NIST Response to MES Request for Information

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1. Introduction

This is a response from the National Institute of Standards (NIST) to OMG's Request for Information concerning the Manufacturing Execution System (MES) area [RFI3]. There has been quite a bit of previous work at NIST, related to this RFI which influenced our response. This work included: development of a distributed shop floor control architecture - the Manufacturing Systems Integration (MSI) architecture [MSICEI], development of an activity model of the technical aspects of the product realization process for discrete metal parts (the Systems Integration for Manufacturing Applications Reference Architecture cited in the MES RFI) [SIMA96], involvement with validation and evolution of the SEMATECH CIM Application Framework [CIMFW], integration case studies with scheduling tools, and process planning /engineering experience [FENG].

This paper proposes a definition of the MES area as it applies to the work of the OMG Manufacturing Execution System / Machine Control working group (RFI item 3.1) including a set of functional views adapted from MESA International. In answer to the question of how to partition the MES systems (RFI item 3.3), we have provided a matrix of categories of data related to MES versus actions on that data. In this matrix we identify the functional views that use or cause this relationship. To assist in mapping this partitioning to a set of interfaces that could be requested in a set of RFPs, we have provided a simple object model with a suggested componentization based on the interrelationships among the objects. Finally a brief road-map is suggested for issuing RFPs to define the above interfaces.

2. MES Definition and Scope

The definition of MES given by MESA International [MESA] is useful but its purpose differs in an important way from the purpose of such a definition for the MES/MC working group. The MESA definition was for a class of monolithic applications. The working group is concerned with defining a scope for its efforts in defining interfaces in support of components of software which will make up distributed Manufacturing Execution Systems. We have tweaked the MESA definition accordingly. To further elaborate on the functional scope within this area, we have also taken the MES functionalities defined by MESA and modified them into functional views of the MES area, as we have now defined it. The goal of this section is to provide an answer to address objective 3.1 in the RFI, which was to validate the definition of MES.

2.1 MES Definition

NIST suggests the following definition of MES to be used for discussions of MES related interfaces at OMG. It is a modification of the definition provided in section 2.1 of the MES RFI.

> A Manufacturing Execution System is a collection of hardware/software components that enables the management and optimization of production activities from order launch to finished goods. While maintaining current and accurate data, an MES guides, initiates, responds to and reports on plant activities as they occur. An MES provides mission-critical information about production activities to decision support processes across the enterprise.

The term "order launch" is to be interpreted as initiation of physical production activities, typically beginning with materials preparation or machine preparation. Activities relating to planning and scheduling physical production operations are included within the scope of MES as defined in the following functional definitions (see Section 2.2) but activities related to defining physical operations are not.

(We acknowledge that many software packages that call themselves MES also support engineering and resource planning activities, but MES should be defined by a set of functions, not a set of software packages.)

The word “component” is used in this RFI response in a generic way to mean a separable portion of a larger whole. No architectural solution to CORBA based application composition is proposed as part of this MES definition. Therefore, the components referred to in this section are not CORBA Components as described by the CORBA Component Model RFP nor are they Business Object Components.

The "system" discussed above may be purchased prepackaged as a single unit, or assembled by a user from different vendors' components. In either case, an MES is expected to be a distributed system which must interact with other manufacturing information systems to support the efficient functioning of an enterprise. The OMG will define interfaces to facilitate the assembly (i.e. integration) of MES components into an overall MES and to facilitate the integration of a distributed MES into a manufacturing enterprise. Some aspects of an architecture supporting these integration requirements will be discussed in later sections of this RFI response, but the final form of this architecture won't be known until the Manufacturing DTF approves the related MES technologies.

It should be noted that any application that provides some subset of the functions attributed to MES in the definition above, could potentially be viewed as an MES component. This means that vendors who don't currently consider themselves to be MES vendors may nonetheless find that MES component interface development activities at OMG will be directly relevant to their product.

2.2 Defining MES Functions

A set of MES functions derived from a list provided by MESA International [MESA] is provided in this document for use by the OMG Manufacturing Domain Task Force in clarifying potential MES interface scope. A discussion of this derivation is provided in Appendix A. Note that Process Management has been removed from the list because NIST does not recommend that OMG consider it an MES function. The number assigned to Process Management has not been reused however, because to do so might cause confusion when we refer to the functional views by number within this paper.

1. Resource Allocation and Tracking

This function tracks resource status and maintains a detailed history. It ensures that equipment is properly set-up and that resources and other entities such as documents are available for a production activity to commence. The management of these resources includes reservation in support of the Operations/Detail Scheduling function.

2. Operations/Detail Scheduling

Provides sequencing of independent activities based on priorities, attributes, characteristics, and/or recipes associated with specific production units with the objective of meeting user defined performance goals. It is finite and it recognizes alternative and overlapping/parallel production activities in order to calculate, in detail, exact time or equipment loading and adjust to shift patterns.

3. Production Unit Dispatching

Directs workflow of production units in the form of jobs, orders, batches, lots, and work orders according to production plans and detailed schedule. Dispatch information is presented in the sequence in which the work needs to be done and changes in real time as events occur on the factory floor. It has the ability to alter prescribed schedule and/or production plan on the factory floor. Additions and alterations may include material preparation and handling, and process operations such as rework, recovery, and salvage. Dispatch also has the ability to control the amount of work in process at any point with buffer management.

4. Specification Management

Controls, manages and delivers information packages associated with the production unit, including work instructions, recipes, drawings, standard operation procedures, part programs, batch records, engineering change notices, and shift-to-shift communications. For example, it sends instructions to operators or recipes to device controls. It also supports editing "as planned" information and maintains version histories of specifications. It would also include the control and integrity of environmental, health and safety regulations, and information such as Corrective Action procedures.

5. Data Collection/Acquisition

This function acquires and updates production information used for product tracking, maintaining production histories, and other production management functions. It may use some combination of scanners, entry terminals, and software interfaces to manufacturing controllers and other software to perform this function. The data may be collected from the factory floor either manually or automatically in an up-to-the-minute time frame.

6. Labor Management

Provides status of personnel in an up-to-the-minute time frame. Includes time and attendance reporting, certification tracking, as well as the ability to track indirect activities such as material preparation or tool room work as a basis for activity based costing. It may interact with resource allocation to determine optimal assignments.

7. Quality Management

Provides timely analysis of product and process measurements taken from manufacturing operations, in order to ensure product quality control. This includes inter-process evaluations of product instances, tracking overall product and process behaviors, and identifying problems or trends requiring real-time attention. It may include SPC/SQC tracking via "off-line" inspection operations or variance analysis in laboratory information management systems (LIMS). It may include alerting factory personnel and/or automated control and dispatch systems to process behaviors or product results that are outside acceptable tolerances. It may include recommendation of actions to find the problem, correct the problem or minimize the impact, including correlating the symptom, actions, and results to determine the cause. It may provide additional interfaces to process control and measurement systems to capture the measurement data (distinct from the conventional Shop Floor Data Collection activities).

