems and machines, and with improvements in artificial intelligence.

14.5.1.3 Self-Maintenance (Beyond Predictive)

Much of today's industrial maintenance is either:

- Reactive (fixing equipment after it fails), or
- Proactive (fixing equipment on a regular schedule whether it needs it or not).

Predictive maintenance (PdM), sometimes called condition-based maintenance, is maintenance of equipment based on its condition or need. The condition or need is determined by the monitoring of that equipment for use or wear. The goal of predictive maintenance is to achieve lower costs through near-zero downtime performance. Achieving near-zero down time requires real-time assessment of a machine's performance using one of several nondestructive testing methods such as:

- Acoustic,
- Corona detection,
- Infrared,
- Oil analysis, and
- Vibration analysis.

Future machines need to be networked together, machine-to-machine (M2M), in order to increase the lifespan and reduce the cost of existing plant and equipment. This means going beyond predictive maintenance to "intelligent prognostics".

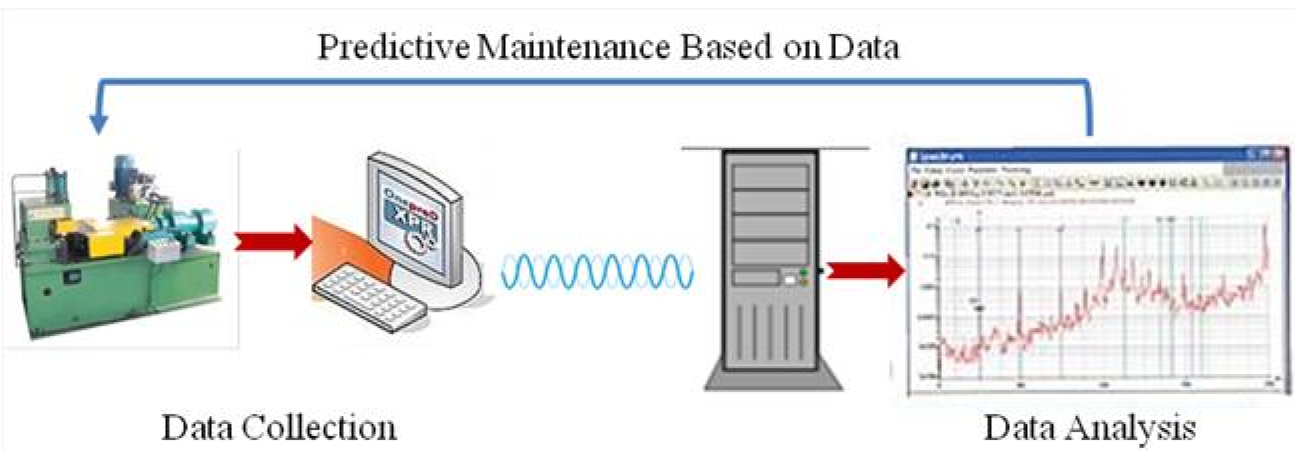


Figure 14-7 Predictive Maintenance

Intelligent prognostics is defined as a systematic approach that continuously monitors and tracks the health and degradation of a machine and then predicts the risks of an unacceptable event happening. The analysis can identify exactly which components of a machine are likely to fail and when. This insight into the future health of a machine or component will enable the move to e-maintenance based on the transparency of data.

14.5.2 The Future of Materials

During the Bronze Age and Iron Age "material science" focused on metals. Today, material science is focusing on many non-metal solutions. This trend reflects the need to increase performance, reduce weight and cost, and lower environmental impacts. However, new materials often pose new problems for manufacturers that must find new ways to shape, move, assemble, test and inspect products made from new materials. These new materials require advanced production knowledge if a company is to work on:

- Micro, or even nano scale,
- Multiple material combinations (sandwich structures, metal matrix, and other com posites),
- Smart materials involving integration of sensing and actuation technologies within a material, and
- Bio-inspired materials (biomimicry).

The Defense Advanced Research Projects Agency (DARPA and all of the Services and Agencies support advanced materials projects, often through Manufacturing Technology (ManTech) projects or SBIR/STTR projects. These programs seek to advance material science on many technology fronts. Programs range from developing physics- and chemistry-based models that allow for the design of novel materials that possess radically improved or new properties, to innovative processing methods that dramatically reduce the cost of producing new materials. Many of these projects focus on:

- Novel Materials and Material Processes
- Multifunctional Materials and Material Systems
- Biologically Inspired Materials
- Green and Sustainable Materials

14.5.2.1 Novel Materials and Material Processes

New materials are often needed to lower the weight and increase the performance of aircraft, ground vehicles, and spacecraft structures. These new materials include ceramics, composite materials, polymers, metal alloys and digital materials. The Army in response to IEDs and other terrorist weapons need materials that are lightweight, high strength and damage resistant (survivable). The Air Force is looking for faster and stealthier aircraft and need materials that will give them these properties. The Navy is looking to establish a littoral capability and need materials that can withstand these environments. Advanced materials to fill these requirements can be seen in the form of matrix composites, thermoplastics and thermoset materials, various sandwich structures, nanomaterials, etc.

14.5.2.2 Multifunctional Materials and Material Systems

As military systems and missions become more complicated, the materials that support those missions must be more dynamic (e.g. be heat resistance and structural loadbearing). In addition, these new materials are expected to yield improved capabilities across multiple military platforms. Current projects in this focus area include:

- Revolutionary new armor systems that exploit unique high-strength steel/polymer composite hybrid configurations for military vehicles;
- Self-healing materials that have the ability to repair damage caused by usage over time;
- An extremely small, ultra lightweight air vehicle system with the potential to perform indoor and outdoor military missions; and
- Barriers that can be rapidly emplaced and reversed to allow fluid U.S. force movement.

14.5.2.3 Bio-Based/Bio-Inspired Materials

Nature is exquisite designer of inorganic materials using biomolecules as templates. Diatoms create intricate silica wall structures with fine features using the protein family of silaffins as templates. Marine sponges create silica spicules also using proteins, termed silicateins. DOD is looking to nature to answer some of the mysteries of material science. This includes materials that may be bio-derived (bio-based) or bio-inspired. Bio-derived materials are engineered materials that are made from substances derived from living matter (e.g. rayon is made from wood pulp). Bio-inspired materials are engineered materials whose design was inspired by nature (e.g. Velcro takes its hook-and-loop fastening mechanism from the burr of the burdock plant). Some current technologies the DOD is pursuing include:

- Spider Web (thread strength),
- Slug mucous (adhesive),
- Abalone Shell (protective shell),
- Barnacle (adhesives),
- Lotus flower (waterproofing),
- Venus Flower basket (better fiber optic cables).

Velcro Burdock

Figure 14-8 Bio-based Designs

14.5.2.4 Green and Sustainable Materials

Numerous laws, Executive Orders, and international pressure are being put on material users to purchase green or sustainable materials. A good example of this pressure lies in the 1990 film "Erin Brockovich", in which a legal clerk leads a legal dispute against a large corporation for poisoning the water supply of a town by dumping hexavalent chromium. Since life often imitates art fast forward to 2009 when the DOD issued a memo requiring DOD to reduce the military's use of hexavalent chromium after facing its own environmental liabilities.

There is a difference between being "green" and being "sustainable."

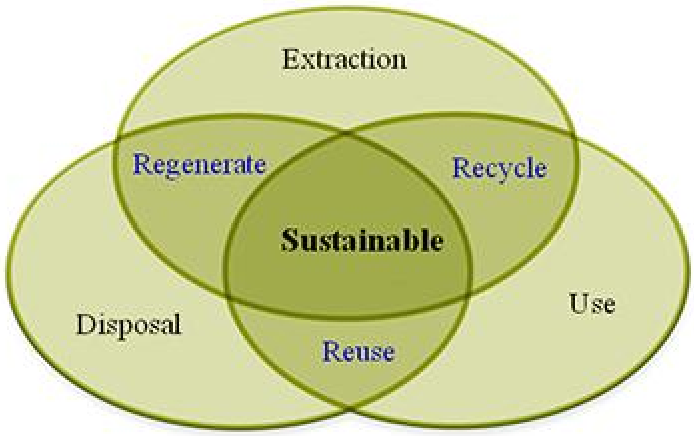


Figure 14-9 Spheres of Sustainable

Green products, sometimes called environmentally preferred products, are "products or services that have a lesser or reduced effect on human health and the environment when compared with competing products or services that serve the same purpose."

Sustainable products are "products that reduce environmental impacts by using source materials that are either renewable or can be sustainably harvested." Sustainably harvested means that the source material is gathered in a way that does not harm the surrounding area, pollute the air, water or ground, or permanently deplete the supply or source of that material.

Many new green or sustainable materials and products are being introduced each year. Each of these materials has the opportunity to be introduced into DOD weapon systems. Because there are so many of these new materials being developed each year, it is up to the reader to stay on top of changes in this area.

14.5.3 The Future of Methods

Any change to the factory floor has a ripple effect. Therefore if there is a change in materials, it may impact how a product is processed within the plant. This could include changes to machines, tools, and training for manufacturing personnel. This section will identify coming attractions in the area of methods.

14.5.3.1 Electronic (Visual) Work Instructions

Work instructions are a basic manufacturing tool, developed to assist a worker in doing a particular task correctly. A work instruction details the sequence of steps that an employee must follow every time they perform a task. The work instruction organizes the work into logical steps so that an employee can easily follow it independently. Work instructions for a process can be very long with multiple steps or fairly short. In explaining the difficulty in developing a good work instruction teachers often give students the task of writing an instruction on "how to construct a peanut butter and jelly sandwich." Then the fun begins. So what does it take to make a good work instruction? Consider the following:

- Credible
- Clear
- Accessible
- Consistent

Electronic or visual work instructions are a rapidly growing methodology along with software solutions that visually links the customer orders, product options, routes and assembly build procedures. Electronic work instructions provide shop floor workers with screens that provide detailed instructions, including graphics, on how to build, assembly, test and inspect a product. Electronic instructions have been proven to improve build quality, reduce end of line errors, rework and warranty claims and are quickly becoming the de facto standard in many plants. What can we expect in the future?

- Dynamic 3-D content;
- Animated work instructions;
- Instructions on hand-held devices;
- Manufacturing, Engineering and other disciplines synchronized; and
- Model Based Definition easily deployed and displayed with critical features and tolerances.

14.5.3.2 New Materials Means New Methods

As new materials evolve and become available to the DOD and DOD contractors then we must understand the impact these new materials may have on the end properties of the systems that they are put into, the cost of those changes and how that manufacturing and quality workforce with engage in processing, testing and accepting these materials. Take for example the introduction of carbon nanotubes as an additive to composite materials to enhance the thermal, electrical or structural properties of the end product. One of the steps calls for the mixing of the carbon nanotubes with the resin matrix material, but a process needs to be developed and proven to ensure that the nanotubes were evenly disbursed within that resin.

14.5.3.3 Mass Customization

Mass Customization is the customization and personalization of products and services for individual customers at a mass production price. Traditionally, customization and low cost have been seen as mutually exclusive. Prior to Henry Ford developing the moving assembly line, almost all automobiles were custom made. There were in fact over 300 companies in America along that produced automobiles. Ford saw the benefit of uniformity and commonality as a major focus of his moving assembly line. If fact to old joke goes, "you can get a Model T in any color you want as long as it was black." Mass production provided low cost but at the expense of uniformity.

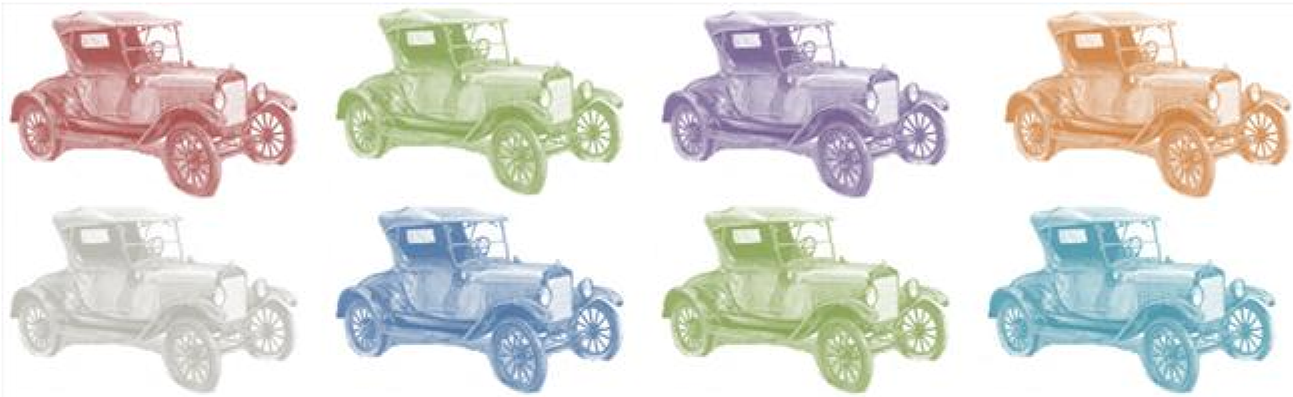


Figure 14-10 Custom Painted Model T's

Today's interactive technologies (Internet, e-sales, supply chains, etc.) allow customers to interact with manufacturers and suppliers to identify their specific requirements which are then produced on demand often by automated systems. Agility allowed companies to move from a product-centered manufacturing approach to a customer-centered approach. Dell Computer was one of the first companies to launch a customer-centered approach to sales and in doing so was able to:

- Offer tailored product based on customer demands;
- Reduce inventories to historic low levels;
- Provide for demand without charging a premium for service;
- Do it all within the same business cycle (no change in lead time).

14.5.3.4 Molecular Manufacturing or Nanotechnology

Molecular manufacturing (MM) means "the ability to build devices, machines, and eventually whole products with every atom in its specified place," or in a more common language it means to build things from the bottom up, at the atomic level. Molecular manufacturing (nanotechnology or molecular nanotechnology) has the promise of being able to:

- Achieve the ultimate in precision: with every atom in exactly the right place.
- Make complex and molecularly intricate structures as easily and inexpensively as simple materials.
- Reduce manufacturing costs to little more than the cost of the required raw materials and energy.

Nanotechnology theories were first developed by Dr. Richard Feynman in 1959, Norio Taniguchi coined the term nanotechnology in 1974, and Dr. K. Eric Drexler popularized the word "nanotechnology" in various journals in the 1980's. A highly fictionalized version of nanotechnology can be found in the television series "Star Trek" in which people can produce whatever they want using a replicator. In the future, perhaps years away, we will be able to connect and rearrange atoms, the fundamental building blocks of nature and create almost anything we want.

Today, rapid prototyping is an example of the automatic construction of physical objects using additive manufacturing technology. Rapid prototyping provides a capability to produce production-quality parts in relatively small numbers. Examples of rapid prototyping capabilities include:

- Selective laser sintering (SLS) uses a laser to melt powders (metal, ceramic, plastic, and glass) into a 3D final form. SLS claims to have better accuracy, strength, and stability over other rapid prototyping technologies.
- Direct metal laser sintering (DMLS) fuses metal powder into a solid part by melting it locally using a focused laser beam. Parts are built up layer by layer until a final form is achieved.
- Fused deposition modeling (FDM) uses heat to melt small beads of thermoplastic material to form the layers of the object. The material solidifies on contact and forms a 3D model.
- Stereolithography (SLA) uses liquid resin and a UV laser to build parts that are capable of being machined. It is one of the oldest and most common methods of rapid prototyping.
- Laminated object manufacturing (LOM) positions layers and glues plastic, paper, or metal on a platform. A carbon dioxide laser cuts the pattern into the top layer of the material. This process is repeated until a final form is achieved. No additional manufacturing is required.
- Electron beam melting (EBM) creates metallic objects from metal powder. A layer of powder is placed onto an adjustable surface in a vacuum then an electron beam melts that layer of powder. The EBM keeps layering and melting material until a final form is achieved. No additional machining is needed.
- 3D printing (3DP) is currently the faster and less expensive of the rapid prototyping technologies on the market. 3D printing is achieved by laying down successive layers of material onto a platform until a final form is achieved.

Governments moved to promote and fund research into nanotechnology with programs such as the National Nanotechnology Initiative. The National Nanotechnology Initiative is a United States federal nanoscale science, engineering, and technology research and development program. Initiative participants (cited below) state that its four goals are to:

1. Advance a world-class nanotechnology research and development (R&D) program;

2. Foster the transfer of new technologies into products for commercial and public benefit;

3. Develop and sustain educational resources, a skilled workforce, and the supporting infrastructure and tools to advance nanotechnology; and

4. Support responsible development of nanotechnology.

14.5.3.5 Quality and Continuous Improvement Will Still Rule

ASQ began studying the future of quality in 1995 and has repeated that study every three years since. ASQC has learned several things from these studies.

- The rate of change is accelerating.
- Whatever we can anticipate about the future will be overcome by what we can't anticipate.
- Our world is shrinking and "globalization," will be the single largest force of change to deal with.

To understand the future, look to the past. World War II had a tremendous impact on the U.S. industrial base. Statistical Process Control (SPC) was used to control quality and improve reliability and was such a significant factor in production operations that the DOD classified SPC as "secret." Dr. Deming became very prominent after the war when he visited Japan and brought modern quality methods to the Japanese, and they unlike many American companies embraced those practices espoused by Dr. Deming. Since then many quality consultants have picked the best ideas and techniques from these the gurus and repackaged them into things like MIL-Q-9858A, ISO 9000, Total Quality Management (TQM), Lean and Six Sigma. As a result of implementing these techniques, many companies were able to transform into productive machines. If these same companies are to weather the next onslaught of business challenges then they need to steer the course. Advanced decision-making tools, rapid prototyping, and other technologies are helping producers to improve their quality and productivity. However, there is still the need for embracing the quality management practices of the 1940's. Leadership involving quality and continuous process and product improvement should be basis business practice and should be around for a very long time.

14.5.4 The Future of Measurements

Eli Whitney has been credited with pushing America into a new industrial age with his promotion of firearms using interchangeable parts. In 1801 Whitney took ten rifles he had built and in front of Congress he disassembled the ten rifles, mixed up the parts and then reassembled the rifles. Congress was so impressed that they awarded him a sizeable contract but Eli was never able to successfully implement a production system that would give him the capabilities he promised. Part of the problem lied in fact that most industrial machines and processes were not that precise at that time to allow for the production of identical or interchangeable parts. Precision and the ability to manufacture and measure parts is a critical capability that must be met before interchangeability can become a reality. Precision is no less important today than it was over 200 years ago, if fact it is perhaps even more critical today as companies start building products that are in some cases only atoms wide.

14.5.4.1 In-Process Measurement and Control

Most businesses need to acquire the newest process control technologies in order to deliver high quality products at the lowest cost. These technologies range from process control equipment, to equipment for monitoring and maintenance, to production, planning and scheduling equipment.

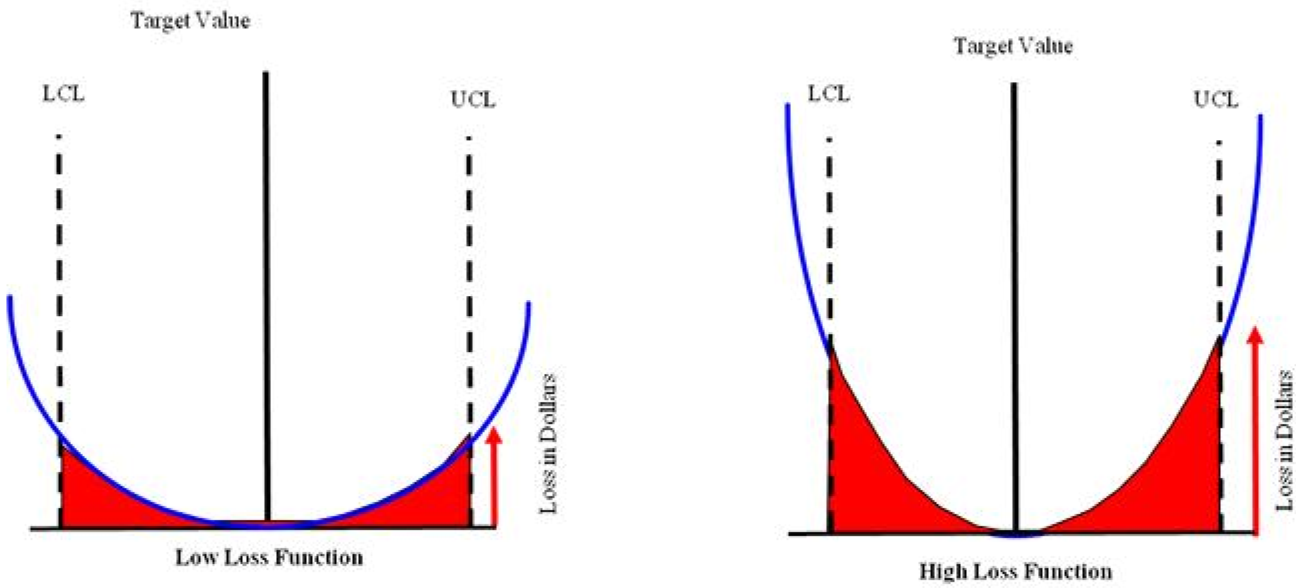
Many of these systems are purchased as stand-alone entities. But as the industry works to achieve more efficient and effective operations, then software systems associated with these technologies will have to become more tightly integrated without becoming unmanageable. In a recent National Science Foundation (NSF)/National Institutes of Standards and Technology (NIST) Process Measurement and Control Workshop they identified the following current methods and future needs in this area:

- Nonlinear model predictive control
- Performance monitoring
- Estimation and inferential control
- Identification and adaptive control
- Molecular characterizations and separations
- Process sensors
- Microfabricated instrumentation
- Information and data handling

Quality monitoring is becoming much more proactive with the measurement and control of machines in-process rather that after a process has been completed. Many new quality monitoring tools for assessing product shape and material quality are also able to quickly handle unusual or out-of-control situations and bring those processed back into control automatically.