8. Process Management

This activity is completely described in the Dispatching and Quality Management functions and only appears in this list to avoid the confusion which might be caused by changing the numbers from how they appear in the MESA function list. The MESA model makes this a separate activity because it may be performed by a separate system.

9. Maintenance Management

Tracks and directs the activities to maintain the equipment and tools to insure their availability for manufacturing and insure scheduling for periodic or preventive maintenance as well as the response (alarms) to immediate problems. It maintains a history of past events or problems to aid in diagnosing problems.

10. Product Tracking and Genealogy

Provides the visibility to where work is at all times and its disposition. Status information may include who is working on it; component materials by supplier, lot, serial number; current production conditions; and any alarms, rework, or other exceptions related to the product. The on-line tracking function creates a historical record, as well. This record allows traceability of components and usage of each end product.

11. Performance Analysis

Provides up-to-the-minute reporting of actual manufacturing operations results along with the comparison to past history and expected business result. Performance results include such measurements as resource utilization, resource availability, product unit cycle time, conformance to schedule, and performance to standards. May include SPC/SQC. Draws on information gathered from different functions that measure operating parameters. These results may be prepared as a report, presented on-line as current evaluation of performance, or used to trigger alarms when derived parameters deviate from acceptable ranges.

While some of this analysis is similar to that done by ERP, it clearly is an important data source to aid in the operations and optimization of other functions such as scheduling and dispatching.

12. Material Management*

Manages the movement, buffering and storage of materials (stock, parts and tools) and consumables. Such movement may be in direct support of process operations or other functions such as equipment maintenance or setup.

* This function was not part of the original MESA list. However, we believe that it is an MES function although it is not clear how it may relate to the Resource Allocation and Tracking function.

3. Partitioning

The functions of an MES largely revolve around data. Components of MES manage (in an Information Technology sense) a great deal of this data. They also create, collect, modify, analyze, and react to this data. An analysis of this manufacturing data and how it is used by MES functions will reveal relationships which may map to a distributed system architecture for MES. We provide such an analysis in Table 1 and then provide a more detailed object model which incorporates some of the lessons that we have learned from past work about componentizing this functionality.

3.1 Partioning the Data

3.1.1 Data Category Descriptions

The descriptions of MES functions in section 2.2 refer to the following notional categories of manufacturing data:

- Dispatch Data – The job/operation dispatch list, or dispatch commands to operators and equipment.
- Equipment Resource Data – Resource state, staffing, setup, current operations and assignments, and job usage history.
- Labor Resource Data – Personnel availability and tracking information, and job assignment history.
- Maintenance Data – Machine availability data, maintenance history, and machine usage data.
- Material Location Data – Location and state of materials in the manufacturing facility with respect to active resources and material handling components, including groups and quantities of material.
- Order Data – Units of a particular product to be manufactured as defined by a manufacturing planning system, including status and associations with particular material groups.
- Performance Data – Cost and usage data – cost of operations performed and materials and resources used, idle time, setup time, etc.
- Process Control Data – Process control parameters.
- Product Data (WIP) – Materials tracking data – the amount, state, and disposition of materials in production and their relationship with manufacturing orders.
- Quality Analysis Data – Data resulting from the quality analysis function, that is interpreted measurements of process and product.
- Quality Data – Product and process measurement data. Can include such data taken from process operations.
- Resource Description Data – Characteristics of labor and equipment resources such as capabilities, skills, types, and assigned cost.
- Schedule Data – Allocation of resources to jobs and processes per time period. Resource types may include equipment, labor, and some tooling.
- Shop Floor Data – Raw data collected by data collection systems that can be used to derive Product (WIP) data, Resource data, and other types of data primarily used for tracking and history maintenance.
- Specification Data – specifications for how to perform a manufacturing process, including sequence of operations to be performed, equipment, tooling and skills requirements, and materials to be used.
- Tooling Resource Data – Usage, location and allocation information which may be used for tracking, scheduling and maintenance of tools.

Table 1 shows the nature of the data usage by the MES activities described in Section 2.2. The numbers in each cell correspond to the numbers of the activities described in Section 2.2. The designations HRM, ERP, and PPE refer to non-MES systems of the enterprise that use some of the same data. HRM refers to Human Resource Management systems, ERP refers to Enterprise Resource Planning Systems, and PPE refers to Product and Process Engineering systems.

Table 1: Relationship of Data to MES Activities

	Collects	Creates	Changes	Manages	Analyzes	Reacts to	Delivers	Displays	Derived from:
Dispatch data		3	3, 8			8, 10, 12 Control	3	3, 10	
Equipment Resource data	5		5, 9	1	9	2, 3			
Labor Resource data	6		10	6, HRM	11	2, 3			
Maintenance data	5	9	9	9	9, 10	2, 3, 9	9		
Material Location data	5, 12	12	12	12		3, 10		12	Shop Floor data
Order data	ERP		10	ERP		2, 3, 10	ERP	2, 10	Product data
Performance data		11		11		ERP, P/PE	11	11	Resource data, Schedule data, Shop Floor data, Process data, Product data
Process Control data		P/PE	8			Control	8		
Product data (WIP)	5		7, Control	10	11	2, 10, ERP		10	Shop Floor data, Process data
Quality Analysis data		7		7, 10		3, 9	7	7	Quality data
Quality data	5?, 7	Control		7	7, 10	?			Product data, Process data
Resource Description data		ERP, HRM, P/PE		6, HRM, ERP, P/PE		2, 3			
Schedule data		2	2	2	11	2, 3			
Shop Floor data	5			5	2, 10	2, 3	5		
Specification data	P/PE	P/PE	4	4		3, 7	P/PE		
Tooling Resource data	12	12	Control	1, 10		2, 3, 10			

3.2 Defining the Object Model

From the list of "data categories" in Table 1, we can identify the important manufacturing "business objects[1]" — things that are described by the data and are manipulated by manufacturing processes. Some of these objects are physical objects around which information

[1] The term *Business Object* is commonly used in some modeling communities. See http://www.yy.cs.keio.ac.jp/~suzuki/object/bo.html or OMG document bom/97-12-04 for more details on this concept.

is organized and others are logical objects which are important to the management of the manufacturing processes.