14.5.4.2 Off-Line Quality Control

It has been long recognized, but seldom practiced, that quality must be designed in rather than inspected in. Genichi Taguchi developed a practical methodology to identify where the best opportunity was to eliminate variation in both the design of a product and its manufacturing process. Taguchi believed that any departure from the design or target value resulted in decreased customer satisfaction and this constituted a "loss function (see Figure 14-11)." The loss may be in the form or scrap, rework or repair, it may be a maintenance or repair cost due to poor reliability. The important lesson to learn is that reducing variation can reduce the loss function.



Notes:

- Some characteristics have higher Loss Functions than other characteristics
- The characteristics with a high Loss Functions become your key characteristics
- You need to control your key characteristics

Figure 14-11 Taguchi Loss Function

Taguchi's approach for quality engineering can be used in both product and manufacturing process design and involves three stages:

1. System design;
2. Parameter (measure) design; and
3. Tolerance design

System design refers to the earliest stage. The stage when ideas for a new system are used to decide upon the combinations of factors that will be used to obtain a functional and economical design.

Parameter design refers to the stage when factor settings are selected that make the system less sensitive to variations. Once the concept has been established, the nominal values of the all the dimensions and design parameters need to be set. This is the detail design phase for most engineering projects. Taguchi's approach was to make the design "robust" that is to minimize the effects on performance that result from variation in manufacture, environment and cumulative damage.

Tolerance design refers to the final stage when tolerances are tightened around the best value. This requires an understanding of the effect that the various parameters have on performance so that resources can be focused on reducing and controlling variation in the critical few dimensions often referred to as key characteristics.

14.5.4.3 Measurement at the Molecular Level

Frank Robinson is credited with the quote "close only counts in horseshoes and hand grenades." Everything else must be more precise and when it comes to measurement at the molecular level, it needs to be much more precise. When talking about nanotechnology and building product at the molecular level, one atom at a time, then measuring the product must be done at the molecular level. A nanometer is one billionth of a meter. It would take ten hydrogen atoms side by side to equal the width of a nanometer and a pinhead is a million nanometers in diameter.

Many companies are focusing on developing high precision dimensional measurement technologies in order to meet the measurement challenges for emerging manufacturing requirements. Miniaturisation, increasing part complexity, and shrinking dimensions will require new and novel approaches to performing high-speed "in-situ" measurements that will facilitate inspection, testing, process monitoring and control.

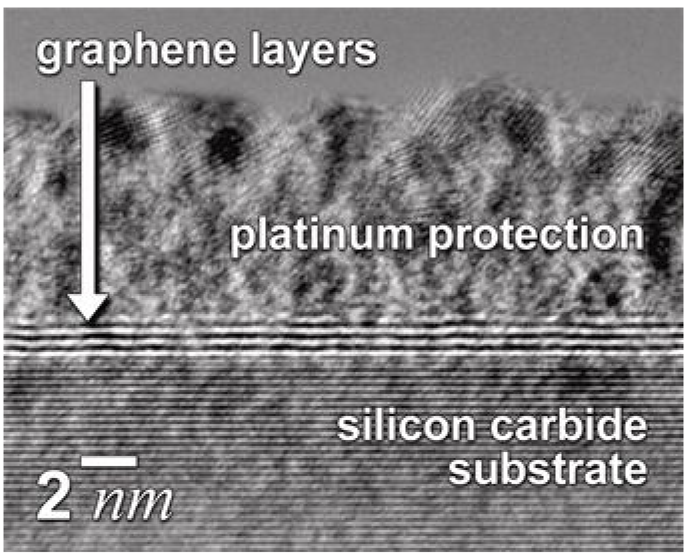


Figure 14-12 Electron Micrograph of Graphene

For many years the semiconductor industry had the only real use of manufacturing at the nano level. However, there has been a dramatic increase in nanomanufacturing processes due to the availability of nanoscale materials and nanostructuring techniques. These emerging nanomanufacturing processes will require measurement and control systems that:

- Are inexpensive;
- Quick; and
- Accurate.

In the aerospace industry, equipment on board aircraft must be tested *in situ* , or in place, to confirm everything functions properly as a system. This often requires the development of special test equipment is available for this *in situ* testing. In 2009, NIST awarded ARRA-funded contracts totaling $6 million for nanomeasurement tools, and it plans to make additional such awards in 2010. Also using ARRA funds, NIST awarded $34.3 million in 2010 to support construction of nanoscience facilities at U.S. universities.

14.5.4.4 Integrated Measurement Systems

The future of integrated measurement systems (IMS) is towards the development of intelligent measuring systems that will support the achievement of zero-defect manufacturing. The IMS's being developed must be quick, accurate (high resolution), and interact with other management information systems. The system's features should include remote units and a distributed measurement system (based on Intranet and Internet technologies), that can provide high accuracy sensor data processing by the use of artificial neural networks. The distributed measurement system connects intelligent sensors, intelligent actuators, and other intelligent control units together. The 2012 International Conference on Computer Distributed Control System (DCS) and Environment Monitoring identified the following topics for future presentation and discussion:

- Computer Distributed Control System Technology:
    - Distributed Control System Architecture;
    - Digital Communication Technology;
    - Advanced Hardware and Software Technology;
    - Advanced Computer Networks;
    - Next Generation DCS Technology; and
    - Industrial Application of DCS.
- Intelligent Instrument & Advanced Control Technology:
    - Smart Sensors;
    - Multi-Sensor Information Fusion;
    - Intelligent Information & Retrieval Systems and Data Mining;
    - Artificial Intelligence & Neural Networks for Advanced Data Acquisition;
    - Virtual Instrumentation Systems;
    - Autonomous Control & Fuzzy Logic;
    - Intelligent Controller Design;
    - Machine Learning, Adaptive Systems and Expert Systems;
    - Failure Detection and Identification;
    - Intelligent & Wireless Sensors and Wireless Sensor Networks; and
    - Data Acquisition & Measurement Engineering.

The National Institutes of Standards and Technology (NIST) FY 2012 Measurement Science and Engineering Research Grants Programs emphasizes several computing areas to include cyber-physical systems, intelligent systems, and systems integration. NIST's Intelligent Systems Division is conducting research in manufacturing process and equipment interoperability, industrial control system security, intelligent systems and robotics, and intelligent control of mobility systems; machine tool and machining process metrology; smart manufacturing systems; and sensor networking and integration. This is the future of measurement.

14.5.5 The Future of Manpower

In a 2011 report published by The Manufacturing Institute and Deloitte entitled *The Skills Gap In US Manufacturing* revealed that "82 percent of manufacturers now have a moderate to severe shortage of available, qualified production workers; 67% have a moderate to severe kills shortage in their overall workforce; 56 percent anticipate these shortages to grow worse over the next three to five years; and 64 percent of respondents say that workforce shortages and skills deficiencies in production roles are having a significant impact on their ability to expand operations or improve productivity." The same report discovered that American companies cannot fill an estimated 600,000 skilled positions across the nation right now despite record unemployment. There are several reasons for the lack of talent:

- The Aging of America as baby boomers retire and have no one to fill the void;
- There is not enough technical training in hard manufacturing skills;
- There are not enough people with the right levels of skills, especially advanced STEM (Science, Technology, Engineering and Math) skills.

The need is there if the skills are there, and these are the skills many companies are looking for:

- Foreign language: Manufacturing is often global and that requires the ability to communicate, build teams and execute assignments in multiple languages.
- Technical: Manufacturing personnel need a strong baseline of technical expertise and ability. It is a new world with many new technologies and getting ahead means keeping up.
- Information technology: Manufacturing has become a high-tech enterprise. Technology enables greater productivity and cost efficiencies, and is an essential element to success in today's high-skilled manufacturing enterprises.
- Management: Manufacturing needs leaders that can work as team leaders on cross functional teams.

14.6 The Future of Design

The term "systems engineering" was first coined in the early 1940s, and DoD began practicing the concept later that decade with the initial development of missiles and missile-defense systems. Systems engineering started gaining momentum following World War II. Because of its role in acquiring and developing large-scale, complex systems, DoD led the way in codifying the fledgling discipline by developing and releasing the first systems engineering standard in 1969. The principles in that baseline military standard (and later revisions) are still valid. Efforts aimed at revitalizing systems engineering have retained those aspects of the discipline that have proven successful in developing complex systems in the past in a framework that has evolved over time. The expectation is that this process will continue to be used well into the future. What will change is the tools used in the process and the focus of engineering. The future of design will probably include the following:

- A focus on shorter development times;
- Advanced Simulation;
- A connected and integrated systems engineering process;
- Increased globalization where the design, engineering and build functions all happen in different parts of the globe;
- A focus on sustainable design;
- A focus on Science, Technology, Engineering and Math skills.

14.6.1 Shorter Development Times

The DOD is currently (2012) involved in two conflicts (Afghanistan and Iraq). This global war on terrorism has posed many challenges to military leaders especially in the need to respond quickly to rapidly evolving asymmetric and irregular threats (e.g. use in improvised electronic devices). This means that the DOD needs an acquisition system that is agile and can respond to these threats quickly and provide effective responses that are affordable and perform as expected. This is not a new problem. The DOD industry has been seeking ways to decrease the time to develop and field for new technologies and weapon systems to meet war fighter needs for over 40 years, but without much success. In fact, the time required to develop new DOD products is increasing, while in the U.S. automotive industry it is decreasing (Figure14-13). In a 2008 report by the Center for Public Policy and Private Enterprise, Dr. Jacques Gansler and several colleagues recommended "Using Spiral Development to Reduce Acquisition Cycle Times" as a way to shortening development times of weapon system programs.

In a September 14, 2010, AT&L memo, Dr. Carter outlined several ways to target affordability and control cost growth. One of the requirements was for PMs to set shorter program timelines and manage to them. The memo noted that "The leisurely 10-15 year schedule of even the simplest and least ambitious Department programs not only delays the delivery of needed capability to the warfighter, but directly affects program cost. As all programs compete for funding, the usual result is that a program settles into a level-of-effort pattern of annual funding that does not deviate much from year to year. The total program cost is the level-of-effort times the length of the program. Thus a one-year extension of a program set to complete in 10 years can be expected to result in 10 percent growth in cost as the team working on the project is kept on another year."

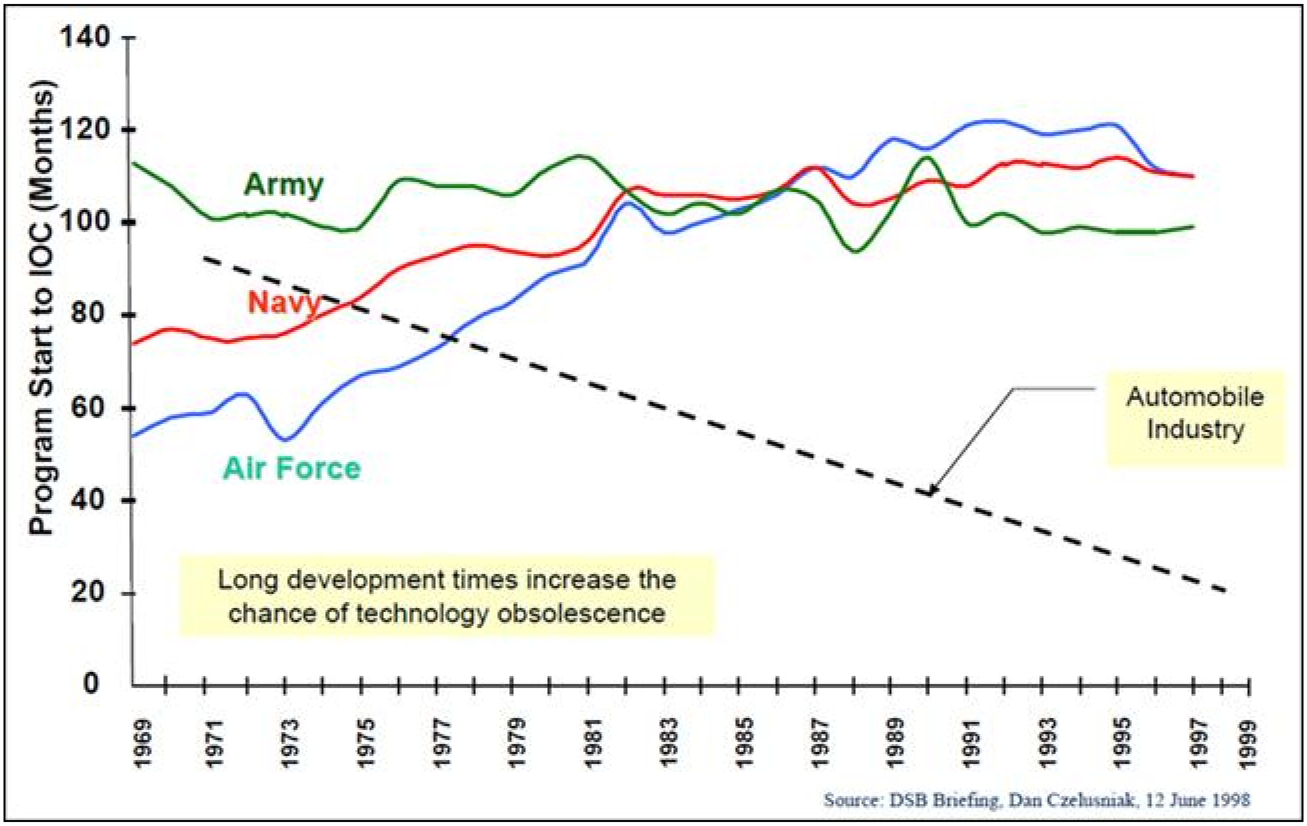


Figure 14-13 Product Development Cycle Times

A note of caution. A headlong rush towards shortening product development time without regard to trades is a surefire blueprint for failure. If engineers push the design too hard and fast the product may not be producible, you may go too fast to adequately test and you may not fully understand all of the life cycle cost implications of the design. Companies that get new products out the door quickly often do so by selecting design alternatives that are not state-of-the-art and often do not give you the 100% solution. But at the same time, these choices are producible, reliable and affordable. Shorter development times can be facilitated by advanced simulation and increased collaboration between team members.

14.6.2 Advanced Simulation

Modeling and simulation (M&S) can be used throughout the warfare systems acquisition lifecycle. M&S can be used by all functions and used for:

- Design;
- Testing;
- Production;
- Cost modeling;
- Supply Chain and logistics.

When this guide was first written (1989) computer aided design (CAD) and computer aided manufacturing (CAM) were just coming into use. Often as stand-alone systems, and often not able to communicate with other systems. Contractors often had different versions and types of software and one would not work with the other. However, all that has changed. Since then, most aerospace and defense manufacturers have included computer-aided engineering (CAE) and high-performance computing (HPC) in their design processes. Today advanced simulation can boost computational performance and decrease development time by:

- Improving engineering collaboration,
- Productivity and product quality,
- Shorten development costs and risks,
- Improving testing capabilities and lessening the dangers of actual testing, and
- Improving trade studies and opportunities to make affordability decisions.

A recent National Defense Industrial Association (NDIA) Joint Committee for Systems Engineering and Manufacturing (JCSEM) report on *Modeling & Simulation Investment Needs for Producible Designs and Affordable Manufacturing* noted that "in the engineering domain, mature modeling and simulation tools currently exist that can be used to quantify the feasibility of a proposed design concept's ability to meet the performance objectives, with these analyses routinely used to guide trade study analyses by providing key knowledge early in the design process. Unfortunately, in the manufacturing domain a void exists in having comparable modeling and simulation capabilities that can be used to identify and predict the severity of anticipated producibility and manufacturing concerns during early systems engineering trade study activities. Hence, innovative quantitative modeling and simulation capabilities are needed to help guide producibility and manufacturing evaluations of proposed design concepts similar to what currently exist for performance based engineering analyses throughout the conceptual, preliminary, and detail design phases of product development." Current factory simulation models focus on throughput and cycle time. These programs allow managers to establish a factory floor or define a process flow and do trade studies on various options. Future factory simulations will go beyond the those basic capabilities and will allow the manufacturing engineer to address:

- Sustainable manufacturing goals (energy, water and other resource usage);
- Monitor and optimize maintenance and calibration requirements;
- Supply Chain collaboration for product design, quality and scheduling; and
- Manufacturing execution and execution systems networked to machines, test and measurement devices, robotics and process planning.

14.6.3 Connected and Integrated

Engineers in the future will be more integrated as teams and will be using software that is more integrated with other processes and functions and with other engineers that are supporting the design to include internal and external engineers.

14.6.3.1 Integrated Product and Process Teams (IPPTs)

Integrated Product and Process Teams (IPPTs) have been around for a long time and for a long time they have been poorly applied. In many cases companies and organizations claim to have an IPPT but in reality it is just the same old team they had last year with no improvements. True IPPTs have the following characteristics:

- Teamwork: The team is balanced by design, there has been some "team training on how to become a team," all members share an identity with the team, there is strong interaction among team members.
- Technologies: There is a strong use of tools and technologies and the technologies are appropriate to that firm or organization. Do not expect a small firm to use high end software systems, but expect them to at least "flowchart their processes." Many teams do not use proven tools such as Quality Function Deployment (QFD) to identify customer requirements, and Design of Experiments (DOE) to identify key characteristics.
- Communications: True IPPTs communicate with each other. They do not necessarily follow the "chain of command or company organization chart." But everybody shares, everybody listens, and everybody understands each other. The closest thing to perfection is what is shown in science fiction as the "Vulcan mind meld."
- Strong Project Focus: Everyone understands the elements and makeup of the project to include the work breakdown structure, the cost and schedule components, the critical path, the goals and objectives and understands their role in the process to achieving the project.
- Creativity: Creativity is fostered, especially in the early stages as the approach is developed and trade studies are accomplished. New ideas flourish and are rewarded. Imagine the CEO is Burt Rutan, Steve Jobs or Robin Williams.

14.6.3.2 Integrated Engineering Software

Engineers of tomorrow will use advanced modeling and simulation tools and these tools will be integrated with other engineers and functions within the organization. Thus the design engineer will be able to communicate directly with manufacturing engineering, quality engineering, and other functions on design options. In addition, these engineers will be able to collaborate with other engineers up and down their supply chain. Thus a mid-tier contractor working on a project will be able to collaborate with engineers on the prime contract above them and with engineers working for suppliers and vendors below them.

14.6.4 Globalization: Design Here - Engineer There - Build Somewhere Else

The world is shrinking. In 1873, Jules Verne published the science fiction novel *Around the World in Eighty Days* . In the novel, Phileas Fogg takes a bet that he cannot circle the globe in 80 days. Of course he wins the bet and made the world just a bit smaller. In 1937, Howard Hughes and a four-man crew circled the globe in just 3 days, 9 hours and 17 minutes. Today astronauts routinely circle the globe in 90 minutes. Our world is shrinking and borders are becoming invisible. Today people travel through most of Europe without going through border stops. The North American Free Trade Agreement (NAFTA) created a trilateral trading bloc made up of Canada, Mexico and the U.S. Meanwhile economic and environmental pressures have driven much of our manufacturing capability overseas. This includes the production of many technologies that were developed here (microelectronics for example). The new model is to design and invent here in the U.S. and then outsource the production overseas. This approach on one hand provides many competitive advantages. For example, many microelectronic devices are tested in Ireland due to the greatly reduced tax structure Ireland enjoys vs. the corporate tax in the U.S. And shipping to Ireland from the east coast is no more expensive than shipping to the west coast. The real disadvantage to this approach is the loss of well paying jobs for Americans and the taxes that would bring in, and the need to rely on another country for goods and services. This is especially troubling if these goods and services are needed to support our national interest.

14.6.5 Sustainable Design

The industrial revolution became a time in which man tried to tame or at least control nature. On many levels we were successful. We were able improve our standard of living, and improve health and safety. We developed transportation systems that allowed us to travel and move goods and services with easy. We improved access to safe and clean drinking water and water for irrigation. We improved sanitation systems which dramatically impacted our quality of life and health. But these successes led to unintentionally consequences, namely a very large population explosion. And this led to massive consumption of resources, especially our natural resources, much of which is non-renewable. Future engineers need to look at the impact of their design decisions on the natural environment and embrace approaches that foster sustainable designs and sustainable manufacturing practices.

14.6.5.1 Sustainable Design

Sustainable design is a design philosophy that values natural resources as a major factor in creating new products and seeks to reduce or eliminate negative environmental impacts though thoughtful consideration of environmental factors. This is also referred to as environmental design, environmentally sustainable design, environmentally-conscious design, design for the environment (DfE), Design for Sustainability (DfS), etc. Sustainable design principles focus on the following:

- Use low-environmental impact materials (non-toxic, sustainably produced or recycled materials);
- Use energy efficient manufacturing processes and produce products which require less energy;
- Advance the state of quality, reliability and durability: longer-lasting products will have to be replaced less frequently;
- Design for reuse and recycling;
- Assess the total carbon footprint of the design to include impacts to production, operation and disposal costs;
- Develop Sustainable Design Standards to assist engineers and product managers;
- Turn to nature and use biomimicry: "redesigning industrial systems on biological lines;
- Renewability: materials should come from nearby (local or bioregional), sustainably managed renewable sources that can be composted when their usefulness has been exhausted.

14.6.5.2 Sustainable Manufacturing

Sustainable manufacturing can be defined as "manufacturing products with economically sound processes while avoiding negative impacts to the environment, on energy and natural resource use, and with regard for the safety of the warfighter, user, employees, and community."

14.6.6 Stem (Science, Technology, Engineering and Math) Education

On 24 June 2011, President Obama launched the Advanced Manufacturing Partnership (AMP), a national effort bringing together industry, universities, and the federal government to invest in ways to create high quality manufacturing jobs and enhance our global competitiveness. Investing in people and skills is one of the foundations for investing in manufacturing. While America is the world's technology leader the supply of graduates in science, technology, engineering and mathematics (STEM) education has not kept up with increasing demand. This trend threatens America's future economic security and our ability to provide warfighters with the breakthrough technologies and products that will give them their edge. But the challenges ahead for this workforce are daunting:

- Jobs requiring math are increasing four times faster than overall job growth (Program for International Student Assessment test, 2004).
- Only 33% of eighth graders are interested in STEM majors and careers and only 6% of high school seniors will get a bachelor's degree in a STEM field.
- Only 18% of high school seniors are rated as science proficient and 33% as math proficient (Digest of Education Statistics, 2009).
- 30% of high school mathematics students and 60% of high school physical sciences students have a teacher who did not major in that subject or is not certified to teach it (National Center for Education Statistics).
- The U.S. is ranked 27th (out of 29) for the rate of STEM bachelor's degrees awarded in developed countries (Organization for Economic Cooperation and Development, 2009), 6% of undergraduates major in engineering in U.S. compared with 12% in Europe, 20% in Singapore, and 40% in China (Rising above the Gathering Storm).

A rebirth in manufacturing can only happen through a workforce with 21st Century learning and skills. Science, technology, engineering, and math (STEM) proficiency will be key when combined with strong oral and written communication, collaboration, critical thinking and problem solving, creativity, time management, and a strong work ethic. Government support (local, state, and national) is required if America is to once again become a dominant manufacturing powerhouse: This includes support for the following:

- Support schools working to implement STEM education using PBL techniques.
- Support business and industry involved in the implementation of STEM education using PBL.
- Ease laws and regulations regarding collective bargaining in education.
- Implement consistent course requirements.
- Provide needed funding.

14.7 Summary

This chapter described the environment and major influences operating to change the nature and role of the factory floor and the numerous interconnected activities and organizations that will be used to produce our future weapon systems. The primary areas of change in the factory of the future are described and a brief summary of the current status is discussed to include:

- Trends in technology;
- Emerging changes to the factory floor and the 5Ms (machines, materials, methods, measurements, and manpower);
- Digital engineering and the integration of design and manufacturing; and
- The integrated supply chain.

14.8 Related Links and Resources

Numerous reference documents impact the manufacturing management function throughout the acquisition process. These documents originate from many sources and range across academic disciplines, functional activities, and job specialties.

The following is a reference list of DOD Directives (D), Instructions (I) Manuals (M), Pamphlets (P) Military Standards (MS), and other documents. The documents listed contain DOD policy guidance applicable to the manufacturing management function. They are listed as sources of DOD manufacturing management information.

Note: Many of the documents listed are no longer required (due to acquisition reform), but still contain some very valuable information.

Number	Title
	NIST Advanced Manufacturing Partnership (AMP)
	ASQs Future of Quality Study: No Boundaries
	The Digital Factory From Concept to Reality
	Factories of the Future PPP Strategic Multi-Annual Roadmap
	Looking Beyond the Last 50 Years: The Future of Materials Science and Engineering
	Modeling & Simulation Investment Needs for Producible Designs and Affordable Manufacturing
	MIT Roundtable: The Future of Manufacturing Innovation - Advanced Technologies

Defense Manufacturing Management Guide for Program Managers
Chapter 15 - Supply Chain Management and Sustainable Manufacturing

15.1 Objective

At the end of this lesson the Program Manager should be able to:

- Describe the SCOR model as it relates to the DOD;
- Identify some of the roles and responsibilities of the various players in SCM;
- Describe some of the problems in managing a supply chain;
- Identify software tools that will help to manage supply chains;
- Describe some SCM metrics;
- Identify contract language that may be used to enhance SCM activities; and
- Define sustainable manufacturing (SM) and identify some SM considerations.

15.2 Background

For Want of a Nail

For want of a nail the shoe was lost.
For want of a shoe the horse was lost.
For want of a horse the rider was lost.
For want of a rider the message was lost.
For want of a message the battle was lost.
For want of a battle the kingdom was lost.
And all for the want of a horseshoe nail.

Figure 15-1 For Want of a Nail

The Toyota Motor company announced that its quarterly profit slid by 18.5 percent as a result of the 2011 tsunami that hit Japan. Much of the reason for the loss in quarterly profit was due to parts shortages which significantly disrupted production and sales. Mitsubishi Materials Corporation (MMC), a subsidiary of Mitsubishi Heavy Industry, had a copper smelting operation in the Fukushima prefecture which was damaged during the quake and had to suspend operations for a period of time. MMC's senior leadership issued an apology to their vendors for the suspension in operations. MMC used existing inventories, moved production to other MMC facilities and worked to find alternative sources of production in an attempt to meet customer schedules. Closer to home, Hurricane Katrina devastated much of the south leaving many areas underwater and uninhabitable. The hurricane impacted the Department of Defense when production of the M117 Guardian Armored Security Vehicle made by Textron was brought to a halt. Although there was only minor damage to one facility in East New Orleans and no damage to another in Slidell production was still halted. The production halt was due mainly to the loss of city infrastructure and the need to relocate many of the employees. Interruptions in a supply chain can come from many sources to include weather (floods, hurricanes, tornadoes, forest fires, etc.), humans (strikes, political unrest, etc.), accidents (equipment breakdowns, fires, etc.), and even war (blockades, transportation under fire, etc.).

Supply chains are at the heart of most manufacturing or production operations. As the old nursery rhyme at the left goes "For want of a nail..." Supply chain managers can reword this to read "for lack of a supplier..."

15.3 Introduction

A supply chain can be defined as the "flow of material from a source to a destination." A supply chain can be as simple as a farmer growing produce and then selling it to customers at a farmers market. Or a supply chain can be very complex like the F-16 involving hundreds of suppliers from around the globe providing materials and services to component manufacturers, who then provide components to subcontractors, who then provide the major subassemblies to the prime contractors that integrate all of the subassemblies. The final product is then bought off by the U.S. Air Force or one of the many countries involved in the co-production of the F-16. Supply chains can be informal where the purchaser just buys material from the low cost provider, or the supply chain can be a formal network of suppliers and vendors with strong contractual relationships. The supply chain could include raw material, work-in-progress (inventory), and finished product. There are many ways to depict a supply chain. One way would be to show a work breakdown structure or WBS. Each of the lower level WBS elements may come from a different supplier, and may get integrated at different WBS levels. Another way is depicted graphically below showing a network of organizations linked together in order to bring products and services to customers.

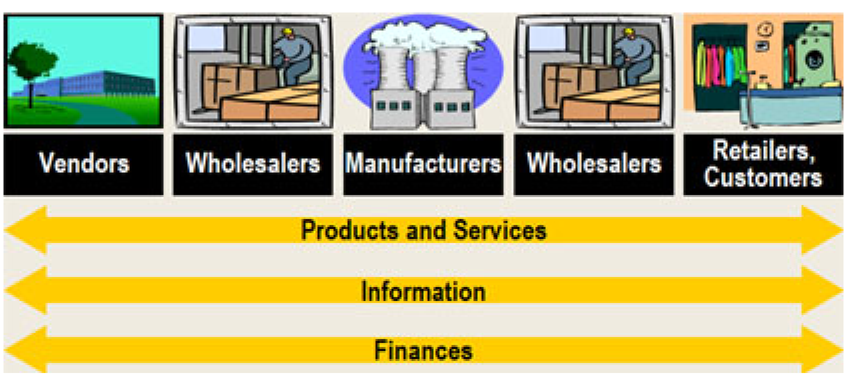


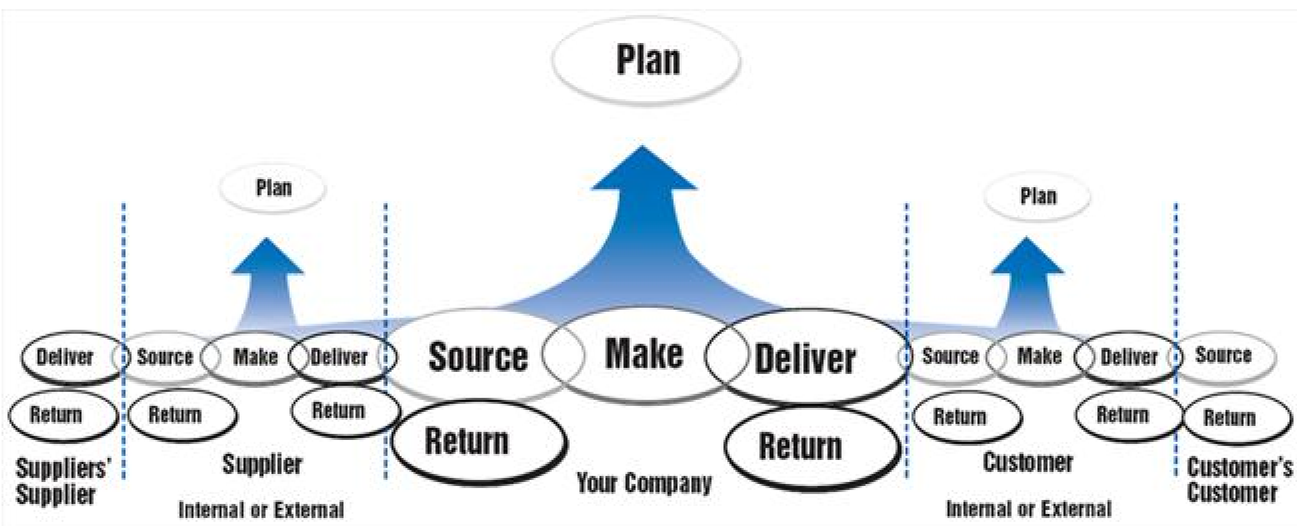
Figure 15-2 Supply Chain

The Association for Operations Management (APICS) defines supply chain management (SCM) as the "design, planning, execution, control, and monitoring of supply chain activities with the objective of creating net value, building a competitive infrastructure, leveraging worldwide logistics, synchronizing supply with demand and measuring performance globally."

The Department of Defense (DOD) has many supply chains and these chains are a multibillion-dollar business. However, many SCM best practices have not been incorporated into the DOD supply chain uniformly because the DOD supply chain is a conglomeration of different supply chains managed under different organizational structures. Some of these supply chains have a logistics view and some have an acquisition view. In many cases, these different supply chains are linked only by the fact that they provide supplies to DOD personnel. Because the DOD supply chain is enormous, making it even slightly more efficient could result in tremendous cost savings.

15.4 Supply Chain Operations Reference (SCOR) Model

The Supply Chain Operations Reference (SCOR) model developed by the Supply Chain Council has been used by many companies and organizations to decrease costs, improve financial performance (revenue and profit), and to become more competitive. The SCOR model provides a framework linking performance metrics, processes, best practices, and people into a cohesive and unified structure. The framework supports communication between supply chain partners. The model integrates Business Process Reengineering (BPR), Benchmarking, and Process Measurement into a cross-functional framework.



Supply Chain Council's SCOR model (http://www.supply-chain.org)

Figure 15-3 The SCOR Model

A Process Reference Model Contains:

- Standard descriptions of management processes;

- A framework of relationships among the standard processes;
- Standard metrics to measure process performance;
- Management practices that produce best-in-class performance; and
- Standard alignment to features and functionality.

15.4 .1 The SCOR Hierarchy

The SCOR model is a hierarchical pyramid representing a plan for improving supply chain performance. The SCOR model deals with three levels of processes that progressively increase in process detail. Level 1 is the top level and defines the scope and contents of the SCOR model, that is the number of supply chains and how their performance is measured. Here the company sets the competition performance targets. This level defines the five management processes of plan, source, make, deliver, and return.

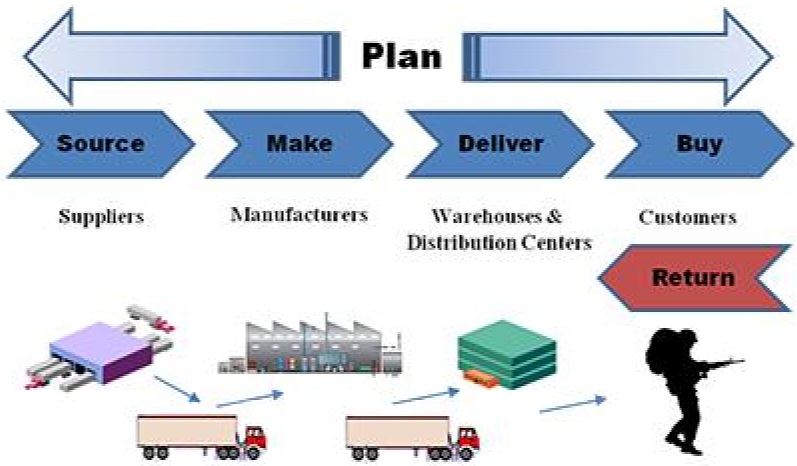


Figure 15-4 SCOR Hierarchy

Plan . Planning is the fundamental process that runs the length of the supply chain. The key is balancing resources with requirements. An organization assesses aggregate supply resources and demand requirements to develop a plan that synchronizes and optimizes production, inventory, distribution, and initial capacity planning.

Source . Sourcing is when an organization manages its purchasing activities and procures raw materials and services to meet its planned and anticipated demands. Vendor and supplier certification, negotiated vendor contracts, quality control, and materials receipt are included in this process. This is essentially a procurement function.

Make . Producing includes make-to-stock, make-to-order, and engineer-to-order products deals with executing and managing the manufacturing, testing, packaging, holding, and releasing of products. It also deals with engineering changes and making finished products to meet the planned and anticipated demands. Under this process, an organization is concerned with infrastructure management, production status and quality, and short-term capacity. This is essentially a production function.

Deliver . Ordering, warehousing, and transporting for stocked, make-to-order, and engineer-to-order products encompass order and credit management, warehouse and transportation management, distribution management, and inventory and quality control. It includes developing and maintaining databases for customers, products, and prices. This process is focused on delivering end products and services to meet planned and anticipated demands. This is essentially a transportation function.

15.4.2 The DOD SCOR Model

Military logisticians face unique challenges as they attempt to manage their military chains, especially during wartime. Thus, they should have a general understanding of the SCOR Model. At the strategic level, military and private organizations are driven by similar opportunities and constraints. They must address the logistics issues of acquisition, distribution, sustainment, and disposition and disposal. No doubt, adopting blanket business solutions and practices and applying them with little thought to the DOD supply chain would be problematic. However, many of the problems faced in today's DOD supply chain are the same ones that the commercial sector has dealt with or is currently facing.

DOD 4140.1R, DOD Supply Chain Material Management Regulation, directs DOD Components to use the supply chain operational reference processes of Plan, Source, Maintain/Make, Deliver, and Return as a framework for developing, improving, and conducting material management activities. Most of the DOD supply chain focus is on operations and logistics. However, there is growing concern within the acquisition communities for improving the way supply chains are managed on large weapon system programs.

15.4.3 Logistics Focus: "Factory to Foxhole"

The DOD logistics supply chain looks a bit different than the classic SCOR model.

- The "company" is replaced with a maintenance activity, inventory control point or distribution/transportation activity;
- The "customer" is replaced with a maintenance depot, or retail supply and maintenance installation support activity; and
- The "customer's customer" is replaced with the Operation Forces.

DOD operates a vast and complex supply chain network consisting of processes and activities to purchase, produce, and deliver materiel - including ammunition, spare parts, fuel, food, water, clothing, personal equipment, and other items - to forces that are highly dispersed and mobile. The sheer size of the military and scope of current operations makes this task very daunting. According to a 2005 GAO report "the DOD undertook a massive logistics effort to support Operation Iraqi Freedom, in many instances the supply chain failed to respond quickly enough to meet the needs of modern warfare. DOD had shortages of critical items due to systemic deficiencies that included inaccurate and inadequately funded Army war reserve requirements, inaccurate supply forecasts, insufficient and delayed funding, delayed acquisition, and ineffective distribution." More importantly, as noted by a WW II Navy Beach Master, "the only thing worse than not having something, is having it and not knowing where it is." Visibility is a critical aspect of supply chain management.

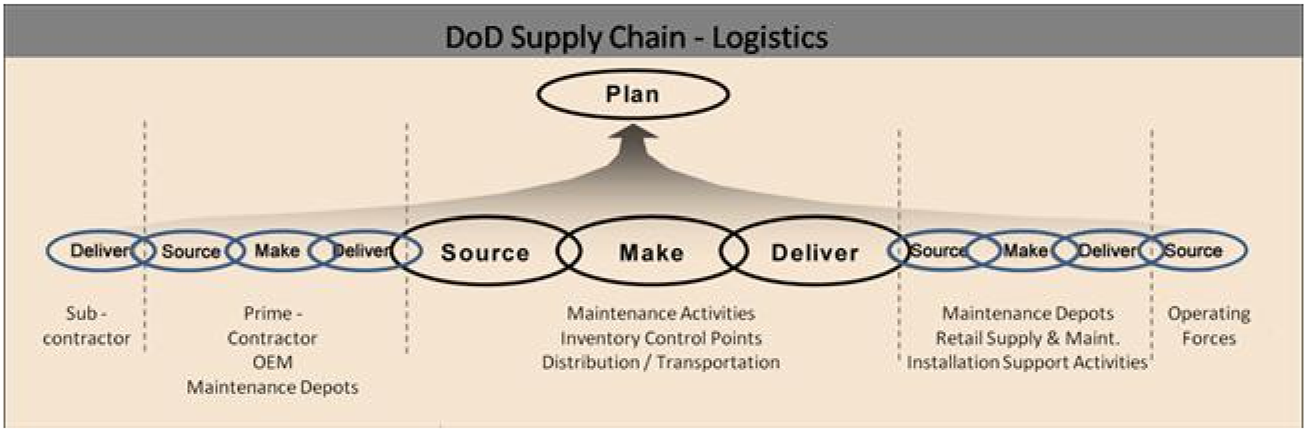


Figure 15-5 The DOD SCOR Model - Logistics Focus

Thus, from factory to foxhole, the DOD logistician provides insight and oversight over their supply chain. However, effective supply chain management begins with an understanding the needs of the customer (the warfighter). It requires developing and establishing metrics across the entire supply chain based on those needs. The DOD SCOR model provides a medium for looking at the entire supply chain to determine how to best meet the warfighter's requirements.

Requirements begin with logisticians gathering critical data, such as order backlog, order fill time, and days of inventory stock, that, when measured against metrics, can provide the means to improve performance. Knowing and understanding the metrics used by organizations across the chain allows managers to better synchronize activities leading to reduced cost and better performance.

DOD logisticians needs to ensure that the priorities related to Material Visibility, Common Supplier Engagement, Acquisition Visibility, and Real Property Accountability are reflected in their business plans. Materiel Visibility is the ability to locate and account for materiel assets throughout their lifecycle and provide transaction visibility across logistics system in support of the joint warfighting mission. Common Supplier Engagement is the alignment and integration of the policies, processes, data, technology, and people to provide a consistent experience for suppliers and DOD stakeholders to ensure reliable and accurate delivery of acceptable goods and services to support the warfighter. Acquisition Visibility is achieving timely access to accurate, authoritative, and reliable information supporting acquisition oversight, accountability, and decision making throughout the Department for effective and efficient delivery of warfighter capabilities. Real Property Accountability provides the warfighter and the Core Business Missions with access to near-real time secure, accurate, and reliable information on real property assets, and environment, safety, and occupational health sustainability.

The Joint Supply Chain Architecture (JSCA) is a process reference model that also provides possible end-to-end supply chain metrics. It provides DOD Product Support Managers (PSMs) a proven model to use in designing and improving their supply chain and a balanced set of metrics to measure a weapon system's end-to-end supply chain. The key is to ensure a direct relationship between the JSCA metrics and the program's Sustainment Key Performance Parameters (KPPs) and Key System Attributes (KSAs). The PSM should understand the interrelationships between each process to understand and be able to manage or transform their weapon system's supply chain into an asset that enables materiel availability.