- Dispatch Data – relates to the logical object class Job.
- Equipment Resource Data – relates to the physical object class Equipment.
- Labor Resource Data – relates to the physical object class Labor.
- Maintenance Data – relates to the physical object class Equipment.
- Material Location Data – relates to the physical object class Material.
- Order Data – relates to the logical object class Manufacturing Order.
- Performance Data – these are reports, extracted from information attached to Order, Job, Equipment, Labor, Product, and Process.
- Process Control Data – relates to the physical object class Process.
- Product Data (WIP) – relates to the physical object class Product.
- Quality Analysis Data – relates to the physical object classes Product and Process.
- Quality Data – relates to the physical object classes Product and Process.
- Resource Description Data – relates to the physical object classes Equipment and Labor and introduces the logical object class Capability.
- Schedule Data – relates to the logical object class Schedule and to the physical object classes Equipment, Labor, and possibly Tool and to the logical object class Job.
- Shop Floor Data – relates to the physical object classes Equipment, Labor, Material, Tool, Product, and Process.
- Specification Data – relates to the logical object classes Process Specification and Item Specification.
- Tooling Resource Data – relates to the physical object class Tool.

This analysis results in the following major conceptual object classes:

- Capability — the ability to perform a Process.
- Equipment — a capital resource that performs Processes.
- Item Specification — a formal description of some thing needed for production.
- Job — the logical unit of work on the factory floor.
- Labor — human resources.
- Manufacturing Order — the unit of work planned by ERP systems.
- Material — some thing used or consumed in the production of product.
- Process — the physical unit of work on the factory floor.
- Process Specification — a formal description of a Process.
- Product — the intended output of a Job.
- Schedule — the relationship of Process, Equipment and Labor to time periods.
- Tool — an item that can be reused in making Product objects.

Figure 1 is a rough model of the “MES Business Objects” and their relationships.

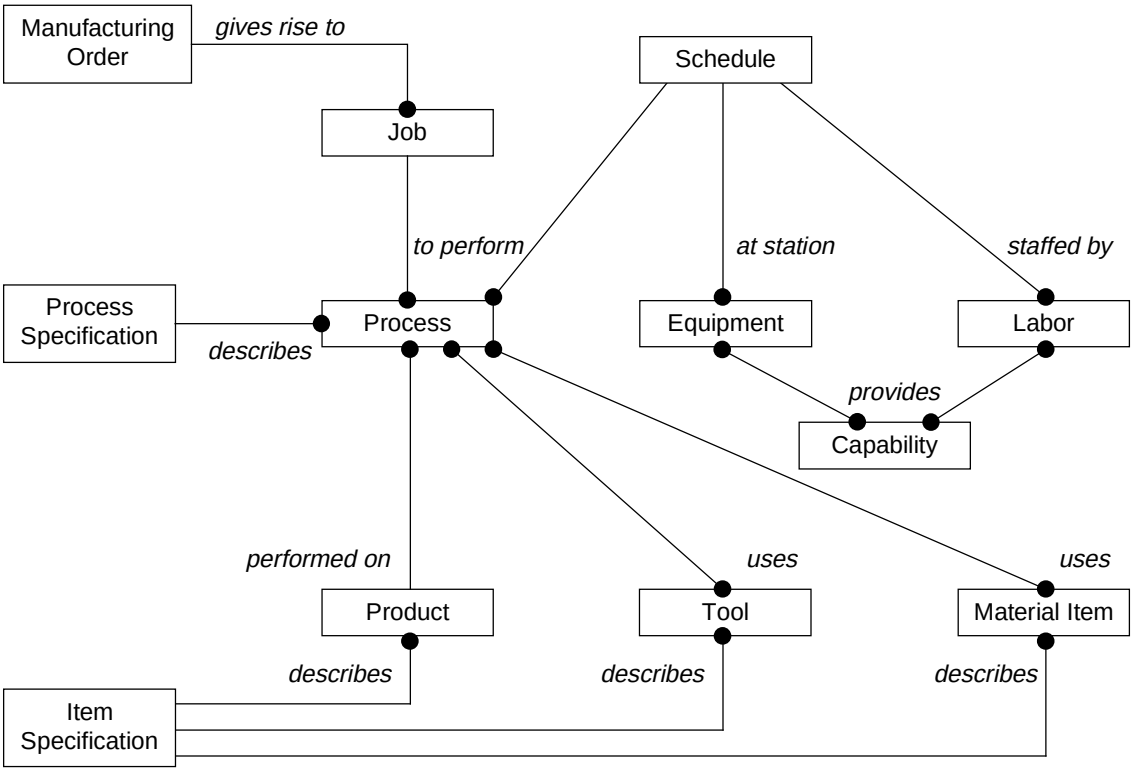

Figure 1[2]: Simplified MES Business Objects

This collection of business objects, however, must be refined and extended in order to capture details of the relationships which are significant in determining how to partition the interface requirements.

In performing this refinement, we borrowed from previous NIST work [MSIpmodels] and from the model in the OMG Machine Control White Paper [MC]. The results of the refinement are shown in Figure 2 and Figure 3, and described in some detail in Section 3.2.1

[2] The notation used in this figure and subsequent object models is a simplified version of the Object Modeling Technique (OMT) notation described in [Rumbaugh]. Appendix C summarizes the notational elements used in this report.

3.2.1 MES Object Model

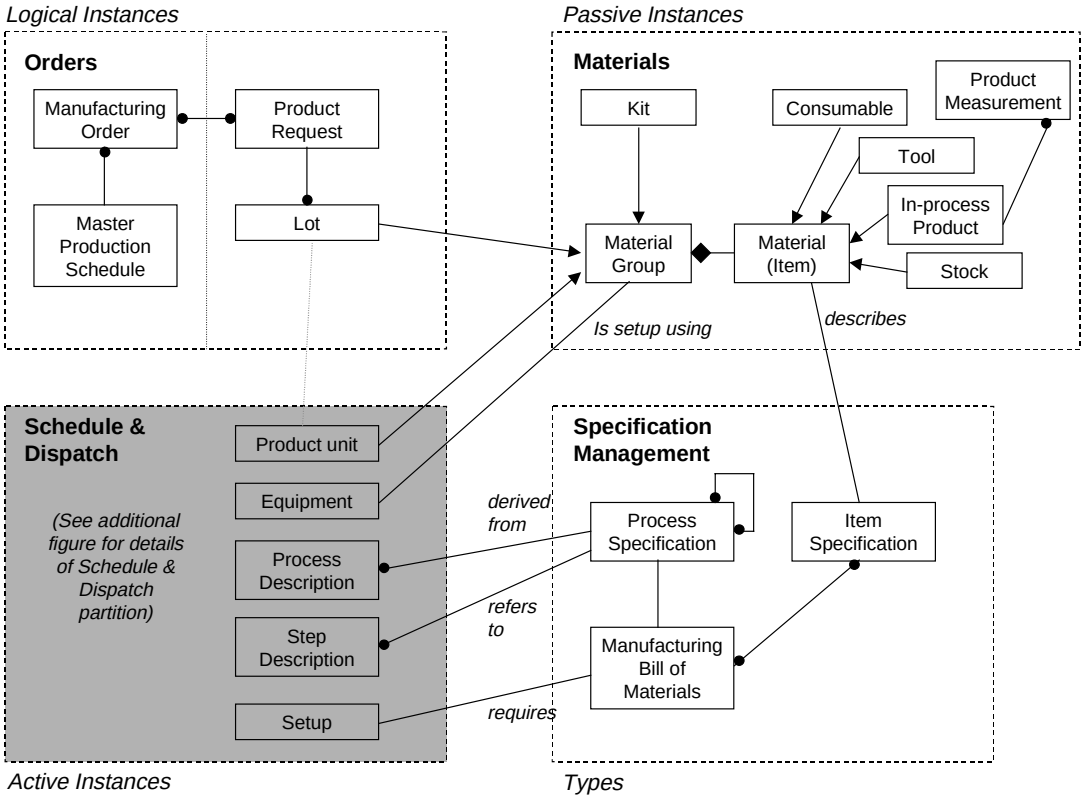

Figure 2: MES Object Model with Partitioning

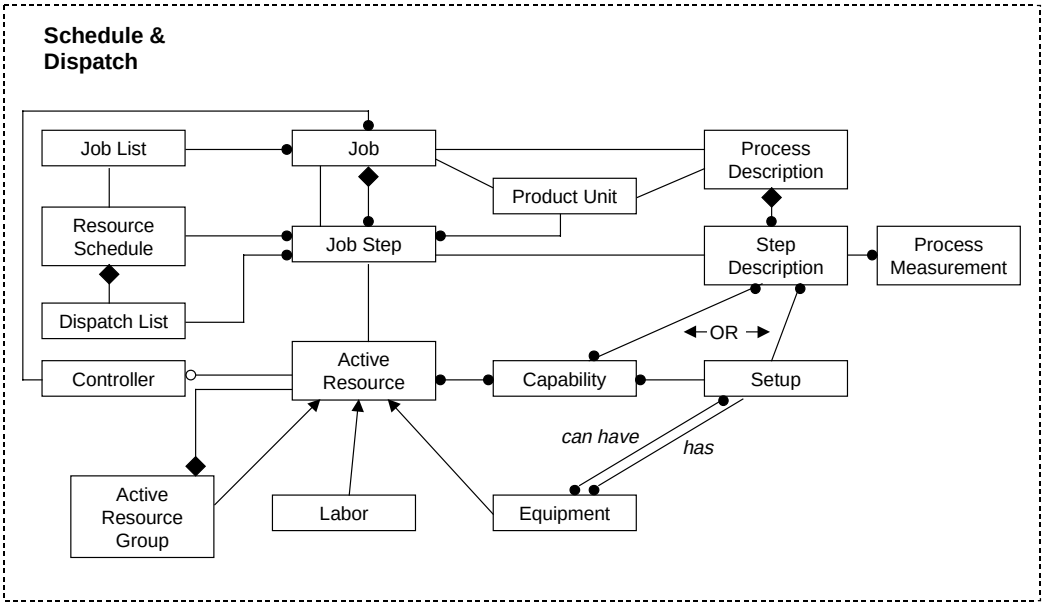

Figure 3: Detailed View of Schedule and Dispatch Partition

3.2.1.1 MES Model Entities

The entities of the MES Object Model shown in figures 2 and 3 are described below:

- *Active Resource* – a physical resource that can perform process operations and supports specified capabilities during manufacturing activities -- people and equipment such as machines, robots, storage devices, transport devices, etc. Some Active Resources are actually groups of people and equipment, such as a workcell, which may be managed as a unit for some set of tasks.
- *Capability* – the ability of a resource to perform a specified operation. For human resources, a capability is sometimes called a (certified) skill. For Equipment resources, this potential may be dependent on Setup and on having an appropriately skilled operator.
- *Consumable* – a unit of material which is used and expended during manufacturing or support processes and usually is accounted for in bulk, such as coolants, lubricants, flux, adhesives, rouge, etc. Some kinds of small parts and tooling components may also be managed as consumables, depending on the local business rules.
- *Controller* – the software system that provides the intelligence needed by an Active Resource to perform all or part of a process operation automatically. In Active Resources that do not have a Controller per se, a human agent supplies the intelligence.
- *Item Specification* — the complete description of a kind of Material item: its shape, weight, handling characteristics, image, etc.
- *Job* – a unit of work assigned to an Active Resource. At the highest level, the unit of work is the fulfillment of a Manufacturing Order, at the Schedule/Dispatch level,

the unit of work is the processing of a Lot; at lower levels the unit of work is a process operation, transport operation, or operation step.

- *Job Step* – is an instantiation of a Step Description, as seen by the planning/scheduling or dispatching system overseeing execution of the Step. By some dispatching process, the Job Step becomes a Job for the Active Resource to which the Step execution is assigned.
- *Kit* – a kind of Material Group that is composed of some combination of roduct instances or units, Tools, and Consumables. It is a physical collection of Materials that is handled as a unit, and may have physical properties of its own.
- *Labor* – a human Active Resource (employee or contractor or group) who performs certain Jobs directly or in collaboration with a Machine. The ability of a human resource to perform a specific kind of process with specific kinds of equipment is called a certified skill.
- *Lot* – the unit of product into which a Manufacturing Order is decomposed for scheduling, dispatching and tracking production operations. A Lot is a conceptual Material Group. The actual corresponding Product Units on the factory floor may be decomposed and regrouped, depending on production policies and needs.
- *Manufacturing Bill of Materials* — a list of the types and quantities of all Materials needed to manufacture a unit of product or to perform a particular process.
- *Manufacturing Order* – a quantity of a particular product to manufacture as specified by an Enterprise Requirements Planning system.
- *Master Production Schedule* – A long-term schedule created and maintained by enterprise planning systems that defines quantities of particular products to be produced in particular time-frames, consistent with customer demands, manufacturing capacity, and resource availability. The entries in the MPS are called Manufacturing Orders and are the “Job” interface between the planning systems and the Manufacturing Execution Systems.
- *Material Item* – a physical resource that is acted upon or used by an Active Resource in the performance of a manufacturing activity. It is characteristic of most Material Items that they can be moved around the factory floor, and it is often the case that their location is tracked in some way. This includes product instances, tooling, Stock Materials and Consumables.
- *Material Group* — a logical or physical collection of Material instances.
- *Process Description* – a recipe for performing a specific task. A Process Description is a breakdown of a process into “sub-tasks” or steps, expressing the requirements for each step and its relationship to other steps in the recipe. Every Process Description has an associated Active Resource that is responsible for planning and executing the process described. Process Descriptions come in many forms: NC programs, routings, operation sheets, recipes, etc. In this model, a Process Description is the form of the recipe that is used by the Active Resource (controller).
- *Process Specification* – the archival form of a Process Description, usually a kind of document. A Process Specification is an Information Resource that is targeted for a particular type of Active Resource and is copied as needed to create Process Descriptions for individual resources, according to effectivity rules.
- *Product In-process* – a Material Item which becomes part of a final product. It is sometimes called a workpiece.
- *Product Request* – a unit of product that is the basis for planning/scheduling activities at the highest level of a Manufacturing Execution System. Typically it represents a Manufacturing Order, or an expansion, aggregation or disaggregation of Manufacturing Orders created for the purpose of planning production in detail.