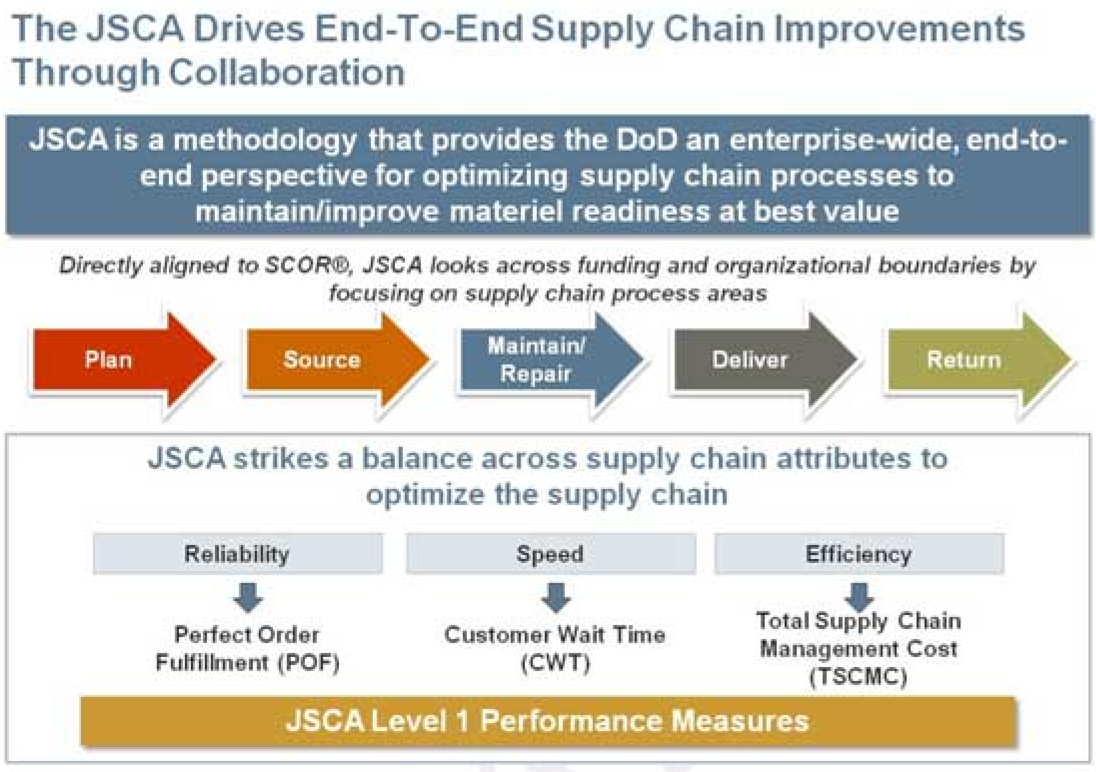


Figure 15-6 The JSCA Process Model

The PSM can also use the process reference model to understand which processes in their supply chain are particularly critical to measure. This is important because legacy systems already have some supply chain measurement in place and any investments in additional process measurement should only be done where it makes sense. New programs, however, have not yet made their complete IT investment and should ensure that they are measuring their supply chain from a complete end-to-end perspective, especially since they have little operational data to indicate which processes are critical to their system's materiel availability.

The end-to-end supply chain metrics span across organizational boundaries by focusing on the five major supply chain process areas: Plan, Source, Maintain/Repair, Deliver, and Return. The entire set of end-to-end metrics are organized around three top-level metrics:

- Reliability, which is measured by Perfect Order Fulfillment (POF).
- Speed, which is measured by Customer Wait Time (CWT).
- Efficiency, which is measured by Total Supply Chain Management Cost (TSCMC).

DOD 4140.1-R, DOD Supply Chain Materiel Management Regulation identifies the supply chain processes of Plan, Source, Maintain/Make, Deliver and Return as a framework for developing, improving and conducting materiel management activities. It requires the DOD Components to:

- Plan process: Conduct demand and supply planning.
- Source process: Perform materiel sourcing and acquisition and manage their sourcing infrastructure.
- Maintain/Make process: Manage production, manufacturing, repair, overhaul, and testing functions performed at organic or private sector facilities or through public and private partnerships at those facilities.
- Deliver process: Manage orders, distribution depots, transportation channels, and other delivery infrastructure.
- Return process: Administer customer returns of defective materiel, excess materiel, and materiel requiring maintenance, repair, or overhaul.

15.4.4 Acquisition Focus: "Dirt to Deterrence"

The acquisition supply chain looks a bit different than the classic SCOR) model.

- The "company" is replaced with the System Program Office (SPO);
- The "customer" is replaced with the Program Executive Office (PEO); and
- The "customer's customer" is replaced with the Warfighter.

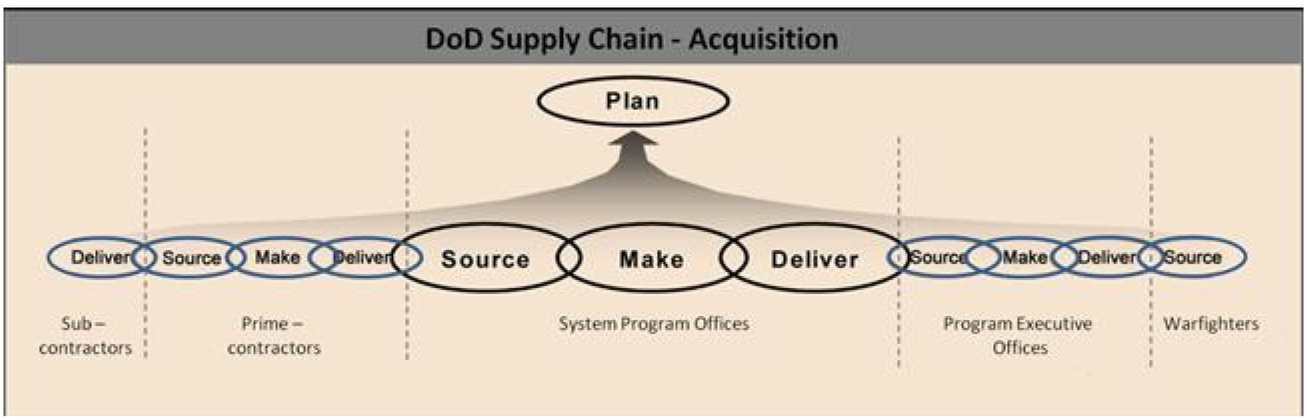


Figure 15-7 The DOD SCOR Model - Acquisition Focus

15.4.4.1 Program Office Focus

The System Program Office or SPO often looks at the supply chain as the prime contractor, major subcontractors and critical vendors and suppliers. At least that is the part of the supply chain that most concerns them. Each level of the supply chain looks upstream to the next supplier in order to pass along their requirements and synchronize deliveries. This process continues until finally someone gets concerned with how dirt gets turned into raw material. Looking forward, the SPO is somewhat concerned with the PEO and their involvement in the various milestone decisions, but their real focus is on the warfighters and the requiring command. Thus from "dirt to deterrence" the DOD program managers' role is to provide insight and oversight over their supply chain. In the end it is the program offices' responsibility to deliver a capability to the warfighter on time, within cost and with the right quality and life cycle sustainability characteristics.

15.4.4.2 Contractor/Subcontractor Focus

Prime contractors are most concerned about their subcontractors, suppliers and vendors and about the program office that manages their contract. Many of the decisions of the program office (rate and quantity) drive other contract, design, logistics and other functions. The subcontractors are concerned about their suppliers and vendors and the requirements coming from the prime contractor. Many of the decisions made by contractors are reflected in make/buy decisions, and these decisions are hopefully made on the basis of more than low cost and schedule.

In addition to make/buy plans the contractors need to be concerned about the development of several planning documents. Many of these documents require insight into the supply chain for the proposed effort. The Integrated Master Schedule, for example, needs to have input from downstream suppliers, and they need critical need dates from the prime contractor. Designers need to know key interface dimensions and other physical characteristics in order to produce parts and subsystems that will eventually be integrated together. Thus prime contractors, subcontractors and vendors are concerned about getting the right item, in the right quantities, to the right locations, at the right time, and with the appropriate quality levels. Cost and manpower estimates need to have inputs from many sources within the supply chain if an accurate estimate is to be had.

15.5 Transforming Defense Supply Chains

The complexity of the DOD supply chain in total or for any one weapon system is staggering with a supply chain that often encompasses hundreds of vendors and subcontractors, from many states and countries, all having a need to maximize profit, while minimizing cost and uncertainty. Adding to the complexity is the fact that on many of our large weapon system programs the prime contractor is often the integrator, with up to 80 percent of the value of the program coming from subcontractor, and other vendors or suppliers. Thus managing the supply chain becomes a key and critical management function.

Transforming the supply chain from a loosely managed function to one that is well integrated, and focusing on the capabilities of upstream partners is a new challenge. The entire procurement team (prime, subcontractors and vendors) need to work together to add value while driving out cost and risks.

15.5.1 Problems Managing the Supply Chain

Uncertainty in the commercial sector sometimes comes many sources. One of the largest sources of uncertainty comes when senior management attempts to estimate the success of a new product and provides a production estimate to supply chain members down the line. If they estimate too low, then they run the risk of running out of product and angering their customers. If they estimate too high, then they are left with excess inventory and must sell the remaining stock at a loss.

Uncertainty in the DOD sector sometimes comes from failure of the contractor and SPO to manage cost, schedule and performance. When the cost becomes too excessive, Congress or others within the administration may elect to reduce the final production quantity. This in turn drives unit cost up, which in turn tends to force another round of rate and quantity reconciliations. This can become a death spiral as once the factory has been set for one rate and quantity curve, any adjustments, up or down, will have an effect on unit costs.

Each of these uncertainties can lead to what is called the "bullwhip effect." The bullwhip effect refers to swings in inventory that are caused by changes in demand. This can cause manufacturing cost, inventories, lead times, and transportation cost to rise and customer satisfaction and profits to fall. Moving upstream from the customer, the effect or impact becomes greater and greater as companies upstream build inventory to mitigate risks to the changes in demand. While inaccurate demand forecasting is often a source of variability that can contribute to the bullwhip effect. Other sources of variation can include:

- Changes to lead times (especially if on the critical path);
- Problems at a key or critical vendor (strikes, poor quality, plant shutdown, etc.); and
- Price fluctuations in critical materials to name a few.

Let's look at two very real scenarios that can drive demand forecasting.

Scenario 1: A rise in the use of improvised explosive devices (IEDs) in Iraq resulted in almost 3,000 U.S. troops being killed. As a result the military had an urgent need for a Mine Resistant Ambush Protected (MRAP) vehicle. Development and rampup of the program had to happen quickly. This required the use of an existing supply chain, using fairly mature materials and proven manufacturing techniques. From the program office, to the prime contractor(s) and their supply chain the message was clear, "work together, work fast, and get results."

Scenario 2: The President calls for the end of NASA's space shuttle program resulting in the cancellation of the Constellation program. One of the major components used in space launches is the shuttle boosters, a solid rocket engine built by ATK in Utah. The shuttle's solid rocket motors are ten times larger than the next biggest solid rocket motor, the Navy's Trident D-4. In fact, the shuttle motors are so large that they constituted 70 percent (by weight) of the demand base for solid rocket motor propellants. Upstream in ATK's supply chain is a company called American Pacific, and they make ammonium perchlorate (AP), a critical propellant ingredient. And that is all they make at their Utah facility. Since their factory has been set up to produce "X" amount of AP at known cost, the cancellation of the Constellation program resulted in a 70 percent cut in production, but their fixed costs remained the same. The cancellation of the Constellation program sent such a sever ripple through the supply chain that Congress called for the Secretary of Defense to review and establish a plan to sustain the Solid Rocket Motor (SRM) Industrial Base (IB).

Some of the ways to cope with the bullwhip effect include:

- Developing strategic partnerships with vendors and suppliers;
- Stronger collaboration of information (especially forecasting data);
- Reducing lead times on the critical path; and
- Reducing variability.

15.5.2 Software Tools That Support SCM

There are numerous supply chain management software (SCMS) tools that can aid in the planning, forecasting and integration of procurement, production, and distribution information between suppliers and customers. These software tools are aimed at the strategic, tactical and operational level and are often used to manage the following applications:

- Supply Chain Planning,
- Demand Planning,
- Vendor Managed Inventory,
- Supplier Management,
- Procurement,
- Strategic Sourcing,
- Warehouse Management,
- Transportation Management,
- Order Fulfillment, and
- Contract Management.

Key capabilities of software tools include the following:

- Demand Planning made up of forecasting tools, web-based collaboration interface, and sales and operations reporting and metrics that help companies predict and shape customer demand with greater accuracy.
- Distribution Planning made up of inventory analysis and time-variable stock target calculations for ensuring the optimal balance between service levels and inventory investment; synchronized replenishment plans points right back to manufacturing and supplier sources for better visibility.
- Manufacturing Planning made up of advanced planning system for engineering, assembly, and repetitive manufacturing environments; similar tools for process manufacturers.
- Production Scheduling made up of finite capacity scheduling for engineering, assembly, and repetitive environments, as well as batch-process production facilities.
- Transportation and Logistics Planning made up of transportation planning, transportation procurement, route planning, transportation management, small parcel shipping, and international trade logistics for global, multi-modal operations.
- Warehouse Management System made up of end-to-end fulfillment and distribution including inventory, labor, and work and task management, as well as cross-docking, value-added services, yard management, multiple inventory ownership and billing/invoicing, and voice-directed distribution.

15.5.3 Supply Chain Metrics

Supply chain metrics are used to track supply chain performance and cover many areas or functions to include procurement, production, warehousing/distribution center, distribution of materiel, and customer response. Tracking metrics will allow for benchmarking, viewing performance over time, identifying problem areas and optimizing the supply chain. Supply chain metrics can be broken down into two types of metrics: supply chain performance and logistics performance.

- Supply chain metrics are tools used to measure and analyze the entire supply chain by integrating the various independent processes. The process must begin with planning the acquisition of customer driven requirements for materiel, including the returns segment of the process, and the flow of required information in both directions among suppliers, logistics managers, and customers. Supply chain metrics must have the capability to "peel back" the data to facilitate review by managers at all levels. Supply chain metrics often employ the balanced scorecard technique to measure the criteria of time, quality, cost, and variability across the entire supply chain. The aim is to purge the logistics process of unnecessary elements - those that do not add value - and to find and act upon opportunities for improvement. Logistics performance metrics are tools used to measure a particular process within the supply chain.
- Logistics includes seven interdependent processes: customer response, inventory planning and management, supply (manufacturing/procurement), maintenance, warehousing/distribution center, distribution of materiel, and reverse logistics. Logistics performance metrics are diagnostic in nature. They also must have the capability to "peel back" the data to facilitate review by managers at all levels.

Measuring the performance of a supply chain has always been difficult to answer in a single slide or metric. There are over a hundred metrics identified by the Supply Chain Operational Reference (SCOR) model. Some metrics that look good one month may not the next. The metrics below are a few that are often used by SC managers and are applicable to logistics and acquisition professionals:

• Fill Rate: • Delivery Performance: • Perfect Order Fulfillment:	Measures Supply Chain Reliability
• Order Fulfillment Lead Time:	Measures Supply Chain Responsiveness
• Supply Chain Response Time • Production Flexibility	Measures Supply Chain Flexibility
• Cost of Goods Sold • Total Supply Chain Management Costs • Warranty Costs	Measures Supply Chain Costs

• Cash-to-Cash Cycle Time • Inventory Days of Supply • Asset Turns	Measures Supply Chain Efficiency

Table 15-1 Potential Supply Chain Metrics

Many of these measures or metrics focus on the "3-Vs:"

- Visibility: Knowing what you have and where it is located;
- Velocity: Getting inventory moving through the system efficiently; and
- Variability: Involves identifying and reducing variability so that the supply chain becomes more predictable.

These metrics are somewhat complicated to calculate and the above descriptions do not adequately describe the full extent of the metric. In addition, given the focus on just-in-time (JIT) inventory management, supply chain managers need to ensure that sources of material to not suddenly dry up. JIT can leave companies and organizations vulnerable to interruptions in the supply chain. Finally, it is important to recognize that there are some cases where JIT should not be applied such as for medical supplies, and for ammunition, water, and rations for the warfighter in a forward area. This is where a good SC manager can assist the program in establishing and understanding the full impact of the metrics chosen, and in developing contingencies to ensure the supply chain remains unbroken.

15.6 The Future of Suppliers

There is no doubt that our world is changing. Within the aerospace and defense industry there has been considerable consolidation with DOD attempting to adopt many commercial best practices. With two wars, the DOD has learned to become more responsive and adaptive, able to bring some new systems to the field in record time (MRAP) while failing to achieve baseline goals on other programs (Joint Strike Fighter). So what is in store for supply chains of the future?

15.6.1 Global

The supply chains of the future will increasingly become global. Programs like the Joint Strike Fighter will not only want to have suppliers from every state to garner political support for a program, but will look towards our allies to become partners in the design, development and production of the next generation of weapon systems. Globalization will require global visibility into the sources and resources within the supply chain.

15.6.2 Connected and Integrated

Global visibility will require a supply chain that is connected and integrated. Engineers will need to be able to share data and designs with other engineers in disparate locations. Procurement personnel will want to share demand data with suppliers and vendors. Every function will need the capability to work in a virtual environment and be able to share critical data in a timely manner. Computing capability, software tools and internet connectivity will become a tools to leverage these various knowledge bases.

15.6.3 Lean and Agile

Variation in demand data is a source of risks in the supply chain and so is variation on the factory floor. Companies need to be able to provide the right material, at the right time, right place, and right cost with the requisite quality if they are to continue to become supply chain partners. Lean and agile need to become basic building blocks of suppliers.

15.6.4 Sustainable and Green

The increasing globalization leads companies towards the development of strategies that support the goals and wishes of multiple customers. This includes the requirements of many countries, especially European countries, that have stiff environmental regulations and goals. The drive towards a sustainable enterprise has been growing constantly since the first Earth Day in 1970. Now it is not enough just to recycle or to produce less waste, or not pollute. Today's businesses need to be proactive and design in to their products the ability to sustain production indefinitely by using resources that are renewable.

15.7 Sustainable Manufacturing

Industry needs materials and natural resources in order to produce products. Those resources are not limitless, and the demand by customers for products is growing. Sustainable manufacturing looks to develop methods for ensuring that future generations will be able to enjoy a high standard of living without damaging the environment.

15.7.1 Sustainable Manufacturing Defined

Sustainable manufacturing can be defined as " *manufacturing products with economically sound processes while avoiding negative impacts to the environment, on energy and natural resource use, and with regard for the safety of the warfighter, user, employees, and community* ." Sustainable manufacturing includes not only the materials and processes used during production, but includes the final product, and that final product must also be economically sound, non-polluting, energy efficient, conserving natural resources during use, and are safe to dispose, safe for the users (warfighters), maintainers, employees and communities in which they are used.

Sustainable manufacturing includes all of the manufacturing functions (manpower, machines, materials, methods and measurements) and all of the other front and back office functions. Sustainable manufacturing should be considered throughout the acquisition life cycle and procurement phases of a program.

The National Institute of Standards and Technology (NIST) has developed a closed loop view of sustainability (Figure 15-8) that is comprised of two connected cycles that require life cycle thinking. This life cycle thinking considers everything from:

- Raw material extraction and processing;
- Pre-design and fabrication of relevant semi-finished product;
- Manufacturing and assembly of the final product: and
- End-of-Life operations to include:
    - Recycling
    - Disposal

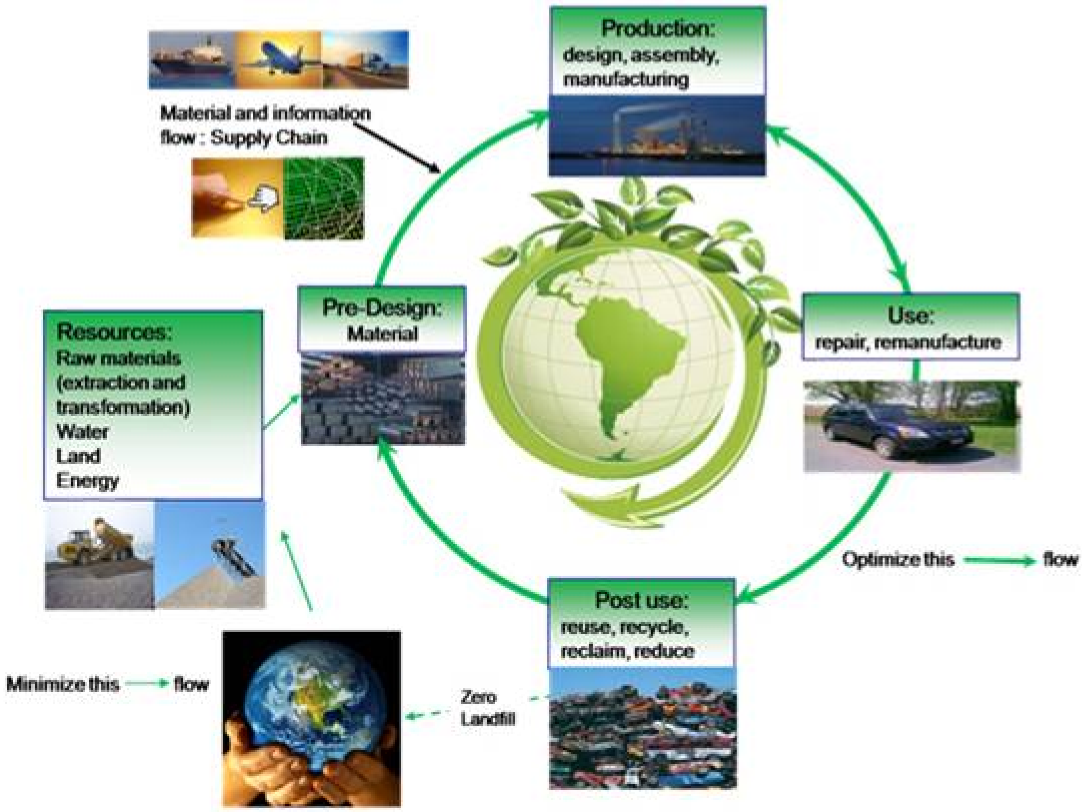


Figure 15-8 NIST Closed Loop View

15.7.2 Sustainable Design

Sustainable "green" design is a design philosophy that values natural resources as a major factor in creating new products and seeks to reduce or eliminate negative environmental impacts though thoughtful consideration of environmental factors. This is also referred to as environmental design, environmentally sustainable design, environmentally-conscious design, design for the environment (DfE), Design for Sustainability (DfS), etc. Design for Sustainability (DfS) includes the following sustainable manufacturing considerations:

- Use Low Impact Materials,
- Reduce Materials Usage,

- Optimize Production Processes,
- Optimize Distribution System,
- Reduce Impact During Use,
- Optimize Initial Lifetime, and
- Optimize End of Life.