- *Product Unit* — a quantity of product (or a group of In-process product items) that undergoes one or more manufacturing activities together (from the point of view of some level of process management). It is usually the basis for planning those activities, but it may also be physically packaged together for execution of transport and process activities.
- *Resource Schedule* – a collection of assignments of Active Resources to Job Steps at specific times.
- *Setup* – a particular configuration of an Equipment resource that results in a set of active Capabilities for that resource.
- *Step Description* — A part of a Process Description that identifies a Job Step to be performed, the Active Resource capabilities and other resources necessary to perform the Job Step, other information needed to plan the Job Step, and, usually, the Process Specification that the Active Resource will use to perform the Job Step activity.
- *Stock Material* – a kind of Material that is the starting point for, or an ingredient in, a unit of product. It can be a pre-fabricated component or a unit of material drawn from a large reservoir in some specific quantity, or a base component cut from a large unit of warehoused material to specific measurements.
- *Tool* – a Material Item used by an Active Resource in the performance of some manufacturing activity. A Tool is a Material Item that is needed during the manufacturing process but is not (usually) consumed and does not become part of the finished goods. Tools are used to set-up an equipment resource, or augment a workstation setup, in order to enable the workstation to perform a particular process operation. It also includes various kinds of carriers used to hold materials for transport within the manufacturing facility.

The following object types appeared in the OMG Machine Control White Paper [MC], but are not depicted in the Figures above. They are general supertypes which may or may not have any common properties and behavior that is important to model.

- *Resource* – A single identifiable object whose use is expressly called out in the complete specifications for the manufacture of some product — a person, a tool, a machine, a part, a unit of material, a specification, etc.
- *Information Resource* – a type of Resource which contains specialized information that is necessary for the execution of a manufacturing activity, such as a product specification or a process specification. Unlike Physical Resources, Information Resources don't need to be allocated to a particular Job, since they can be shared by copying among any number of active processes.
- *Logical Resource* — a type of Resource that is managed and allocated, but is either a conceptual grouping of other Resources or is a software object that has a unique identity and is managed as part of execution of a manufacturing process. A Material Group is a Logical Resource, and a named control variable is a also a Logical Resource.
- *Physical Resource* – a type of Resource that occupies physical space. There are two principal categories of Physical Resources: Active and Material. Active resources are those which perform tasks; Material resources are those which are used in the performance of tasks and are tracked on the factory floor.

3.2.1.2 Model partitions

The partitions that we have shown with dotted boxes in Figure 2, are groupings of model entities that are closely coupled or functionally similar. Coupling between these partitions should be supported via domain specific names or keys. Each partition in the model is described in detail below. While all these partitions are important to MES, they need not all be supported directly

within an MES. We make special note below of those that we consider to be core MES partitions. The tags seen in italics above or below each partition box in the figure are general characterizations of the resource entities within each partition. These are further explained in the text below.

- Orders – the Orders partition contains planning entities. It is divided into two classes of entities:
  1) those that are created by ERP systems and
  2) those which may be MRPII entities.
  This distinction is made here since it is not clear whether MRPII is considered an ERP or MES function. We note that with either view an MES must be able to update instances of Lot. This partition may be partially or wholly implemented by systems upstream of MES. (Lot is very highly used by MES, however.) We have tagged this partition "*Logical Instances*" in the diagram to indicate that the entities within it are logical resources which merely represent groups of physical resources or planned physical resources modeled in other partitions.
- Schedule & Dispatch – This partition is at the heart of MES operations, containing the primary entities involved in scheduling and dispatching (thus supporting this partition is considered a core or mandatory requirement). The entities in this partition are characterized by a high degree of coupling between them, particularly between the Schedule, Job and Process Description entities. If reactive scheduling is to be supported, then Dispatching (Job Control) and Scheduling components must be able to share a common understanding of the internals of a Process Description. This is why the model has a separate entity for Process Description which is distinct from (and an instance is derived from a) Process Specification, since Specifications have different access characteristics such as being retrieved as a blob using effectivity rules. We note with the tag "*Active Instances*" that unlike the entities in the other partitions, many Schedule & Dispatch entities can initiate actions.
- Specification Management – The entities in this partition are grouped together because of their similar access characteristics and only have a loose coupling between them. This means that while some efficiency may be gained by putting all these entities into one component, as long as the access requirements shared by these entities are met, these entities could be stored in multiple components. An example of this would be a facility where Recipes which are a subtype of Process Specification, were held in a recipe manager, while routings, BoMs, and Item Specifications simultaneously were held in a PDM. As this example suggests, the Specification Management partition need not be a part of an MES at all, as long as the server system is available to Operations and WIP tracking components. We note with the tag "*Types*" that this partition contains information resource entities that provide type information used to instantiate or describe other entities.
- Materials – While the entities in the Materials partition are related to material information used in manufacturing planning systems and other material information used in product and process engineering systems, the entities present in an MES are distinguished from those others in that they represent information corresponding to material instances. This partition is used to maintain material status, history, and genealogy data which is a core MES function. It may also provide inventory information. We note with the tag "*Passive Instances*" that the entities in this partition represent physical resources which are manipulated or acted upon by active resources represented in other partitions.

4. Appropriate Standards to consider

There are a number of standards activities underway in the International Organization for Standardization (ISO) with which NIST has had some involvement. The most directly related work is known as MANufacturing management DATa Exchange or MANDATE and is being developed in TC184/SC4/WG8. Related drafts currently in process in this Working Group are:

- ISO/CD 15531-1, MANufacturing management DATa Exchange – Overview and fundamental principles
- ISO/CD 15531-31, Manufacturing resource usage management data – Overview and fundamental principles
- ISO/WD 15531-32, Manufacturing resource usage management data – Conceptual model for resource usage management data
- ISO/CD 15531-41, Manufacturing flow management data – Overview and fundamental principles
- ISO/WD 15531-42, Manufacturing flow management data – Time Model
- ISO/WD 15531-43, Manufacturing flow management data – Conceptual model for flow monitoring and control

The scope of part 41 covers much of the same sort of data that we have discussed in earlier parts of this paper as of a fundamental import to MES. However, neither of these drafts have progressed very far in the standards process, so there is an opportunity for the Manufacturing DTF to collaborate with this group on MES-related standardization efforts.