15.7.3 Sustainable Manufacturing Considerations

"Using Low Impact Materials" means using materials that offer a lower initial and life cycle cost. These materials may be cleaner, renewable, have a lower energy content than other proposed materials, can be recycled and are recyclable.

"Reducing Materials Usage" means aiming to reduce by weight or volume the amount of materials used in the final product or by reducing the transportation and storage cost by decreasing the product's size and total volume.

"Optimizing the Production Processes" means to use techniques (Lean, et. al.) to find lower impacting production processes; using processes that require fewer production steps; using processes that use less energy in the transformation process; using processes that create less waste; using processes that use fewer consumables; and finally using production processes that promote safety and cleanliness.

"Optimizing the Distribution System" means to use less packaging or packaging that is reusable or cleaner; using more energy efficient modes of transportation; and involving or utilizing local suppliers for less travel.

"Reducing Impact During Use" means to use less energy during its life; have the ability to use clean energy; to minimize the use of consumables (e.g. water usage); to use cleaner consumables; and to reduce the wasting of consumables and energy, that is improve efficiency.

"Optimizing Initial Lifetime" means to design for easier maintenance, repair or upgrades through modular design; to design with local maintenance and support/service systems in mind; and to add value to the design so that the user does not need a new model every few years.

"Optimizing the End of Life" means to find ways to re-use the product; by refurbishing and old item that is still usable; by recycling materials; by designing to optimize the disposal and demilitarization costs.

15.7.4 Sustainable Manufacturing Strategy

Each of the services and agencies has a Sustainable Manufacturing (Production) strategy and focus. Strategies that impact the way that program managers conduct major weapon system acquisition and the way that they conduct depot level support.

- **Weapon System acquisition** focuses mainly on the procurement process and the program manager's role in defining the requirements for Sustainable Production to the potential contractors. Then it is up to the contractor, with government oversight, to live up to those requirements. Decisions by the government program office and contractors will define their environmental footprint. The Program Manager and the Integrated Product Team need to be concerned about integrating sustainable manufacturing/design into their planning and processes when acquiring (design, development and production) a new weapon system in order to minimize their environmental footprint that could include lots of design and manufacturing considerations.

- **Depot level support** has the depot managers acting more like the contractor as they have direct hands-on responsibility for Sustainable Production implementation. Their decisions on how they are going to provide MRO functions will define their environmental footprint. Maintenance, repair and overhaul (MRO) facility managers engage depot-level support need to be concerned about environmental laws and sustainable manufacturing practices so they do not leave behind an environmental footprint as they prepare to tear down, repair, rebuild or dispose and de-militarize a weapon system.

15.8 Summary

Bottom-line: Supply chains are our sources of products and services. There are many demands on supply chains that need to be managed if we are going to be able to provide our warfighters with the systems they need in order to do their job. This chapter addressed the following:

- Describe the SCOR model as it relates to the DOD;
- Identify some of the roles and responsibilities of the various players in SCM;
- Describe some of the problems in managing a supply chain;
- Identify software tools that will help to manage supply chains;
- Describe some SCM metrics;
- Identify contract language that may be used to enhance SCM activities; and
- Define sustainable manufacturing (SM) and identify some SM considerations.

15.9 Related Links and Resources

Numerous reference documents impact the manufacturing management function throughout the acquisition process. These documents originate from many sources and range across academic disciplines, functional activities, and job specialties.

The following is a reference list of DOD Directives (D), Instructions (I) Manuals (M), Pamphlets (P), Military Standards (MS), and other documents. The documents listed contain DOD policy guidance applicable to the manufacturing management function. They are listed as sources of DOD manufacturing management information.

Note: Many of the documents listed are no longer required (due to acquisition reform), but still contain some very valuable information.

Number	Title
	The SCOR Model
	Supply Chain Management Strategy (DoD)

	Proposed Joint Supply Chain Architecture (JSCA) Supply Chain Metrics
DoD 4140.1-R	DoD Supply Chain Material Management Regulation
	From Factory to Foxhole: The Transformation of Army Logistics Supply Chain Management: A Recommended Performance Measurement Scorecard

Defense Manufacturing Management Guide for Program Managers
Chapter 16 - Manufacturing Problems and Organic Capabilities

16.1 Objective

The objective of this chapter is to explore the numerous manufacturing problems, and manufacturing solutions that could impact DOD weapons system programs.

16.2 Background

Some manufacturing problems are literally older than dirt. Take for example brick making. The oldest bricks discovered were made from mud and date back to 7500 B.C. Later, around 4000 B.C., artisans in Mesopotamia discovered how to make sun dried bricks. But bricks, like many products, sometimes failed to maintain their integrity, and when that happened walls collapsed often killing the occupants of the building. Hammurabi, the sixth king of Babylonia, enacted a series of laws known as Hammurabi's Code of Laws. These laws often defined contractual relationships between people and required that people take responsibility for the quality of their product. Take these laws for example:

- If a builder builds a house for someone and does not construct it properly, and the house which he built falls in and kills its owner, then that builder shall be put to death.
- If it kills the son of the owner, then the son of that builder shall be put to death.
- If it kills a slave of the owner, then he shall pay slave for slave to the owner of the house.

Thus the builder and producer of the brick now had a vested interest in the quality of their work.

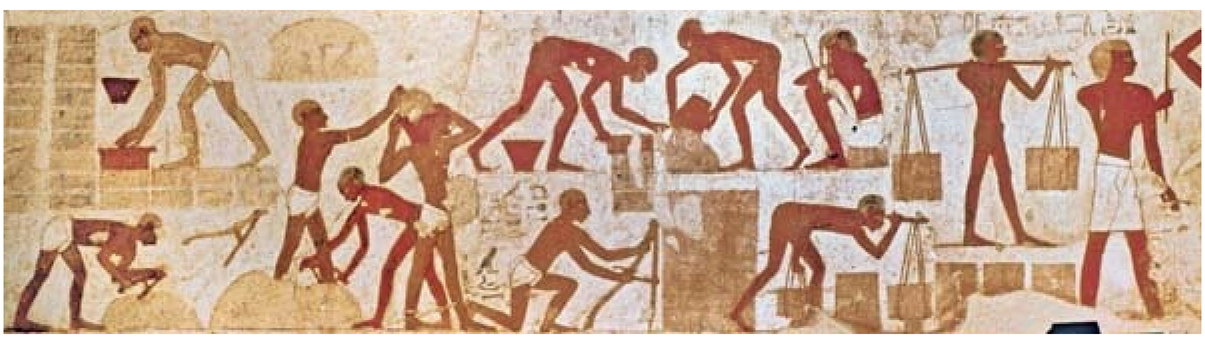


Figure 16-1 Brick making in the Tomb of King Rekhmire the Visor in Thebes

16.3 Introduction

Today's manufacturing environment, though much improved, still has many problems. Manufacturing problems that have led to cost overruns, schedule delays, and field failures, sometimes at the expense of the warfighter. Early M-16's had reliability problems during the Viet Nam war. The Apache helicopter's key weapons and other vital subsystems experienced problems during Desert Storm that were sometimes exacerbated by the harsh desert environment. Logistical support problems, such as parts shortages, grounded some Apache aircraft; however the Apache's overall combat effectiveness was not compromised. An early Blue Ribbon panel was formed by William Cohen (the Secretary of Defense) to review all aspects of the V-22 program. The panel recommended that the program continue, albeit in a restructured format. The panel concluded that there were numerous problems with the V-22 program - including safety, training and reliability problems - but nothing inherently flawed in basic tilt-rotor technology. Because of numerous safety, training, and reliability problems, the V-22 is not maintainable, or ready for operational use.

16.4 Manufacturing Problems

Some manufacturing problems are generic and repetitive, that is they seem to keep on appearing despite DOD' efforts to eradicate them. These recurring issues include:

- Diminishing Manufacturing Sources and Material Shortages (DMSMS) and Obsolescence,
- Corrosion Control,
- Counterfeit Parts,
- International Traffic in Arms Regulations (ITAR),
- Tin Whiskers,
- Environment, Safety, and Occupational Health Evaluation (ESOH), and
- Configuration Control.

16.4.1 DMSMS/Obsolescence

Anyone that has ever worked on an older car has often found that the only place to find a replacement part was at the junk yard. Welcome to the world of Diminishing Manufacturing Sources and Material Shortages (DMSMS). DMSMS can be defined as " *the loss of sources of items or material which surfaces when a source announces the actual or impending discontinuation of a product, or when procurements fail because of product unavailability.* " DMSMS may endanger the life-cycle support and viability of the weapon system or equipment.

DMSMS and obsolescence are often used interchangeably within the DOD, however there is one minor difference between the two terms. Obsolescence is a DMSMS problem that was created by a regulatory or statutory requirement. For example, the banning of lead in electronics by the European Union has led to a drop in the number of suppliers for these products. But whether it's called DMSMS or obsolescence, the outcome is the same; the customer has a product or weapon system that may no longer be supportable.

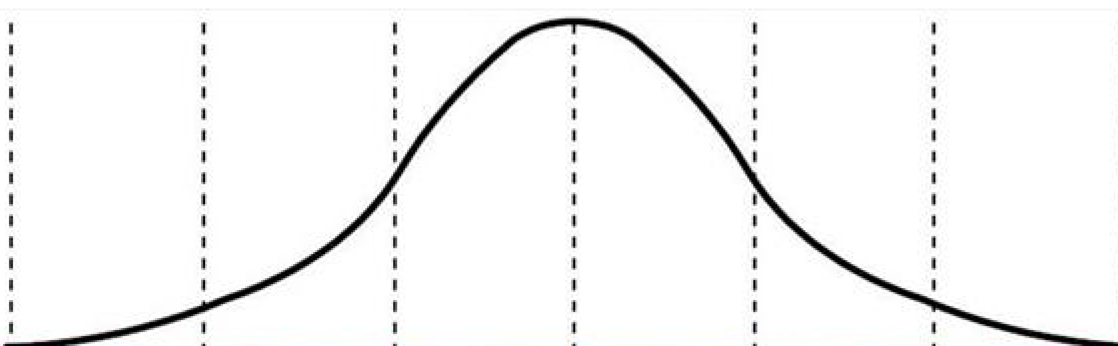
In simple terms DMSMS occurs because the market for an item, and therefore availability, shrinks to the point where it becomes unprofitable for a company to continue to manufacture the item. When this occurs, any customer (*e.g.* , DOD) that still has a requirement for that item will find it increasingly difficult to obtain the item and the cost will be markedly higher due to scarcity. Obsolescence occurs within DOD when:

- Weapon system capability becomes degraded due to reduced availability of parts and sources.

- New technology displaces old.
- Costs become unaffordable for production, support, and sustainment.

A products life cycle is marked by the introduction of new products and the phasing out of older products. Many products have six stages of life as identified in the product life cycle chart:

- **Introduction** occurs when a new product is introduced into the design of a system or subsystem.
- **Growth** occurs as more engineers design products using the item and demand increases.
- **Maturity** occurs when the product becomes a staple component in many designs or systems and there are often multiple sources of supply.
- **Saturation** occurs when there are more devices than there is demand.
- **Decline** occurs when new products are being introduced and the older design is no longer being used.
- **Phase-out** occurs when there is very little requirement for the older part as it has been almost totally replaced by a newer design and production becomes limited until there is no production at all.



	Stage 1 Introduction	Stage 2 Growth	Stage 3 Maturity	Stage 4 Saturation	Stage 5 Decline	Stage 6 Phase-Out
Sales	Slow increase	Increase rapidly	Stable	Leveling out	Decreasing	Lifetime buys offered
Price	Highest	Declining	Stable	Stable	Rising	High
Usage	Low	Increasing	Stable	Stable	Decreasing	Decreasing
Part Modification	Frequent	Major	Periodic changes	Few	Few or none	None
Competitors	Few	High	Stable	Decline begins	Declining	Declining
Manufacturer Profit	Low	Increasing	Stable	Stable	Reasonable for survivors	Reasonable for survivors (aftermath)

Figure 16-2 Product Life Cycle Chart

Microelectronics is a special concern due to its short product life. Gordon Moore was an engineer working for Fairchild when he theorized that the number of transistors on an integrated circuit would double every two years which would greatly to the shortened life cycle of electronics (Moore's Law). Many of DOD's DMSMS and obsolescence problems deal with electronics and electronic parts. However, there are issues with mechanical and material solutions. For example, in the mid-1960's the U.S. Navy brought the U.S.S. New Jersey out of mothballs in order to retrofit the ship to support the war in Viet Nam. Program officials soon discovered that the manufacturers of the 16 inch guns were no longer in business and there were no adequate technical data packages for the worn-out parts requiring replacement.

There are resources available for in a search for support or solutions for DMSMS/ Obsolescence problems to include, the new SD-22, Department of Defense (DOD) "Diminishing *Manufacturing Sources and Material Shortages (DMSMS): A Guidebook of Best Practices and Tools for Implementing a DMSMS Management Program* ," and the Defense Acquisition University (DAU) has several courses on DMSMS to include:

- CLL 201 -- DMSMS Shortages Fundamentals.
- CLL 202 -- DMSMS Executive Course.
- CLL 203 -- DMSMS Essentials.
- CLL 204 -- DMSMS Case Studies.
- CLL 205 -- DMSMS for Technical Professionals.

16.4.2 Corrosion Control

Corrosion is defined as " *the unintended destruction or deterioration of a material due to interaction with the environment* ." Corrosion can include:

- Rusting,
- Pitting,
- Galvanic reaction,
- Calcium or other mineral buildup,
- Degradation due to ultraviolet light, and
- Mold, mildew or other organic decay.

In recognition of the harm that corrosion can cause, Congress enacted, as part of the Bob Stump National Defense Authorization Act of Fiscal Year 2003, legislation that requires DOD to designate a senior official or organization responsible for preventing and mitigating the corrosion of military equipment and infrastructure. As a result of the act the Under Secretary of Defense for Acquisition Technology and Logistics (OUSD(AT&L)) established the Office of Corrosion Policy and Oversight. This office created a state-of-the-art corrosion prevention and control information management and distribution e-portal called CorrDefense. CorrDefense has a Reference Library which includes policy, academia, government and industry references as well as technical papers and images. Members of CorrDefense have access to:

- Searchable DOD corrosion projects database - This is a database of 407 corrosion projects. It contains data elements such as: project title, authors, abstract keywords, and subject terms.
- Member list and search capability - Subject to security restrictions, members will be able to learn about other CorrDefense members and search for particular expertise.

- CPCIPT-sanctioned working integrated product teams - There are presently seven WIPTs and they run the gamut from "Communications and Outreach" to "Training and Certification."
- Member-generated working groups - Members can also propose the formation of working groups dedicated to a particular subject area. Examples include: Army Aviation Corrosion Prevention; Coatings and Linings; and Ships and Submarines.
- Collaboration tools - These capabilities include email, content upload, and announcement/event posting.

The Defense Science Board (DSB) in a 2004 report on Corrosion Control recommended the following:

Defense Science Board Recommendation	DOD Response
Develop incentive structures to ensure corrosion and life cycle cost considerations in all designs and manufacturing.	Concur
Mandate corrosion testing and reporting at all stages of development.	Concur
Issue directive to require that all major weapon system corrosion prevention advisory team members complete a Defense Acquisition University-developed course on corrosion control.	Concur
Accelerate the introduction of activity based cost accounting to ensure future visibility into actual life cycle cost and cost of corrosion.	Concur
Direct the services to conform with these standards and to enable capture of complete and accurate organizational, intermediate, and depot-level corrosion man-hour, material, and cost data.	Concur
Use these data to make fact-based decisions regarding corrosion and corrosion cost and to track progress of platform material improvement efforts.	Concur
Implement well-defined maintenance programs that included continuous corrosion performance improvement and continuing assessment and reporting.	Concur
Require each service to contract and execute its part.	Concur
Have all results reported to a common database for analysis and to support the development of a joint strategy for corrosion maintenance that accommodates the unique factors associated with each service and system.	Concur
Extend assessment database to capture existing aircraft and ship corrosion data.	Concur
Establish a corrosion executive for each service with responsibility for oversight and reporting and full authority over corrosion-specific funding and a strong voice in corrosion-related funding.	Concur

Table 16-1 Defense Science Board Recommendations

According to DOD Directive 5000.1, The *Defense Acquisition System* , corrosion prevention control and mitigation ***will be*** considered during life-cycle cost tradeoffs. Consideration of operational and logistics capabilities (such as readiness, reliability, sustainability, and safety) is critical to ensure the effectiveness of a weapon system, and is usually accomplished during conceptual design, when the effects of corrosion on these capabilities should be addressed as well. Corrosion can have a significant impact on operational readiness and safety (both by itself and in conjunction with other damage phenomena), and its interactions with these factors should be considered during the conceptual design phase.

However, corrosion problems still persist. In a 2007 GAO Report (**GAO-07-618**) they found that most of the weapon system acquisition programs they reviewed had not incorporated key elements of corrosion prevention planning. Of the 51 major acquisitions reviewed in 2007, only 14 had both corrosion prevention plans and advisory teams. And today the DOD spends an estimated $22 billion each year on corrosion-related maintenance on weapon systems and infrastructure. Corrosion can affect mission readiness by taking critical systems out of action. Corrosion also affects safety. For example, since 1985, the Army has reported over 50 aircraft accidents, including 12 fatalities, caused by corrosion. Incorporating corrosion prevention planning early in the acquisition process is the most effective way to reduce and perhaps avoid corrosion impacts in terms of costs, readiness and safety.

The following Corrosion Control resources are available to anyone needing support for problems to include:

- Learning and resource material at https://acc.dau.mil/corrosion .
- CorrDefense resources at https://www.corrdefense.org/default.aspx .

The Defense Acquisition University (DAU) has a continuous learning module on corrosion control:

- CLM 038 -- Corrosion Prevention and Control Overview.

16.4.3 Counterfeit Parts

Generally, the term counterfeit refers to instances in which " *the identity or pedigree of a product is knowingly misrepresented by individuals or companies* ."

DOD draws from a large network of global suppliers and manages over 4 million different parts at a cost of over $94 billion; therefore, counterfeit parts can enter its supply chain. Almost anything is at risk of being counterfeited including fasteners used on aircraft, electronics used on missile guidance systems, and materials used in body armor. Counterfeit parts have the potential to cause a serious disruption to DOD supply chains, delay ongoing missions, and even affect the integrity of weapon systems. Counterfeits are not limited to the DOD supply chain and exist in other government entities, such as the National Aeronautics and Space Administration and the Department of Energy, as well as in many commercial settings as diverse as software, commercial aviation, automotive parts, and consumer electronics and can threaten the safety of consumers.

Counterfeiting can affect the safety, operational readiness, costs, and the critical nature of the military mission. DOD procures millions of parts through its logistics support providers - DLA supply centers, military service depots, and defense contractors - who are responsible for ensuring the reliability of the DOD parts they procure. As they draw from a large network of suppliers in an increasingly global supply chain, there can be limited visibility into these sources and greater risk of procuring counterfeit parts. Also, as DOD weapon systems age, products required to support it may no longer be available from the original manufacturers or through franchised or authorized suppliers but could be available from independent distributors, brokers, or aftermarket manufacturers. Parts and components bought by DOD can come from different types of suppliers, as shown in Table 16-2.

Table 1: Types of DoD Suppliers of Parts and Components Type of Source	**Description**
Original component manufacturer (OCM)	Organization that designs, or engineers, or both, a part and is pursuing or has obtained the intellectual property rights to that part.
Franchised distributor	Distributor with which OCM has a contractual agreement to buy, stock, repackage, sell and distribute its product lines.
Independent distributor	Distributor that purchases new parts with the intention to sell and redistribute them back into the market, and which does not have contractual agreements with OCM.
Broker / broker distributor	In the independent distribution market, brokers are professionally referred to as independent distributors. A broker distributor is a type of independent distributor that works in a just-in-time environment by searching the industry and locating parts for customers.
Aftermarket manufacturer	Manufacturer that either produces and sells replacement parts authorized by the OCM, or produces parts through emulation, reverse-engineering, or redesign that matches OCM specifications and satisfies customer needs without violating OCM intellectual

Table 16-2 Types of DOD Suppliers

In June 2007, the U.S. Department of the Navy, Naval Air Systems Command (NAVAIR) asked the Bureau of Industry and Security's (BIS) Office of Technology Evaluation (OTE) to conduct an assessment of counterfeit electronics in the DOD supply chain. The OTE developed the following general findings:

- All elements of the supply chain have been directly impacted by counterfeit electronics;
- There is a lack of dialogue between all organizations in the U.S. supply chain;
- Companies and organizations assume that others in the supply chain are testing parts;
- Lack of traceability in the supply chain is commonplace;
- There is an insufficient chain of accountability within organizations;
- Recordkeeping on counterfeit incidents by organizations is very limited;
- Most organizations do not know who to contact in the U.S. Government regarding counterfeit parts;
- Stricter testing protocols and quality control practices for inventories are required; and

- Most DOD organizations do not have policies in place to prevent counterfeit parts from infiltrating their supply chain.

Increasing globalization and obsolescence of systems offer continuing and growing opportunities for introduction of counterfeit parts into DOD systems. The vast majority of counterfeit parts are suspected to originate in countries of East and Southeast Asia. These components not only have increased likelihood of failure but also the potential to house malware. A January 2010 report by the Department of Commerce (DOC) on counterfeit electronics found that 39 percent of organizations surveyed had encountered counterfeits. Incidents of counterfeit parts more than doubled from 2005 to 2008. This is of particular concern to the SIB due to the need for reliable, radiation-hardened electronics in spacecraft. The DOC survey also found that most DOD organizations do not have policies to prevent counterfeits from penetrating their supply chain. The GAO had similar conclusions in a March, 2010 report, citing that DOD did not have a standard definition for "counterfeit," a consistent process to detect them, or an effective counterfeit parts tracking system.

There are resources available to help people identify and resolve Counterfeit Parts problems to include:

- Learning and resource material at https://acc.dau.mil/CommunityBrowser.aspx?id=467555 .
- https://acc.dau.mil/CommunityBrowser.aspx?id=484224

The Defense Acquisition University (DAU) has a continuous learning module on Counterfeit Parts:

- CLM 038 -- Counterfeit Parts.
- CLL 032 -- Preventing Counterfeit Parts from Entering the DOD Supply System.
- CLL 206 -- Parts Management Executive Overview.

16.4.4 International Traffic in Arms Regulation (ITAR)

The International Traffic in Arms Regulations (ITAR) was born out of the Cold War in an attempt to restrict technology transfer to the former Soviet Union. ITAR is the government regulation that controls the export of defense-related articles and services that are on the United States Munitions List (USML), including technical data, ensuring compliance with the Arms Export Control Act (22 U.S.C. 2751 et seq.). ITAR is administered by the State Department. ITAR requires that exporters obtain written permission from the State Department's Directorate of Defense Trade Controls (DDTC) prior to exporting defense related articles or services or of ITAR controlled technical data. ITAR also includes a list of countries that are subject to U.S. embargo.

The export of technical data may adversely impact the U.S. national security and industrial base. Some companies try to avoid the challenges of export controls by not bidding on military contracts assuming that export controls do not apply to commercial products (they do), or by not entering export controlled business segments altogether. These actions deprive the industrial base of broader markets, innovation, new technology, and capital. Companies that do sell to the defense sector often sub-optimize their defense products in an attempt to protect their commercial market products. Foreign firms have been energized to fill the void left by U.S. companies and have even create "ITAR-free" products that have no U.S. components leaving them free to sell to a third country.

In a 2008 study by the Center for Strategic & International Studies (CSIS), they stated that the cost of ITAR compliance is about $50M a year, while approximately $600M is lost annually in revenue due to licensing issues. And this is just for the Space Industrial Base. This study also cited that export controls are the top barrier to foreign space markets for the U.S. space companies as they cannot sell their technologies to many foreign governments or to companies within their border.

The impact of export controls can be more severe in the lower industrial base tiers since smaller firms do not have as many resources to cope with compliance costs. This is of concern since significant research and development occurs in the lower tiers. There is renewed interest from both the executive and legislative branches to reexamine export controls, including controls on satellites. Changes to controls must balance U.S. space industry health and competitiveness with national security considerations.

There are resources available to anyone needing support for ITAR Parts problems to include:

- ITAR Regulations at http://www.pmddtc.state.gov/regulations_laws/itar_official.html .
- DFAR PGI 204.73 Export-Controlled Items.
- DAU Acquisition Community Connection on Technology Transfer and Export Control at https://acc.dau.mil/CommunityBrowser.aspx?id=467062 .
- Executive Order 13526 -- Classified National Security Information Memorandum, 29 Dec. 2009.

The Defense Acquisition University (DAU) has a continuous learning module on ITAR:

- CLI 007 -- Technology Transfer and Export Control.
- PMT 203 -- International Security and Technology Transfer and Control.

16.4.5 Tin Whiskers

DOD and the U.S. aerospace industry want electronic components, particularly those used in applications requiring high-reliability performance, that are made with leaded solder and finishes. However, finding such components is difficult because of bans on the use of lead. Without lead, solder is more brittle and, therefore, may not be able to handle mechanical stresses such as the g-force created when spacecraft lift off.

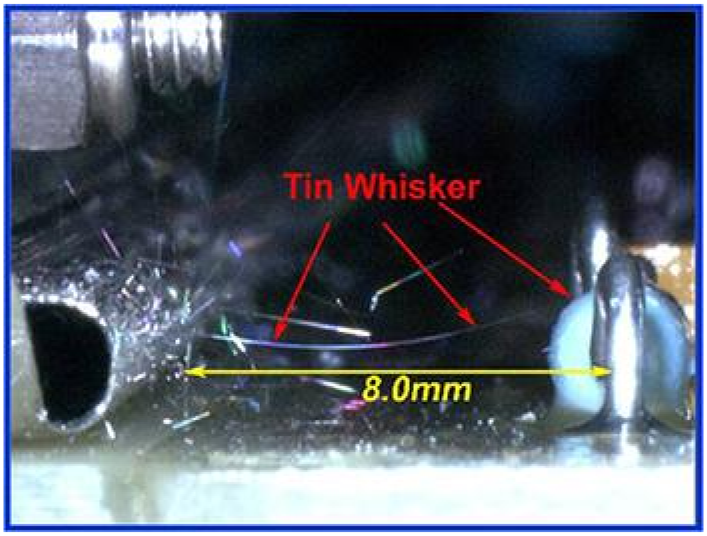


Figure 16-3 Tin Whiskers

Lead-free finishes can be problematic because of the risk of tin whiskers. Tin whiskers (Figure 16-3) are " *elongated, electrically conductive crystalline structures that grow spontaneously from pure-tin surfaces* ." Tin whiskers have caused failures in electronics by short-circuiting to adjacent conductors. Aircraft, satellites, and missiles also have failed due to tin-whisker short circuits. In 1998, a $250 million Galaxy IV communications satellite was lost after two processors failed; the backup satellite could not be used because tin whiskers had shorted it out a year before. At least ten other satellite failures have been blamed on tin whiskers. Most tin whisker-related failures occur after one to three years of service, early in the life cycle of defense weapon systems. Other failures include:

- Nuclear Utilities,
- Patriot Missile (PAC-2),
- Heart Pacemakers, and
- F-15 Radar.

The risks related to leaded versus lead-free components are twofold: the difficulty of finding manufacturers that will produce electronic components using lead solder and finishes, and the difficulty of distinguishing between parts that appear to be identical but are, in fact, different in terms of their lead content - some are lead free while others are not.

Lead has long been known as hazardous to humans and the environment, and its use has, for many years, been banned in many products and processes. In an effort to further reduce the risks, the European Union nations sought to reduce the amount of lead in the manufacturing process by issuing the RoHS and WEEE directives, which became European law in 2003. Beginning on July 1, 2006, the European Union began banning the import of electronic components that include lead and other heavy metals. The United States, Japan, China, South Korea, Argentina, and Australia have taken similar measures.

To be able to sell parts to countries in Europe and beyond, and to remain competitive, manufacturers must comply with the RoHS and WEEE directives. The RoHS and WEEE directives do not apply to defense and aerospace products. However, the defense and aerospace industries depend on commercial manufacturers as their sources for electronic components. Manufacturers design and produce electronic components primarily for the commercial market, and those products are lead free. Producing the same product, but using lead, for the defense and aerospace industries would not be economical, because the defense and aerospace requirement for electronic components accounts for less than one percent of the electronic components market. Few, if any, can afford to operate two independent manufacturing lines for the same product, one without lead and one containing lead. The end result is that many key components and assemblies used in aerospace systems are now available only in their lead-free forms.

There are resources available for research on Tin Whiskers problems to include:

- Learning and resource material at https://acc.dau.mil/ .

The Defense Acquisition University (DAU) has a continuous learning module on Tin Whiskers:

- CLL 007 -- Lead Free Electronics Impact on DOD Programs.

16.4.6 Environment, Safety, and Occupational Health (ESOH)

Hexavalent chromium is a heavy metal that has been used in the metal plating processes for over fifty years to coat, paint, and protect base metals. Hexavalent chromium is an excellent corrosion inhibitor used in numerous DOD weapons systems and platforms to include land, marine, and aircraft systems. In other words, we know this material and manufacturing processes. However, hexavalent chromium is a recognized carcinogen and as such its inherent risks must be managed and controlled. Numerous DOD studies (ManTech projects) are under contract to identify, develop and demonstrate greener materials (nonchromated primers, etc.) and processes to replace hexavalent chromium and other materials of concern.

A 2010 analysis of Program Support Reviews found the following ESHO observations:

- ESOH risk data and technology requirements were not in the PESHE.
- The PESHE did not describe the actual ESOH program.
- The Program Office's System Safety and ESOH efforts were not integrated.
- There was a lack of emphasis on implementing ESOH mitigations.
- There was a failure to address the AT&L hexavalent chrome policy.

DOD Instruction 5000.02 establishes requirements for PMs to manage ESOH risks for a system's lifecycle. The PM is required to have a Programmatic Environment, Safety and Occupational Health Evaluation (PESHE) for Milestone B (or Program Initiation for ships), Milestone C, and Full-Rate Production Decision Review (FRP DR) that includes:

- Identification of ESOH responsibilities.
- The strategy for integrating ESOH considerations into the systems engineering process.
- Identification of ESOH risks and their status.
- A description of the method for tracking hazards throughout the life cycle of the system.

- Identification of hazardous materials, wastes, and pollutants (discharges /emissions / noise) associated with the system and plans for their minimization and/or safe disposal.
- A compliance schedule covering all system-related activities for the NEPA.

Program Managers (PMs) must prevent ESOH hazards, where possible, and manage their associated risks where hazards cannot be eliminated. Risk acceptance and implementation of mitigating measures is necessary to avoid loss of life or serious injury to personnel; damage to facilities or equipment; failure with adverse impact on mission capability, mission operability, or public opinion; and harm to the environment and the surrounding community.

The preferred mitigation strategy is source reduction or elimination of the hazards (pollution prevention). The PM should strive to eliminate or reduce ESOH risks as part of the system's total lifecycle risk reduction strategy. If effectively executed, ESOH risk management identifies system-specific ESOH risk information. The PM should integrate into the ESOH risk management data any additional ESOH risks or mitigation measures identified during the formal National Environmental Policy Act (NEPA)/ Executive Order 12114 analysis process.

The PM should monitor and assess the effectiveness of mitigation measures to determine whether additional control actions are required. The PM then documents the effectiveness of mitigation measures in the Programmatic Environment, Safety, and Occupational Health Evaluation (PESHE). Relevant information may include related mishap data, adverse health effects, and significant environmental impacts from system development, testing, training, operation, sustainment, maintenance, and demilitarization and disposal.

There are resources can help people solve ESOH problems to include:

- Learning and resource material at https://acc.dau.mil/esoh .

The Defense Acquisition University (DAU) has several continuous learning modules on ESOH:

- CLE 039 -- Environmental Issues in Test and Evaluation.
- CLE 009 -- ESOH in Systems Engineering.
- CLR 030 -- WSOH in JCIDS.
- CLM 035 -- ESOH: Lessons from PMT 352A.
- CLL 043 -- Green Logistics.
- CLL 046 -- Green Procurement.
- FAC 035 -- Green Purchasing for Civilian Acquisition.

16.4.7 Configuration Control

Configuration management is defined as " *a process for establishing and maintaining consistency of a product's performance, functional and physical attributes with its requirements, design and operational information throughout its life.* "

The DOD Instruction 5000.02, Enclosure 12, paragraph 5, directs the use of configuration management across the total system life cycle per the following extract:

" *The PM shall use a configuration management approach to establish and control product attributes and the technical baseline across the total system life cycle. This approach shall identify, document, audit, and control the functional and physical characteristics of the system design; track any changes; provide an audit trail of program design decisions and design modifications; and be integrated with the SEP and technical planning. At completion of the system level Critical Design Review, the PM shall assume control of the initial product baseline for all Class 1 configuration changes* ."

Configuration management is the application of sound program practices to establish and maintain consistency of a product's or system's attributes with its requirements and evolving technical baseline over its life. It involves interaction among government and contractor program functions such as systems engineering, hardware/software engineering, specialty engineering, logistics, contracting, and production in an Integrated Product Team environment. The program manager should use configuration management to establish and mature the technical baseline throughout the acquisition life cycle.

The technical baseline includes user requirements, program and product information and related documentation for all configuration items (i.e., those system elements under configuration management). Configuration items can consist of the integrated master schedule, system requirements, specifications, hardware, software, and documentation (data). A configuration management process guides the system products, processes, and related documentation, and facilitates the development of open systems. Configuration management efforts result in a complete audit trail of plans, decisions and design modifications. Configuration management functions include the following:

- Planning and Management - Provides total life-cycle configuration management planning for the program/project and manages the implementation of that planning.
- Identification - Establishes configuration information and documentation of functional and physical characteristics of each configuration items. Documents agreed-to configuration baselines and changes to those configurations that occur over time.
- Change Management - Ensures that changes to a configuration baseline are properly identified, recorded, evaluated, approved or disapproved, and incorporated and verified, as appropriate. A common change method is the Engineering Change Proposal. See MIL-HDBK-61A .
- Status Accounting - Manages the capture and maintenance of product configuration information necessary to account for the configuration of a product throughout the product life cycle.
- Verification and Audit - Establishes that the performance and functional requirements defined in the technical baseline are achieved by the design and that the design is accurately documented in the technical baseline.

There are resources available for managers needing support for Configuration Control problems to include:

- Learning and resource material at https://acc.dau.mil/CommunityBrowser.aspx?id=22141 .

- MIL-HDBK-61A Configuration Management Guidance.
- Defense Acquisition Guidebook: Configuration Management Guidance in Chapter 4.2.3.6 and Chapter 5.2.1.4.

The Defense Acquisition University (DAU) has a continuous learning module on Configuration Control:

- LOG 204 -- Configuration Management.

16.5 Organic Capabilities

Solutions for some of our manufacturing and production problems may be available in the form of an organic capability. The defense industrial base in the U.S. includes our organic capabilities to perform research and development, design, produce, and maintain military weapon systems, subsystems, components, or parts to meet military requirements. Included in these organic capabilities are:

- Navy ManTech Centers of Excellence,
- Navy Depots,
- Air Force Logistics Centers,
- Army Depots, and
- Army Arsenals.

16.5.1 Navy Mantech Centers of Excellence

There are currently nine centers engaged in ManTech activities. The Centers of Excellence were established as focal points for the development and transition of new manufacturing processes and equipment in a cooperative environment with industry, academia and the Naval Research Enterprise. These centers:

- Execute projects; manage project teams;
- Serve as corporate expertise in technological areas;
- Collaborate with program offices / industry to identify and resolve manufacturing issues;
- Develop and demonstrate manufacturing technology solutions for identified Navy requirements;
- Provide consulting services to Naval industrial activities and industry; and
- Facilitate transfer of developed technologies.

The Centers of Excellence include:

16.5.1.1 Benchmarking and Best Practices Center of Excellence (B2PCOE)

The Benchmarking and Best Practices Center of Excellence (B2PCOE) mission is to identify, validate, and disseminate best in-class practices, processes, methodologies, systems, and best practice technologies with the end objective of improving the level of competitiveness of the defense industrial base and the affordability of performance of defense platforms and weapons systems.

16.5.1.2 Center for Naval Shipbuilding Technology (CNST)

The mission of the Center for Naval Shipbuilding Technology (CNST) is to identify, develop, and deploy advanced manufacturing technologies that will reduce the cost and time to build and repair Navy ships. The projects are focused on improving major ship construction and repair processes, such as predicting and reducing weld distortion, developing more efficient structural fabrication product lines, increasing the use of robotic welding methods and eliminating inefficiencies in training, material usage, and supply chain procedures.

16.5.1.3 Composites Manufacturing Technology Centers (CMTC)

The Composites Manufacturing Technology Center (CMTC) provides expertise to address composites manufacturing technology needs. CMTC's current portfolio includes composites manufacturing projects for manned and unmanned aircraft, surface ships, submarines, missiles, and land vehicles.

16.5.1.4 Electro-Optics Center (EOC)

The Vision of the Electro-Optics Center (EOC) is to be the national resource for the advancement of electro-optics and related technology for the primary benefit of national security. The mission of the EOC is to:

- Provide the latest electro-optic (E-O) technologies for the warfighter;
- Conduct basic and applied electro-optic research and technology demonstrations;
- Seek out and facilitate technology transfer leading to the commercialization of E-O technologies; and
- Expand the current and prospective workforce through education and outreach.

16.5.1.5 Electronics Manufacturing Productivity Facility (EMPF)

The Electronics Manufacturing Productivity Facility (EMPF) is focused on the development, application and transfer of new electronics manufacturing technologies. The EMPF's principal goals are to: improve responsiveness to the needs of DOD electronics systems; ensure that deliverables make a significant impact in the electronics manufacturing industry; facilitate the development and transition of technology to the factory floor; and expand the customer base to a national level.

16.5.1.6 Energetics Manufacturing Technology Center (EMTC)

The Energetics Manufacturing Technology Center (EMTC) provides a full spectrum of capabilities including energetics research, development, modeling and simulation, engineering, manufacturing technology, production, test and evaluation, and fleet / operations support. Applications include missile, rocket, and gun propulsion; stores or ordnance separation;

warheads and munitions; obstacle and mine clearance; flares; decoys; fire suppression; and aircrew escape. The Center develops solutions to manufacturing problems unique to military system / subsystem acquisition and production requirements and the energetics industry.

16.5.1.7 Institute for Manufacturing and Sustainment Technologies (iMAST)

The Institute for Manufacturing and Sustainment Technologies (iMAST) primary objective is to address challenges related to Navy and Marine Corps weapon system platforms in the following technical areas: mechanical drive transmission, materials processing, laser processing, advanced composites, manufacturing systems, repair and sustainment, and complex systems monitoring. iMAST supports the Navy and Marine Corps systems commands, as well as PEOs and Navy laboratories.

16.5.1.8 Navy Joining Center (NJC)

The Navy Joining Center (NJC) supports the development of materials joining expertise and the deployment of emerging manufacturing technologies to Navy contractors, subcontractors, and other activities. The NJC team represents a collaborative effort among industry, academia, and government and is experienced in identifying joining problems, developing and deploying solutions, and transferring technology. Typical projects provide joining solutions for metallic, non-metallic, ceramic, and composite materials that support Navy ManTech strategic plans.

16.5.1.9 Navy Metalworking Center (NMC)

The Navy Metalworking Center (NMC) is the national resource for the development and transition of advanced metalworking and manufacturing technologies, materials and related processes. NMC drives new technologies from research and development to naval weapon systems application with two objectives: 1.) to implement new technologies that will improve weapon system performance; and 2.) to develop new production means for weapon systems prime contractors and suppliers that lower the production cost of naval weapon systems.

16.5.2 Navy Depots

The Navy Depot Maintenance system includes the following activities:

Naval Shipyards . Portsmouth Naval Shipyard, ME; Norfolk Naval Shipyard, VA; Puget Sound Naval Shipyard and Intermediate Maintenance Facility, WA; and Pearl Harbor Naval Shipyard and Intermediate Maintenance Facility, HI, maintain, modernize, repair, and dispose of Navy ships and related components.

Naval Aviation Fleet Readiness Centers . Fleet Readiness Center East, Cherry Point, NC; Fleet Readiness Center Southeast, Jacksonville, FL; Fleet Readiness Center Mid-Atlantic, Oceana, VA; Fleet Readiness Center Southwest, North Island, CA; Fleet Readiness Center West, Lemoore, CA; and Fleet Readiness Center Northwest, Whidbey Island, WA, repair, overhaul, and modify sea-based and maritime aircraft and related aeronautical systems and equipment.

Naval Warfare Centers . Naval Undersea Warfare Center, Keyport, WA, maintains and repairs fleet undersea weapons, ordnance, and associated equipment. Naval Surface Warfare Center, Crane Division, IN, maintains and repairs fleet surface weapons, ordnance, and associated equipment.

Space and Naval Warfare Systems Centers . Space and Naval Warfare Systems Centers San Diego, CA, and Charleston, SC, maintain and repair Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR) systems and equipment.

The Navy Depot Maintenance Strategic Plans are organized around the following four strategic elements:

- Transform the depots to align operations and metrics with warfighter outcomes;
- Identify and sustain requisite core maintenance capabilities;
- Develop and sustain a highly capable, mission-ready workforce; and
- Ensure an adequate infrastructure to execute assigned maintenance workload.

16.5.3 Air Force Logistics Centers (ALC)

The mission of an ALC is to provide a weapon system sustainment capability to the warfighter based on the type of weapon system and core capabilities.

Ogden Air Logistics Center : Ogden ALC has worldwide engineering, manufacturing, sustainment/logistics management and maintenance support for many Air Force weapon systems, including the Minuteman intercontinental ballistic missiles (ICBM), low-observable (stealth) aircraft structural composite materials, the B-2 multi-role bomber, and program management for two of the Air Force's fighter aircraft. The center is responsible for the management, depot level overhaul and repair for all types of landing gear, wheels, brakes and tires and is the logistics manager for all conventional air munitions, solid propellants and explosive devices used throughout the Air Force.