Other work has been done in SC4, under the auspices of STEP (STandard for the Exchange of Product model data) which relates mostly to Item Specification. A few of these related parts are:

- ISO 10303 – 202:1996, Associative Draughting
- ISO 10303 – 203:1994, Configuration Controlled Design
- ISO/DIS 10303 – 210, Electronic Assembly Interconnect and Package Design
- ISO/CD 10303 – 214, Core Data for Automotive Mechanical Design Processes

Of the above parts, 202 and 203 have reached International Standard status.

NIST has been and will continue to promote communications between the Manufacturing DTF and ISO TC184/SC4 so that efforts can be coordinated where mutually beneficial.

5. Roadmap

Our suggested MES object model (in section 3.2) and its partitioning provide some guidance on how the roadmap for the Manufacturing Domain Task Force should be amended to support the creation of OMG MES interface specifications. The goal in defining such interfaces is to support distributed Manufacturing Execution Systems that can easily be integrated with other manufacturing information systems. Because of the relationships among entities within a partition, requirements for all the entities in any given partition should be kept together in a corresponding RFP. Thus we expect that the four partitions will map to four RFPs in the roadmap for the Manufacturing DTF.

As Table 1 shows for the data categories, there is an overlap of interest between the MES and other manufacturing systems. As a consequence, corresponding RFPs may involve other working groups in their specification. The requirements for the Orders partition could correspond to part of an ERP RFP, and the requirements for the Specification Management partition could correspond to part of a Product and Process Engineering RFP. Note that access control interfaces which will be required for a Specification Management proposal, could be adapted from

the PDM enablers. The remaining two partitions, Materials and Schedule & Dispatch, are clearly fundamental to MES and thus the corresponding RFPs should be sponsored by the MES/MC working group.

We provide the following list of suggested RFPs and because of dependencies between them, they should be issued in the order shown:

- Specification Management RFP – provide interfaces supporting version and effectivity driven retrieval of complete specifications needed for production (supporting the MES Specification Management function described in section 2.2).
- Orders RFP – provide interfaces for initiating and tracking manufacturing plans and orders.
- Materials RFP – provide interfaces to be used for maintaining state and location of material instances (supporting the MES Product Tracking function).
- Operations RFP – provide interfaces and object models of the elements needed for performing and tracking multi-level scheduling, dispatching (job execution) and interoperation control (supporting the MES Resource Tracking, Scheduling, Dispatching, Data Collection, Labor Management, and some Quality Management functions).

Following these RFPs, others could be issued to support functions from section 2.2 not supported by the RFPs just suggested. These would be: a Maintenance Management RFP, a Material Movement RFP, and possibly a Performance Analysis RFP.

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Appendix A: Derivation of MES Functional Views

This appendix contains an explanation of how our new set of functional views was derived from the set of MES functional groupings defined by MESA International [MESA].

Functional Views

In the list below, each MES function name and definition is quoted as it appears in Appendix A of MESA white paper 6 [MESA] pp12. Each function is then followed by NIST comments (where needed) as to how these should be modified (or deleted) for use by the OMG Manufacturing Domain Task Force in clarifying a potential MES interface scope. A version of this with only the resulting NIST suggested functional view definitions, is provided as the text of section 2.2 of this document. Note that Process Management has been quoted as a base for discussion, even though NIST does not recommend that OMG consider it an MES function.

1. Resource Allocation and Status

> Manages resources including machines, tools labor skills, materials, other equipment, and other entities such as documents that must be available in order for work to start at the operation. It provides detailed history of resources and insures that equipment is properly set up for processing and provides status real time. The management of these resources includes reservation and dispatching to meet operation scheduling objectives.

NIST would prefer that this function be entitled "Resource Allocation and Tracking." "tools labor skills," should probably be "tools, labor, skills." The last sentence in the paragraph is confusing as it seems to overlap with the dispatching function discussed later. It would be better stated as "The management of these resources includes reservation in support of the Operations/Detail Scheduling function."

> This function tracks resource status and maintains detailed resource history. It ensures that equipment is properly set-up and that resources and other entities such as documents are available for a production activity to commence. The management of these resources includes reservation in support of the Operations/Detail Scheduling function.

2. Operations/Detail Scheduling

> Provides sequencing of independent activities based on priorities, attributes, characteristics, and/or recipes associated with specific production units at an operation such as shape of color sequencing or other characteristics which, when scheduled in sequence properly, minimize set-up. It is finite and it recognizes alternative and overlapping/parallel operations in order to calculate in detail exact time or equipment loading and adjust to shift patterns.

The example embedded in the text above obscures other uses of scheduling. NIST replaces this text with more general language in the text below.

> Provides sequencing of independent activities based on priorities, attributes, characteristics, and/or recipes associated with specific production units with the objective of meeting user defined performance goals. It is finite and it recognizes alternative and overlapping/parallel production activities in order to calculate, in detail, exact time or equipment loading and adjust to shift patterns.

3. Dispatching Production Units

Manages flow of production units in the form of jobs, orders, batches, lots, and work orders. Dispatch information is presented in sequence in which the work needs to be done and changes in real time as events occur on the factory floor. It has the ability to alter prescribed schedule on the factory floor. Rework and salvage processes are available, as well as the ability to control the amount of work in process at any point with buffer management.

Change to:

Directs workflow of production units in the form of jobs, orders, batches, lots, and work orders according to production plans and detailed schedule. Dispatch information is presented in the sequence in which the work needs to be done and changes in real time as events occur on the factory floor. It has the ability to alter prescribed schedule and/or production plan on the factory floor. Additions and alterations may include material preparation and handling, and process operations such as rework, recovery, and salvage. Dispatch also has the ability to control the amount of work in process at any point with buffer management.

4. Document Control

Controls records/forms that must be maintained with the production unit, including work instructions, recipes, drawings, standard operation procedures, part programs, batch records, engineering change notices, shift-to-shift communications , as well as the ability to edit "as planned" and "as built" information. It sends instructions down to the operations, including providing data to operators or recipes to device controls. It would also include the control and integrity of environmental, health and safety regulations, and ISO information such as Corrective Action procedures. Storage of historical data.

NIST would prefer this function to be entitled Specification Management. No one should have the ability to edit "as built" information and the recording of "as built" information properly belongs in the Product Tracking and Genealogy function. Therefore, we recommend removing the words "and ‘as built' " from the text above.

alternative version:

Controls, manages and delivers information packages associated with the production unit, including work instructions, recipes, drawings, standard operation procedures, part programs, batch records, engineering change notices, and shift-to-shift communications. For example, it sends instructions to the operators or recipes to device controls. It also supports editing "as planned" information and maintains version histories of specifications. It would also include the control and integrity of environmental, health and safety regulations, and information such as Corrective Action procedures.

5. Data Collection/Acquisition

This function provides an interface link to obtain the intra-operational production and parametric data which populate the forms and records which were attached to the production unit. The data may be collected from the factory floor either manually or automatically from the equipment in an up-to-the-minute time frame.

The above definition describes more about how the Data Collection function is performed than what function is performed. An alternate definition is provided below.

This function acquires and updates production information used for product tracking, maintaining production histories, and other production management functions. It may use some combination of scanners, entry terminals, and software interfaces to manufacturing controllers and other software to perform this function. The data may be collected from the factory floor either manually or automatically in an up-to-the-minute time frame.

6. Labor Management

> Provides status of personnel in an up-to-the-minute time frame. Includes time and attendance reporting, certification tracking, as well as the ability to track indirect activities such as material preparation or tool room work as a basis for activity based costing. It may interact with resource allocation to determine optimal assignments.

NIST observes that this is a particular instance of the Resource Allocation and Tracking function . We wonder why is it called out separately? Does this function also duplicate some functions of human resource systems? We contend that any legitimate human resource function not covered by function (1) is an ERP function.

7. Quality Management

> Provides real time analysis of measurements collected from manufacturing to assure proper product quality control and to identify problems requiring attention. It may recommend action to correct the problem, including correlating the symptom, actions and results to determine the cause. May include SPC/SQC tracking and management of off-line inspection operations and analysis in laboratory information management system (LIMS) could also be included.

We would prefer that the title of this function be changed to "Quality Analysis" and propose the following text to replace that currently used to describe this function.

> Provides timely analysis of product and process measurements taken from manufacturing operations, in order to ensure product quality control. This includes both inter-process evaluations of product instances and tracking overall product and process behaviors and identifying problems or trends requiring real-time attention. It may include SPC/SQC tracking via "off-line" inspection operations or variance analysis in laboratory information management systems (LIMS). It may include alerting factory personnel and/or automated control and dispatch systems to process behaviors or product results that are outside acceptable tolerances. It may include recommendation of actions to find the problem, correct the problem or minimize the impact, including correlating the symptom, actions, and results to determine the cause. It may provide additional interfaces to process control and measurement systems to capture the measurement data (distinct from the conventional Shop Floor Data Collection activities).

8. Process Management

> Monitors production and either automatically corrects or provides decision support to operators for correcting and improving in-process activities. These activities may be intra-operational and focus specifically on machines or equipment being monitored and controlled as well as inter-operational, which is tracking the process from one operation to the next. It may include alarm management to make sure factory person(s) are aware of process changes which are outside acceptable tolerances. It provides interfaces between intelligent equipment and MES possible through Data Collection/Acquisition.

This item appears to be describing process control (with or without human assistance). The intra-operational control portion of this function is properly in the domain of Machine Control systems, while the inter-operational control portion is already addressed in the MES function list by a combination of the previously described functions of Scheduling (2), Dispatching (3), NIST's redefined Quality (7) function, and the Material Management function which NIST added to this list. We therefore recommend the deletion of the Process Management function from the MES function list.

9. Maintenance Management

Tracks and directs the activities to maintain the equipment and tools to insure their availability for manufacturing and insure scheduling for periodic or preventive maintenance as well as the response (alarms) to immediate problems. It maintains a history of past events or problems to aid in diagnosing problems.

10. Product Tracking and Genealogy

Provides the visibility to where work is at all times and its disposition. Status information may include who is working on it; components materials by supplier, lot, serial number, current production conditions, and any alarms, rework, or other exceptions related to the product. The on-line tracking function creates a historical record, as well. This record allows traceability of components and usage of each end product.

This is Work in Process (WIP) tracking and product/production history data storage and management. This is an MES function and should include management of "as built" data (a function which MESA attributes to Document Control).

11. Performance Analysis

Provides up-to-the-minute reporting of actual manufacturing operations results along with the comparison to past history and expected business result. Performance results include such measurements as resource utilization, resource availability, product unit cycle time, conformance to schedule and performance to standards. May include SPC/SQC. Draws on information gathered from different functions that measure operating parameters. These results may be prepared as a report or presented on-line as current evaluation of performance.

While some of this analysis is similar to that done by ERP, it clearly is an important data source to aid in the operations and optimization of other functions such as scheduling and dispatching. We suggest that the following text be appended to the last sentence, "or used to trigger alarms when derived parameters deviate from acceptable ranges."

12. Material Management*

Manages the movement, buffering and storage of materials (stock, parts and tools) and consumables. Such movement may be in direct support of process operations or other functions such as equipment maintenance or setup.

* This function was not part of the original MESA list. However, we believe that it is an MES function although it is not clear how it may relate to Resource Allocation and Tracking.

Appendix B: Unification of the Quality Analysis and Process Control Functions

In our view, quality analysis, and process control are inseparable functions, even though they may be carried out by distinct software modules. In fact, these functions are replicated several times in the quality management activities of a production facility.