Oklahoma City Logistics Center Air : The Oklahoma City ALC provides depot maintenance and repair for a variety of bombers, refuelers and reconnaissance aircraft including the E-3 AWACS, C/KC-135, KC-10, B-1, B-2 and B-52. The Center is the worldwide manager for a wide range of aircraft and missile engines and commodity items.

Warner Robbins Air Logistics Center : The Warner Robins ALC performs sustainment and depot maintenance on a number of U.S. Air Force weapon systems. Specifically it supports AC-130, C-5 Galaxy, C-17 Globemaster III, C-130 Hercules, E-8 Joint STARS, EC-130, F-15 Eagle, HC-130, HH-60 Pave Hawk, MC-130, MH-53 Pave Low, RQ-4 Global Hawk, U-2 Dragon Lady, and UH-1 Iroquois aircraft.

16.5.4 Army Depots

The mission of the Army Depot Maintenance Enterprise (DME) is to provide the resources, skills and capabilities to sustain the life cycle readiness of the warfighter's weapon systems and equipment in a reliable and efficient manner.

Anniston Army Depot, AL : Anniston performs maintenance on heavy- tracked combat vehicles and their components, artillery, and small arms to include the M1 Abrams Tank, M60, AVLB, M728, M88 and M551 combat vehicles.

Corpus Christi Army Depot, TX : CCAD is the Army's organic facility for the repair and overhaul of rotary wing aircraft to include the UH-60, AH-64, and OH-58.

Letterkenny Army Depot, PA : The Letterkenny Army Depot was originally established as an ammunition depot, but today is known as the Center of Excellence for Air Defense and Tactical Missile ground support equipment, mobile electric power generation equipment, and Patriot missile recertification.

Red River Army Depot, TX : Repairs, rebuilds, overhauls, and converts the Army's light tracked combat vehicle fleet, including the Bradley Fighting Vehicle System, the Multiple Launch Rocket System (MLRS).

Tobyhanna Army Depot, PA : Tobyhanna Army Depot, a major element of the Communications-Electronics Command is the largest and most progressive communications-electronics repair, overhaul and fabrication facility in the Department of Defense.

16.5.5 Army Arsenals

Part of the U.S. Army's large industrial base is their management of five arsenals. Arsenals typically are government owned and operated facilities that make ordinance items such as gun tubes for artillery pieces and tanks. These industrial facilities provide the U.S. with much needed production and sustainment capabilities.

Picatinny Arsenal : Picatinny Arsenal is the Joint Center of Excellence for Armaments and Munitions, providing products and services to all branches of the U.S. military. Picatinny specializes in the research, development, acquisition and lifecycle management of advanced conventional weapon systems and advanced ammunition. Picatinny's portfolio comprises nearly 90 percent of the Army's lethality and all conventional ammunition for joint warfighters.

Pine Bluff Arsenal : PBA supplies specialized production, storage, maintenance and distribution of readiness products, and delivers technical services to the Armed Forces and Homeland Security. PBA also designs, manufactures and refurbishes smoke, riot control, and incendiary munitions, as well as chemical/biological defense operations items. It serves as a technology center for illuminating and infrared munitions and is also the only place in the Northern Hemisphere where white phosphorus munitions are filled.

Redstone Arsenal : Redstone's mission is perform basic and advanced weapons system research and development, placing the right missile and aviation systems with the troops, keeping them ready to fight, providing weapon systems, services and supplies to our allies, to manage weapon systems such as the Cobra and PATRIOT, and to support project managers within the program executive office structure.

Rock Island Arsenal : The Arsenal is the only active U.S. Army foundry, and manufactures ordnance and equipment, including artillery, gun mounts, recoil mechanisms, small arms, aircraft weapons sub-systems, grenade launchers, weapons simulators, and a host of associated components. Some of the Arsenal's most successful products include the M198 and M119 towed howitzers, and the M1A1 gun mount.

Watervliet Arsenal : The Watervliet Arsenal became America's "Cannon Factory" in 1813 to support the, "Second War for Independence," and today the arsenal continues to be a valuable resource for world class defense manufacturing. The arsenal remains as America's sole manufacturing source for large caliber cannons in production volume. Watervliet Arsenal is relied upon to produce today's most advanced, high-tech, high-powered weaponry for cannons, howitzers, and mortars.

16.6 Random Thoughts

Over the past 30 years working on numerous DoD programs (Army, Navy, Air Force and Missile Defense Agency) I have collected a few random thoughts I would like to share with you:

- The acquisition process is a technical process not a contracting process. The laws of physics and economics continue to work regardless of legal formalities.
- There is no law that says just because you can design it, you can build it.
- Managing supply chains is a critical task. What cannot be seen (visually or digitally) cannot be managed, and you cannot manage what you do not see. Visibility is a key to managing supply chains.
- Special tooling (jigs and fixtures) are required for almost all mechanical production, construction and assembly. If the tooling is wrong the system will be constructed incorrectly resulting in cost, schedule, performance and quality issues. Tooling is a program in and of itself and must be managed as such. Any tooling problems should be considered an automatic read flag.
- Use the Defense Contract Management Agency (DCMA) personnel they are your continuous eyes and ears on the contractor's shop floor.
- The testing of new manufacturing processes should be done at full production representative scales and at representative process rates, using the actual processes conducted by normally trained manufacturing personnel.
- Manufacturing operations/facilities are complex, interactive systems and they display non-linearities, interactions, possess feedback loops and time-lagged behavior. As a result, they may produce surprises and cause-and-effect may not be easily perceived.
- Many managers are under the misperception that identical production facilities will experience the same problems this is not so. They may also assume that when a facility that is operating smoothly it will again operate smoothly if moved this in not so; variability due to disassembly, movement, and reassembly will occur.

- The contractor follows the government's lead. If the PM and Technical Director do not ask manufacturing questions then the contractor receives the message that these issues are secondary. In addition, CDRLs, in and of themselves, do not result in effective concrete action nor will they replace effective communication.
- Major programs are organized around core design team, usually comprised of 20-50 of the contractor's best engineers. This core design team makes 90-95% of all critical decisions. If manufacturing is not one of their primary concerns then manufacturing issues will be delegated to secondary teams.

16.7 Summary

Numerous manufacturing and production problems have been around for a long time and continue to cause problems on numerous DOD weapon system programs to include:

- Diminishing Manufacturing Sources and Material Shortages (DMSMS) and Obsolescence,
- Corrosion Control,
- Counterfeit Parts,
- International Traffic in Arms Regulations (ITAR),
- Tin Whiskers,
- Environment, Safety, and Occupational Health Evaluation (ESOH), and
- Configuration Control.

There are numerous sources of support for DOD program managers in helping to resolve some of their manufacturing and production problems in the form of organic capabilities to include:

- Navy ManTech Centers of Excellence,
- Navy Depots,
- Air Force Logistics Centers,
- Army Depots, and
- Army Arsenals.

Take advantage of these resources.

16.8 Related Links and Resources

Numerous reference documents impact the manufacturing management function throughout the acquisition process. These documents originate from many sources and range across academic disciplines, functional activities, and job specialties.

The following is a reference list of DOD Directives (D), Instructions (I) Manuals (M), Pamphlets (P), Military Standards (MS), and other documents. The documents listed contain DOD policy guidance applicable to the manufacturing management function. They are listed as sources of DOD manufacturing management information.

Note: Many of the documents listed are no longer required (due to acquisition reform), but still contain some very valuable information.

Number	Title
	DMSMS/Obsolescence Knowledge Sharing Portal
	Corrosion Control
	Counterfeit Parts Knowledge Sharing Portal
	International Traffic in Arms Regulation (ITAR) Department of State Homepage
	Tin Whiskers Threaten Reliability of Electronics Components
	Environmental, Safety, and Occupational Health Portal
	Configuration Management and Control Portal

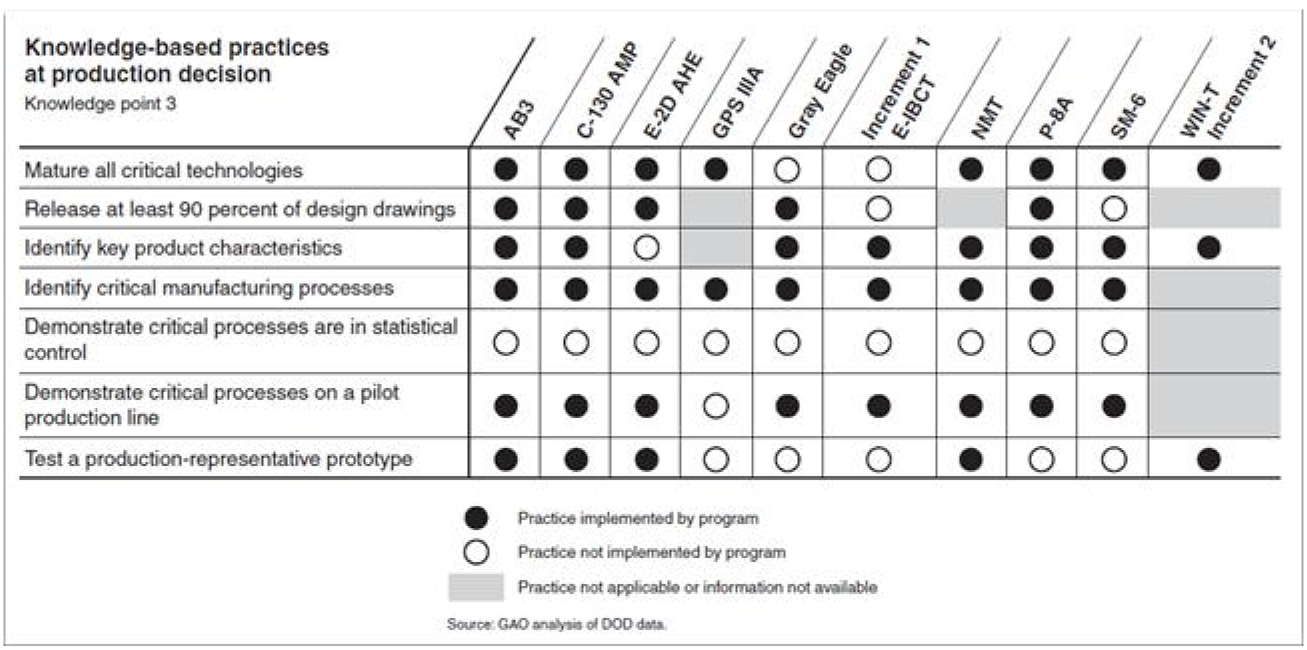
17.1 Objective

This chapter:

- Introduces the notion of Manufacturing Readiness Levels (MRLs);
- Describes the roles and goals of manufacturing management process;
- Defines current mandatory/statutory requirements, policy and guidance for assessing risks;
- Defines and describes the various manufacturing readiness levels;
- Provides an overview of the MRL Matrix; and
- Describes the MRL assessment process and the development of Manufacturing Maturation Plans.

17.2 Background

According to a March 2011 Government Accounting Office (GAO) report on *Defense Acquisitions - Assessments of Selected Weapon Programs* almost all programs that held a production decision since 2009 planned for manufacturing; however, ***none*** of the programs demonstrated that critical manufacturing processes were in control and only half tested production-representative prototypes prior to this decision (Figure 17-1). Capturing critical manufacturing knowledge before entering production helps ensure that a weapon system will work as intended and will be affordable.



Knowledge-based practices at production decision Knowledge point 3	AB3	C-130 AMP	E-2D AHE	GPS IIIA	Gray Eagle	Increment 1 E-IBCT	NMT	P-8A	SM-6	WIN-T Increment 2
Mature all critical technologies	●	●	●	●	○	○	●	●	●	●
Release at least 90 percent of design drawings	●	●	●		●	○		●	○	
Identify key product characteristics	●	●	○		●	●	●	●	●	●
Identify critical manufacturing processes	●	●	●	●	●	●	●	●	●	
Demonstrate critical processes are in statistical control	○	○	○	○	○	○	○	○	○	
Demonstrate critical processes on a pilot production line	●	●	●	○	●	●	●	●	●	
Test a production-representative prototype	●	●	●	○	○	○	●	○	○	●

● Practice implemented by program
○ Practice not implemented by program
Practice not applicable or information not available (shaded)

Source: GAO analysis of DOD data.

Figure 17-1 GAO Assessment of Knowledge-Based Practices

DOD's December 2008 revision to its acquisition policy requires programs to test production-representative articles before entering production. Only 5 of the 10 programs that held a production decision since 2009 reported testing a production-representative prototype before their production decision. Bottom-Line: Programs cannot answer the question "are they ready for production"? But this is not a new problem. When the USS THRESHER sank off of the coast of New Hampshire on 10 April 1963, she was not ready. The Navy Board of Inquiry determined that the Navy went "too far, too fast." And manufacturing problems were considered to be at the heart of this loss.

17.3 Introduction

The basic goal of all acquisition programs is to provide the required capability to the field in a timely manner. In addition, the system should be affordable and supportable. In order to be successful, the following two key risk areas must be managed effectively:

1. Product technologies, and
2. Manufacturing capability.

Technology Readiness Levels (TRLs) measure risk associated with maturing product technologies. Manufacturing Readiness Levels (MRLs) measure risk associated with maturing manufacturing capabilities. MRLs in combination with TRLs can help program manager's deal with these risks. These metrics are also important to technology development managers because they can be used to achieve and convincingly demonstrate a level of readiness for technology transition that acquisition program managers will find credible. Understanding and mitigating risks associated with maturing technologies and manufacturing capabilities will greatly increase the probability of technology insertion for the technology development community and ultimately aid in improvements in cost, schedule and performance for programs of record.

17.4 Assessment of Manufacturing Readiness

An assessment of Manufacturing Readiness can be defined as "an assessment of a program's readiness to manufacture and produce its intended design." The assessment is a tool that provides a structured methodology and criteria for assessing manufacturing risks leading to the development of a path forward.

17.5 Policy and Guidance

The Manufacturing risk assessments have been performed on defense acquisition programs for over 50 years in a variety of forms (e.g., Manufacturing Feasibility Assessments, Production Readiness Reviews, Manufacturing Management/Production Capability Reviews, etc.). However, these reviews did not use a uniform metric to measure and communicate manufacturing risk and readiness. Nor were they conducted on technology development efforts or in the early acquisition phases. In addition, the frequency and depth of these types of reviews has declined sharply since the 1990s. Furthermore, many of the skilled personnel that had performed these reviews have either retired or moved on to other acquisition career fields, leaving acquisition programs ill prepared to perform detailed manufacturing risk assessments.

Manufacturing-related impacts on cost, schedule, and performance have grown significantly paralleling the decline in manufacturing assessments. Studies by the GAO cite a lack of manufacturing knowledge at key decision points as a leading cause of program cost growth and schedule slippages in major DOD acquisition programs. Consequently, laws have been passed and DOD policy has been developed to strengthen the way in which manufacturing issues and risks are considered in the defense acquisition system. The rest of this section will address laws, policy and guidance related to the assessment of manufacturing risks.

17.5.1 Law

The National Defense Authorization Act (NDAA) Section 812 required the Secretary of Defense to issue comprehensive guidance on the management of manufacturing risk in major defense acquisition programs and that the guidance shall at a minimum:

- Require the use of manufacturing readiness levels as a basis for measuring, assessing, reporting, and communicating manufacturing readiness;
- Provide guidance on the definition of manufacturing readiness levels and how manufacturing readiness levels should be used to assess manufacturing risk and readiness;
- Specify manufacturing readiness levels that should be achieved at key milestones and decision points for major defense acquisition programs;
- Identify tools and models that may be used to assess, manage, and reduce risks that are identified in the course of manufacturing readiness assessments; and
- Require appropriate consideration of the manufacturing readiness and manufacturing readiness processes of potential contractors and subcontractors as a part of the source selection process.

The act also requires that the workforce be trained in critical manufacturing readiness knowledge/skills.

17.5.2 Policy

Department of Defense Instruction (DODI) 5000.02 establishes new policy to address manufacturing over the entire life cycle. For example:

- During the **Materiel Solution Analysis (MSA) Phase** , the policy requires the Analysis of Alternatives (AoA) to assess manufacturing feasibility.
- During the **Technology Development (TD) Phase** , the new policy also affirms that:
    - Prototype systems or appropriate component-level prototyping shall be employed to evaluate manufacturing processes.
    - A successful preliminary design review will identify remaining design, integration, and manufacturing risks.

    - A program may exit the TD Phase when the technology and manufacturing processes for that program or increment have been assessed and demonstrated in a relevant environment" and "manufacturing risks have been identified.
- During the **Engineering and Manufacturing Development (EMD) Phase** , the goal is to "develop an affordable and executable manufacturing process." Consequently, "the maturity of critical manufacturing processes" is to be described in a post-Critical Design Review (CDR) Assessment; the System Capability and Manufacturing Process Demonstration shall show "that system production can be supported by demonstrated manufacturing processes;" and the EMD Phase shall end when "manufacturing processes have been demonstrated in a pilot line environment."
- During the **Production and Deployment (P&D) Phase** , the policy establishes two entrance criteria:
    - "No significant manufacturing risks," and
    - "Manufacturing processes [are] under control (if Milestone C is full-rate production).
    - "Low Rate Initial Production (LRIP) should result in an "adequate and efficient manufacturing capability" so that the following knowledge will be available to support Full-Rate Production (FRP) approval to include:
        - Demonstrated control of the manufacturing process;
        - The collection of statistical process control data; and
        - Demonstrated control and capability of other critical processes.

17.5.3 Guidance

The Defense Acquisition Guide (DAG) Chapters 2 and 4 provide several recommendations or guidelines for assessing manufacturing risk. This includes the following guidance:

Chapter 2.2.9 Industrial Capability and Manufacturing Capabilities: During the Materiel Solution Analysis Phase, the industrial and manufacturing capability should have been assessed for each competing alternative in the AoA. The results of the assessment should be used to develop the TDS by illustrating the differences between alternative approaches based on industrial and manufacturing resources needed.

Chapter 2.2.9.1 Industrial Capability and Manufacturing Readiness: The Technology Development Strategy (TDS) should summarize plans for how the manufacturing readiness will be addressed in the Technology Development (TD) Phase to ensure that manufacturing is mature enough to enter Engineering and Manufacturing Development (EMD), particularly for new or high risk manufacturing endeavors.

Chapter 2.3.9.3 Industrial and Manufacturing Readiness: The Acquisition Strategy should highlight the strategy for assessing manufacturing readiness. During the EMD and P&D Phases, the manufacturing readiness should be assessed to identify remaining risks prior to a full-rate production go-ahead decision.

Chapter 4.4.14.2. Assessment of Manufacturing Readiness: Manufacturing risk is evaluated through manufacturing readiness assessments which are integrated with existing program assessments during the acquisition lifecycle. Assessment shall begin in the programs earliest phase; it should also be continuous and concluded prior to each systems engineering technical review, Program Support Review (PSR) or their equivalent, and before each milestone decision.

Successful manufacturing has identified nine manufacturing risk areas which should be assessed during technical reviews and before acquisition milestones. These nine risk areas include:

1. Technology and Industrial Base, including small business
2. Design
3. Cost and Funding
4. Materials
5. Process Capability and Control
6. Quality Management
7. Manufacturing Personnel
8. Facilities
9. Manufacturing Management

17.6 Manufacturing Readiness Definitions

The MRL Definitions were created by the DOD MRL Working Group. This group was formed in 2004 under the auspices of the Joint Defense Manufacturing Technology Panel (JDMTP). Their direction was to develop and promulgate a maturity model along the lines of the Technology Readiness Level (TRL) to assess, measure and mitigate manufacturing risks. Along with the definitions below are a set of MRL descriptions. These descriptions can be found on the Defense Acquisition University's (DAU) Acquisition Community Connection (ACC) for Production, Quality and Manufacturing (PQM).

17.6.1 MRL Definitions

There are ten MRLs that are correlated to the nine TRLs in use.

- **MRL 1:** Basic Manufacturing Implications Identified.
- **MRL 2:** Manufacturing Concepts Identified.
- **MRL 3:** Manufacturing Proof of Concept Developed.
- **MRL 4:** Capability to produce the technology in a laboratory environment.

- **MRL 5:** Capability to produce prototype components in a production relevant environment.
- **MRL 6:** Capability to produce a prototype system or subsystem in a production relevant environment.
- **MRL 7:** Capability to produce systems, subsystems, or components in a production representative environment.
- **MRL 8:** Pilot line capability demonstrated; Ready to begin Low Rate Initial Production.
- **MRL 9:** Low rate production demonstrated; Capability in place to begin Full Rate Production.
- **MRL 10:** Full Rate Production demonstrated and lean production practices in place.

17.6.2 MRL Considerations

The ten MRLs considerations below come from an MRL Overview Chart:

MRLs 1-3: This is the lowest level of manufacturing readiness. The focus is on:

- Basic research (budget activity 6.1) and is often in the form of a study.
- Applied research (budget activity 6.2) translates basic research into solutions for broadly defined military needs.
- Applied Technology Development (budget activity 6.3). Materials and/or processes have been characterized for manufacturability and availability. Experimental hardware models have been developed in a lab environment that may possess limited functionality.

MRL 4: Manufacturing processes have been identified along with key processes. Producibility assessments have begun.

MRL 5: Manufacturing processes are beginning to emerge. Producibility assessments are on-going and manufacturing cost drivers have been identified.