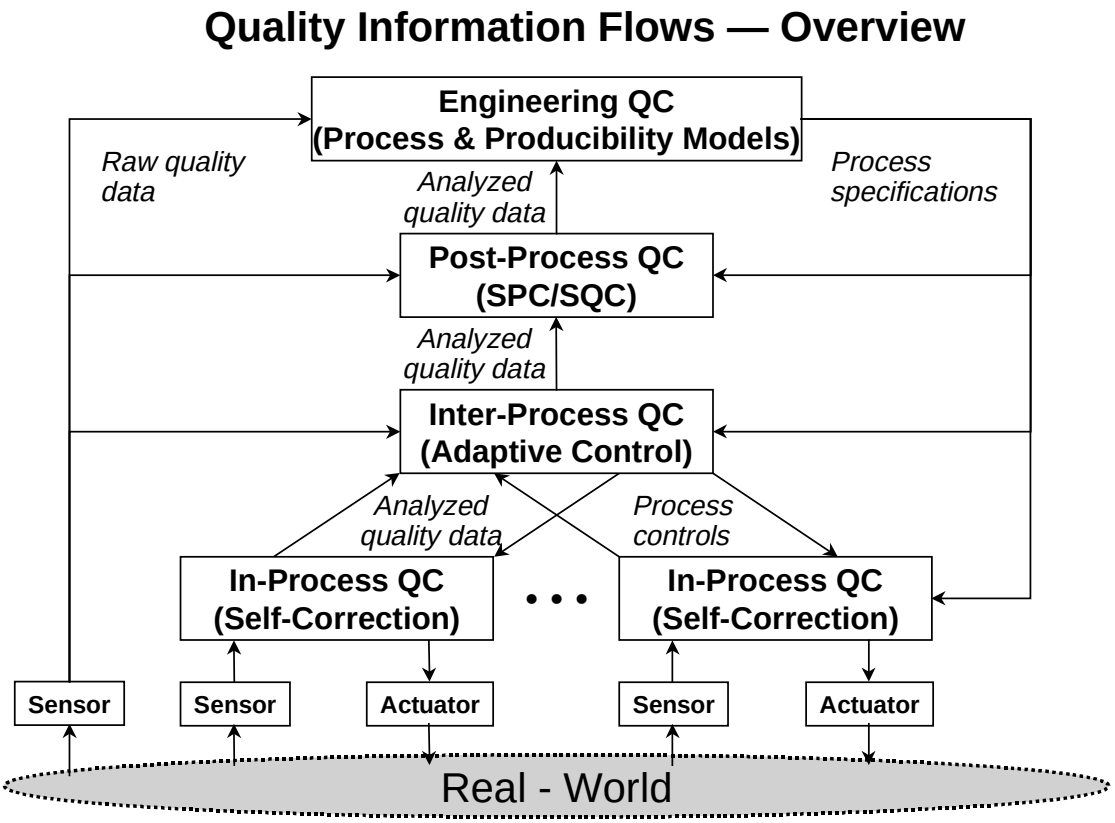


Figure B.1

Figure B.1 depicts the overall architecture of product quality management as four levels of data acquisition, data analysis, and decision making.

At the lowest level of quality management are the in-process activities of a machine controller or process controller attempting to perform a production process to specification. The controller uses sensory devices to make raw measurements of the product -- dimensions, positions, chemical and thermal behaviors, etc. -- or of the process itself -- duration, ambient pressure and temperature, end-effector and joint positions, feed volumes, etc. Typically using some kind of control law, the controller converts the raw measurements into process perturbations and takes corrective actions in the form of parameter adjustments to the individual process controls.

At the next level, inter-process quality control systems may use their own sensors, or take raw or analyzed data from the controllers to measure product instances and evaluate that data to determine whether the product and process are still within tolerances. Such systems can also take corrective action in the form of feedback to the responsible controller to adjust control parameters so as to improve the quality of the next product instance and keep the process in bounds. They can also take corrective action on the affected product instances to rework them to an acceptable state for the next process, or rarely, feed forward process corrections to the next process to rectify the marginal characteristics of the product instance.

At the final production level, post-process inspection of a finished product again takes raw product measurements and analyzes them to determine whether the product instance or batch meets quality standards. This results in decisions for disposition of the product instance/batch as good, bad, or "reworkable", or in some cases (when "statistical quality control" is used) estimates of the percentage of the batch that will meet standards. This activity can also identify gradual drift in the process behaviors by observation of gradual change in certain measurements of the resulting products ("statistical process control") and take corrective actions usually of a grosser nature, such as shutting down and resetting the process.

At a further level of quality management, process engineers evaluate the raw and analyzed data from the production quality control systems to determine the real quality maintenance of the processes as defined, and use this data to reengineer the production processes to obtain higher quality. This is often referred to as "improving the process models."

The important idea here is that there is a continuum of quality maintenance activities, ranging from the internal behavior of the controller to the external behavior of the process engineers, each of which feeds information to, and is affected by, the decisions of the others.

In addition, there is a common model of this behavior that occurs at every "level" of this continuum, no matter where the "level boundaries" are drawn. This pattern is depicted in Figure B.2 -- measure the product and/or the process, analyze measurements to determine product quality, decide on and take actions with respect to the product or the process, in order to maintain target quality.

The "virtual" sensors represent real-world sensors or analyzed information taken from other control systems, and similarly, the "virtual" actuators represent real actuators at the lowest-level of control and commands or control parameters fed to "lower-level" control and quality maintenance systems.

Quality Information Flows — Control View

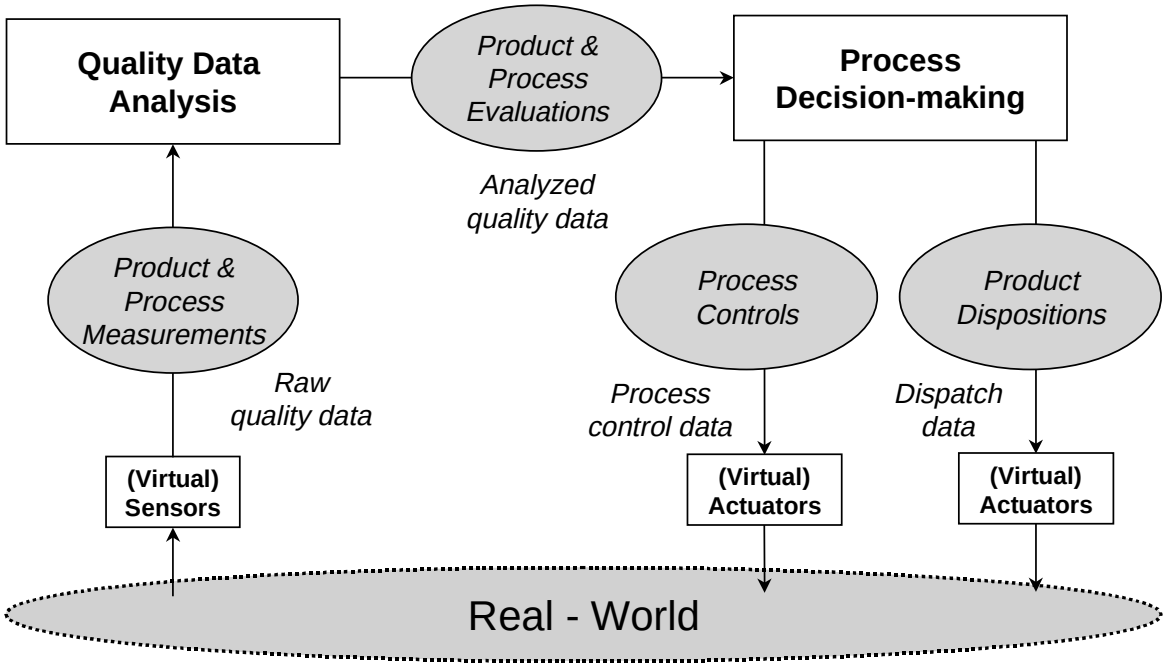
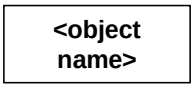


Figure B.2

Appendix C: Description of Graphical Notation Used in Object Models

The graphical notation used for the object models in this report is a slightly modified subset of the Object Modeling Technique (OMT) notation described in [Rumbaugh]. The modifications which we made to the language, allowed for drawing the models with a simple drawing tool. The graphical constructs used are shown in the figure below:

Table C.1

Modeling construct description	Graphical Representation
Object Class	
"Part of" relationship	
One to one relationship	
One to zero or one relationship	
One to many relationship	
"Is a" or specialization relationship	