MRL 6: Manufacturing processes are now being demonstrated in a relevant environment. Manufacturing cost drivers have been analyzed and long lead items have been identified. Production equipment is in a relevant environment.

MRL 7: Manufacturing processes are in development and producibility improvements are underway. Trade studies are being conducted having manufacturing implications, and supply chain management practices are in place.

MRL 8: Manufacturing process maturity is being demonstrated on a pilot line. All materials are ready for low rate initial production (LRIP). Manufacturing processes are now proven and the supply chain is stable for LRIP.

MRL 9: Manufacturing processes are operating at target quality, cost and performance goals. The supply chain is established and meeting lead times, cost and performance objectives.

MRL 10: The manufacturing is mature and is meeting full rate production (FRP) goals. Lean/Six Sigma practices have been put in place and are reaping benefits. The program is meeting or exceeding (in a positive way) cost, schedule and performance goals.

17.6.3 MRL Threads

Central to accomplishing acquisition Program Management goals is an under-standing of the risks associated with the industrial process in DOD acquisition, and developing risk mitigation plans and actions. These risk elements are both discrete (are embedded in each phase), and are comprised of nine (9) threads. These threads begin at discovery and invention, go through engineering and development, through production and deployment, and end with operations and support. These nine threads include:

- **Technology and Industrial Base Thread** : Requires an analysis of the capabilities of the national technology and industrial base to support the design, development, production, operation, uninterrupted maintenance support of the system, and eventual disposal (including environmentally conscious).
- **Design Thread** : Requires an analysis of the degree to which the identified, evolving or system design will meet user requirements and the degree to which the design is new and unproven.
- **Materials Thread** : Requires and analysis of the risks associated with materials (including basic/raw materials, components, semi-finished, parts, and sub-assemblies).
- **Cost and Funding Thread** : Requires an analysis of the risk that the system development and deployment will not meet the DOD cost and funding goals.
- **Process Capability and Control Thread** : Requires an analysis of the risk that the manufacturing processes may not be able to reflect the design intent (repeatability and affordability) of key characteristics.
- **Quality Management Thread** : Requires an analysis of the risk and management efforts to control quality, and foster continuous quality improvement.
- **Personnel Thread** : Requires the assessment of the required skills and availability in required numbers of personnel to support the manufacturing effort.
- **Facilities Thread** : Requires an analysis of the capabilities and capacity (Prime, Subcontractor, Supplier, Vendor, and Maintenance Repair) that are key risks in manufacturing.
- **Manufacturing Planning, Scheduling, and Control Thread** : Requires an analysis of the orchestration of all elements needed to translate the design into an integrated and fielded system (meeting Program goals for affordability and availability).

17.7 The MRL Matrix

The MRL Matrix is an expansion of the "Definitions and Descriptions" and includes:

- Nine major threads and twenty sub-threads;
- Evaluation criteria for each thread; that are
- Plotted against every acquisition phase and milestone decision point.

Acquisition Phase		MSA	Tech.	Dev.	Engr & Mfg Dev.		LRIP	FRP
Thread	Sub-Thread	MRL 4	MRL 5	MRL 6	MRL 7	MRL 8	MRL 9	MRL 10
Technology & the Industrial Base	Technology Maturity							
	Transition to Production							
	Mfg. Tech Development							
Design	Producibility Program							
	Design Maturity							
Cost & Funding	Production Cost							
	Man Tech Investments							
Materials	Availability							
	Supply Chain							

Figure 17-2 The MRL Matrix

The matrix allows a user to separately trace and understand the maturation progress of each of the threads and sub-threads as readiness levels increase from MRL 1 though MRL 10. These thread and sub-thread MRL criteria should be applied when appropriate to the situation and may be tailored to a particular technology, or application, or production environment. For example, a pilot line for a mass assembly product like a Humvee is going to be different than a pilot line for an aircraft like the Joint Strike Fighter, or for small build programs like satellites.

17.8 The MRL Assessment

An assessment of manufacturing readiness is an important tool for evaluating manufacturing maturity and risk that is most useful in the context of a broader manufacturing risk management process. These assessments should lead to actions such as:

- Setting goals for increased manufacturing maturity and reduced manufacturing risk;
- Creating action plans and funding estimates to reach those goals;
- Reaching decisions about the readiness of a technology or process to transition into a system design or onto the factory floor; and
- Reaching decisions on a system's readiness to proceed into the next acquisition phase.

Therefore, an assessment of manufacturing readiness should compare the status of the key program elements to a nominal MRL appropriate for the stage of the program, describe the risk associated with elements that fall short of the goal, and lay the foundation for manufacturing risk mitigation planning and investment. An assessment should be able to answer the question "are you ready?"

Too often many DOD acquisition programs did not ask the question "are you ready?" As a result by not asking the question, and not doing an adequate risk assessment, the programs ran into problems. As noted in several GAO reports, programs that did not have adequate knowledge of technology, design and production risk, ran into problems. Those programs that included production considerations early had fewer problems.

Program	Experience	Status
Liberty Ship	• Mass produced using welding not riveting (saved labor) • Fabricated in sections, then welded together • Strong use of commonalty • Plan build of 2751, 2710 actually built, and over 2400 survived WW II	Ready
DIVAD Sgt. York	• In development from 1977 1985 • Had significant operational issues (mistook latrine fan for an enemy aircraft) • Had significant RAM-D (reliability, availability, maintainability and durability) issues • Was put into production with many design issues not resolved • 50 units produced before the program was cancelled	Not Ready
F-16	• Designed to be a low cost, low maintenance aircraft • Focus on producibility • 4,500 produced at a cost of $14.6M in FY 1998 dollars • Production began in 1976, still in production today (FMS)	Ready
V-22 Osprey	• In 1986 Unit Cost estimated at $24M each for a planned procurement of 923 aircraft • By 2009, planned production of only 458 aircraft at a Unit Cost of $83.7M • Schedule has slipped by 148 percent and the program has been re-baselined eight times	Not Ready
F-18 E/F	• Has had virtually no cost growth • Schedule has slipped only 3 months • Was recognized in a GAO report Capturing Design and Manufacturing Knowledge Early Improves Acquisition	Ready

	Outcomes • Planned build of 462 aircraft at $95.3M each	
Joint Strike Fighter	• Has spent over 6 years in EMD • Planned to build 2,988 aircraft in 1996 • Planned unit cost in 2001 was $81M • By 1996 the planned build dropped to 2,443 aircraft and the Unit Cost went up to $115M • Development cost went from an original estimate of $24.8B to $44.5B	Not Ready

Table 17-1 GAO Assessment of Production Programs

The MRL assessment is like most of the other systems engineering technical assessments and is organized around the key steps identified in Figure below.

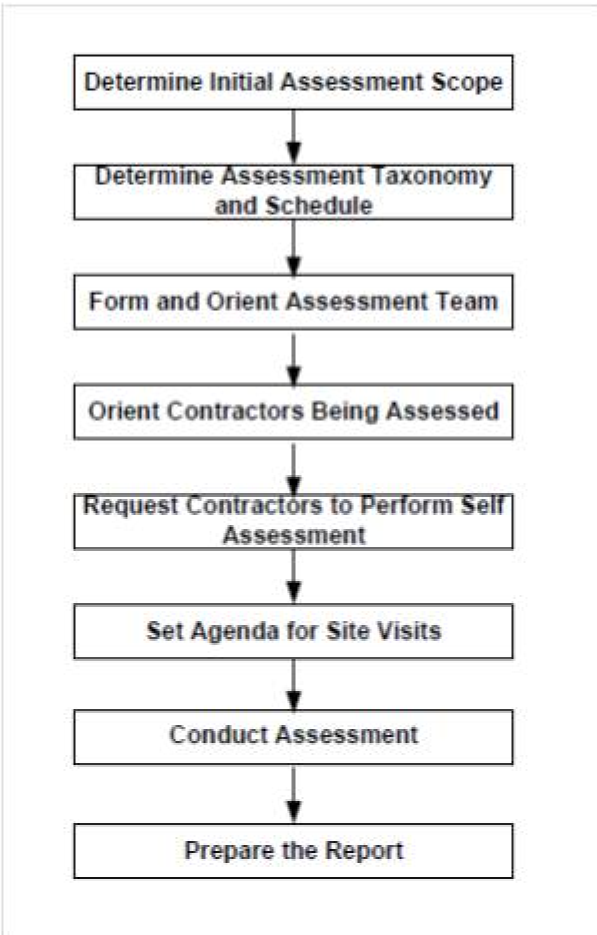


Figure 17-3 MRL Assessment Process

17.8.1 Determining Initial Scope

It is rarely feasible to visit every supplier of every material, component and assembly to examine the manufacturing risk. Some elements should be assessed on-site and others may utilize alternative approaches. The type and depth of the assessment is determined by the risk level of the element. On-site evaluations are typically reserved for the locations where one or more of the following apply:

- The highest percentage of manufacturing cost is incurred;
- Final assembly and test is conducted;
- The most sensitive manufacturing tasks are accomplished;
- The materials, components or subsystems that are the least technologically mature are produced or availability issues exist; or
- Known significant problems or risks exist (low yields, high costs, immature manufacturing processes, etc.).

17.8.2 Determine the Taxonomy and Schedule

The assessment taxonomy encompasses what will be assessed, where the assessments will take place, and who will lead the assessment.

The government program/project office, in conjunction with the prime contractor, should make an early determination of potential issues by breaking out system, subsystem, or component level for analysis and then determining the applicability of components for evaluation. Consideration should also be given to associated test and assembly processes. The following questions have been developed to assist in the determination of *elements* to be assessed. All Critical Technology Elements and other significant areas of the work breakdown structure or bill of materials should be subject to the following filtering questions. Any "yes" responses imply that an assessment of manufacturing readiness may be needed for that element as a function of risk.

17.8.3 Forming the Team

The assessments of manufacturing readiness are typically performed by teams and the government program/project office is responsible for forming them. The government program/project office to lead the team at prime contractors and the prime contractor to lead the team for the sub-tiers.

Team members should be experienced and knowledgeable in manufacturing engineering, industrial base, quality, supply chain, systems engineering, and production to identify potential manufacturing constraints, risks, and the capability of the technology and industrial base to execute the manufacturing efforts. Subject matter experts (SMEs) may be required to identify specific manufacturing issues not expected to be uncovered by general production personnel. Representatives from DOD staff organizations may participate as well, if the assessment is being performed on an acquisition program approaching a milestone decision. The program/project office should consider contacting the appropriate office of the Defense Contract Management Agency (DCMA) to gather information on the contractor's current and past performance.

Team selection can begin once the scope and a rough schedule of activity is developed. These teams will vary in size depending on the scope of the assessment. Sub teams may be put together to focus on various subsystems or technologies. Reviews should be tailored to the specific circumstances of the program.

Team members will need to understand the purpose of the assessment as well as the following:

- Initial schedule;
- Format and timing of reporting their results to the team;
- Standards of behavior at the contractor's facility;
- Security clearances or nondisclosure agreements;
- Personal preparation;
- The need for a detailed understanding of their assigned area and the role of shop floor observations and off-line discussions with contractor personnel; and
- Responsibilities after the on-site review.

17.8.4 Orient the Contractors

The leader of the assessment should orient the contractor to be assessed before the assessment occurs. This orientation may involve including contractor personnel in planning meetings as well as providing the contractor with an orientation package that includes:

- The MRL definitions and threads;
- Self-assessment questions; and
- An initial identification of critical technologies or processes for self-assessment.

For on-site assessments, the orientation package should also include:

- The questions the assessment team will use;
- An agenda for the assessment visit;
- Identification of evidence to be provided at the onsite visit;
- High-interest areas where shop floor visits and/or discussions will be expected; and
- Expectations of resources, time, etc. required for the assessment.

Make arrangements with the contractor for an assessment team meeting room to be available where private discussions can be held and team members can record their observations. Also, make arrangements with the contractor for assessment team members to bring computers into the facility to facilitate the capture of their observations in electronic format.

17.8.5 Request Contractor Self-Assessment

The leader of the assessment should ask the contractor(s) to conduct a self-assessment to address the following basic questions:

- What is the current MRL for each of the key technologies being developed and each key manufacturing process being used?

- If currently funded activities continue as planned, what MRL will be achieved for each key technology or process by the end of this acquisition phase or program? What activities and schedules are required to achieve this MRL?
- In the case of an ATD or ACTD, what MRL would be sufficient for you or an OEM using your technology to commit to it in a product baseline design?

In the case of on-site assessments, the contractor should be prepared to brief the results to the assessment team when it is on-site. For companies that provide key components or subassemblies and for which a site visit is not feasible, the contractor's written self-assessment should be analyzed by the assessment team.

17.8.6 Set Visit Agenda

Site visits are intended to provide a more detailed understanding than can be gained from briefings and documents. Assessments of manufacturing readiness should be structured in such a way as to take maximum advantage of discussions with contractor experts and first-hand observations of the status of shop floor activities. A balance must be struck between the time spent in briefing rooms and the time spent making observations in the contractor's facility and having discussions with individuals and small groups of the contractor's personnel. A typical agenda for a review may contain the following elements:

- Contractor welcome, review of agenda, assessment schedule. and orientation to the facility;
- Introduction of assessment team and contractor personnel;
- Briefing to contractor describing objectives and expectations for the on-site visit;
- Contractor overview and discussion of the results of their self-assessment;
- Shop-floor visits to key areas by individuals or small groups;
- Small group discussions between assessment team members and contractor SMEs;
- Private meeting of assessment team to record and discuss observations; and
- Out-briefing by assessment team to contractor.

17.8.7 Conduct the Assessment

When conducting an assessment of manufacturing readiness, there should be a well-defined hierarchy among the elements assessed. The hierarchy should start at the system level and flow down to the lowest component that forms the smallest unit for examination. The assessment team should determine the MRL threads applicable to each element in the hierarchy and identify the needed system level test and assembly processes that require an MRL assignment. This includes test and assembly steps that would be included in a subsystem or component fabrication.

During the assessment process, a component or subsystem may be found to be more complex than originally thought, so an even more detailed analysis or 'deep dive' may be warranted. If the assessment team determines further examination of critical components is necessary, the MRL threads should be applied at that level. Sub-components are examined along with process steps, and an MRL is determined for this final sub-tier element. Team members should seek existing, objective documentation that supports assessment results in key areas (*e.g.* , plans, yield data, reports, briefings, work instructions).

In determining the manufacturing readiness of a component or subsystem, the key emphasis is on the manufacturing risk. Utilize the MRL Matrix to structure the review and establish target criteria for each thread/sub-thread. If the target criteria are not met, utilize the risk matrix approach in the "DOD Risk Management Guide for Acquisition" to characterize the risks. The team assesses the number and severity of the risks to determine the manufacturing readiness of the component or subsystem.

Finally, the assessment team should include the actions necessary to bring readiness up to the target level in time to transition a technology or support a milestone decision with manageable risk.

At the end of each day, DCMA personnel should be asked to provide their perspective and insight on the contractor's presentations and status. If the contractor was unable to provide adequate information to support an assessment in a key area, assign an action item for the contractor to provide the information by a specific date.

Near the end of the assessment, the team should meet at the contractor's facility to discuss its observations and capture its impressions in electronic format. The team should also provide an out-brief to the contractor highlighting strengths and risks, MRL achievements compared to targets, and action items. Finally, the contractors' hospitality and cooperation should be recognized.

MRL assessments are not a simple go/no-go gauge. Therefore, assigning a single MRL to an entire technology or weapon system has little value. Even in a relatively simple case, where an assessment is being accomplished on a single technology with perhaps a half-dozen hardware components, it is likely the MRL will vary widely from component to component and perhaps even manufacturing process by manufacturing process for a specific component. Some components may be off-the-shelf, standard hardware, or made with well-established materials and processes from reliable suppliers, thus perhaps having an MRL in the range of 8 to 10. Other components may incorporate new design elements that move well beyond the proven capabilities of a key manufacturing process and perhaps are at MRL 4.

Using a 'weakest link' basis, a technology or system would have to receive an overall MRL that reflects the element of that technology that had the lowest level of readiness, in this case, MRL 4. In many instances, this approach could be misleading and give the impression of an overall level of risk greater than the actual situation. For assessments of more complex subsystems and systems, this simplification becomes even less useful since it is unlikely that every element is going to be, for example, at MRL 6 by Milestone B.

Therefore, the assessment report (as described in section 4.9), should contain a bottom-up assessment of the relative manufacturing readiness at the system, sub-system and component level. Findings for lower level components can be fit into a format for analysis and decision making at higher levels of the program as shown in Table 4-1. Each MRL (at any level) should be identified to provide insight into specific risks.

17.8.8 Write the Report

The results should be documented by team members in a format agreed to in advance. This could be in the form of a briefing or a written report. Often the outbriefing is an interim report. Usually some analysis is required by the assessment team after site visits are complete to clearly define the manufacturing readiness and risk status of the key technologies and manufacturing processes and to put the identified risks into a program context. These final results are then typically documented in a written report or out-brief containing the following:

- A description of the technology, component, subsystem or system which identifies the elements that were assessed; the key objectives of the development effort; and a discussion of the current state of the art;
- A discussion of the companies which are responsible for the elements that were assessed;
- A list of team members;
- Dates and locations of site visits;
- A description of the manufacturing processes for the elements that were assessed;
- The MRL for each element that was assessed;
- Areas where manufacturing readiness falls short of target MRL;
- Plans to reach target MRL;
- Assessments of the type and significance of risk to cost, schedule or performance; and
- Assessments of the effectiveness of current risk mitigation plans.

The government program/project office is the primary audience for the report since it forms the basis for managing manufacturing risk. In general, the report establishes a manufacturing maturity baseline that should be used to either create a Manufacturing Maturation Plan to increase manufacturing readiness/maturity sufficiently to support transition to the next phase of acquisition or to demonstrate that the technology is ready for transition. The report may also provide information to an MDA determination of whether the level of manufacturing risk supports Milestone approval.

These plans should include a description of the approach to resolve the risk, cost estimates, resources available, and schedule impacts. The manufacturing maturation plan is normally delivered along with the assessment report.

17.9 The Manufacturing Maturation Plan

A key product resulting from an assessment of manufacturing readiness is the Manufacturing Maturation Plan (MMP), which addresses the manufacturing risk and provides a mitigation plan for each risk area throughout the duration of the program/project, including supplier and sub-tier supplier risk management shortfalls. Every assessment of manufacturing readiness should have an associated MMP for those areas where the MRL has not achieved its target level.

In conjunction with the contractor, the program/project office should prepare an MMP that covers all manufacturing risk areas. The MMP should be delivered along with the results of the assessment of manufacturing readiness. The following outline for a MMP includes the most essential items in planning for the maturity of a specific element of assessment found to be below its target MRL:

1. Title
2. Statement of the problem
    a. Describe the element of assessment and its maturity status
    b. Describe how this element of assessment would be used in the system
    c. Show areas where manufacturing readiness falls short of target MRL including key factors and driving issues
    d. Assess type and significance of risk to cost, schedule or performance
3. Solution options
    a. Benefits of using the preferred approach
    b. Fall-back options and the consequences of each option
4. Maturation plan with schedule and funding breakout
5. Key activities for the preferred approach
6. Preparations for using an alternative approach
7. The latest time that an alternative approach can be chosen
8. Status of funding to execute the manufacturing plan
9. Specific actions to be taken (what will be done and by whom)
10. Prototypes or test articles to be built
11. Tests to be run
    a. Describe how the test environment relates to the manufacturing environment
12. Threshold performance to be met
13. MRL to be achieved and when it will be achieved

17.10 Contract Language

The contract Statement of Work (SOW) should include language similar to the following:

- The contractor shall conduct assessments of manufacturing readiness using the definitions, criteria, and processes defined in the *Manufacturing Readiness Level Deskbook* as a guide. Assessments will be conducted at the locations and frequencies specified. They will be led by the government program office at the prime contractor's facilities. The prime contractor shall lead the assessments at suppliers and include government participants.
- The contractor shall develop and implement manufacturing maturation plans or their equivalent for areas in which the MRL is lower than required to meet major milestone decisions .
- The contractor shall monitor and provide status at all program reviews for in-house and supplier MRLs and shall re-assess MRLs in areas for which design, process, source of supply, or facility location changes have occurred that could impact the MRL.

17.11 Summary

This chapter defined key terms associated with manufacturing readiness. It introduced the notion of Manufacturing Readiness Levels (MRLs) and described the roles and goals of manufacturing management and the elements of the manufacturing management process. It also defined current mandatory/statutory requirements and DOD policy guidance as it relates to the assessment of manufacturing risk and readiness. It defined the various manufacturing readiness levels and provided an overview of the MRL Matrix. This chapter also described the MRL assessment process to include the development of Manufacturing Maturation Plans.

17.12 Related Links and Resources

Numerous reference documents impact the manufacturing management function throughout the acquisition process. These documents originate from many sources and range across academic disciplines, functional activities, and job specialties.

The following is a reference list of DOD Directives (D), Instructions (I) Manuals (M), Pamphlets (P), Military Standards (MS), and other documents. The documents listed contain DOD policy guidance applicable to the manufacturing management function. They are listed as sources of DOD manufacturing management information.

Note: Many of the documents listed are no longer required (due to acquisition reform), but still contain some very valuable information.

Number	Title
	MRL Definitions and Descriptions

MRL Single Page Overview Chart
MRL Matrix
MRL Deskbook
MRL within the new 5000.02
MRL Tutorials