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Economic Impact of Inadequate Infrastructure for Supply Chain Integration

Prepared by:
RTI International
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Prepared by

William J. White, Ph.D.
Alan C. O'Connor
Brent R. Rowe
RTI International
Health, Social, and Economics Research
Research Triangle Park, NC 27709

RTI Project Number 07007.013

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Acronym List

AIAG	Automotive Industry Action Group
ASIC	application-specific integrated circuit
AVL	approved vendor list
B2B	business-to-business
BTO	“build to order”
CAD	computer-aided design
CAE	computer-aided engineering
CAM	computer-aided manufacturing
CD	compact disk
CPUs	central processing units
CRM	Customer Relationship Management
CRP	continuous replenishment
CTO	“configure to order”
DFM	design for manufacturing
DRAM	dynamic random access memory
DSL	digital subscriber line
EC	engineering changes
ECN	engineering change notice
EDI	electronic data interchange
EMS	electronics manufacturing service
ERP	enterprise resource planning
GM	General Motors Corporation
IBM	International Business Machines Corporation
ICs	integrated circuits
IM	inventory management

IT	information technology
JIT	just-in-time [delivery]
LANs	local-area networks
MAC	media access control
MOSFETs	metal oxide semiconductor field-effect transistors
MRP	Materials Requirements Planning
NAICS	North American Industry Classification System
NEMI	National Electronics Manufacturing Initiative, Inc.
NIST	National Institute of Standards and Technology
ODM	original design manufacturer
OEMs	original equipment manufacturers
PC	personal computer
PCA	printed circuit assemblies
PCBs	printed circuit boards
PDEs	partial differential equations
PIPs	Partner Interface Processes
R&D	research and development
RFID	radio frequency identification
ROI	return on investment
SCI	supply chain integration
SCM	supply chain management
SIC	standard industrial classification [code]
SKUs	stock keeping units
SMT	Surface Mount Technology
SOC	system on a chip
VI	vertically integrated
VLSI	very-large-scale integration
VMI	vendor-managed inventory
WANs	wide-area networks
WSJ	*Wall Street Journal*
WTO	World Trade Organization

XML	extensive markup language
XTS	Li & Fung's Electronic Trading System

Executive Summary

The emergence of low-cost communications and information processing has made it possible for firms to revolutionize the way they operate internally, especially in distributing information throughout their organizations. Through the use of Manufacturing and Enterprise Requirements Planning (MRP and ERP) systems, they can operate with lower levels of inventory, can respond more quickly to changes in customer requirements, and can eliminate or outsource costly accounting functions.

However, companies have made much less progress in improving the efficiency of communications between their facilities and those of their suppliers and customers, along what is known as their ***supply chain***. A lack of universally accepted and implemented standards for the format and content of messages that flow between supply chain partners reduces the potential for inventory and expense savings, as well as leading to duplication of effort, maintenance of redundant systems, and investment in non-ideal information processes.

In this study, we examine the current state of ***supply chain integration (SCI)***, estimate the ***economic impact of inadequate integration***, and identify opportunities for governmental organizations to provide ***critical standards infrastructures*** that will improve the efficiency of supply chain communications. We estimate the total annual costs of inadequacies in supply chain infrastructures to be in excess of $5 billion for the automotive industry, and almost $3.9 billion for the electronics industry. These figures represent about 1.2% of the value of shipments in each industry.

1 HOW WORK GETS DONE IN SUPPLY CHAINS

Firms engaged in supply-chain relationships, as customers, suppliers, or providers of services, need to share a great deal of information in the course of their interactions. Over the years, companies have managed these information flows in a number of ways, including telephone calls, letters, telex, faxes, and electronic data interchange (EDI). More recently, firms have begun using the power of the Internet to create more effective and open transmission protocols for machine-to-machine communication of the same high-frequency data now handled by traditional EDI.[1]

2 EFFICIENCY OF INFORMATION EXCHANGE

Supply chain information systems require a great deal of data input, both from automated sources (software applications, control systems, bar code readers, sensors, analytical instruments) and manual interactions. In an ideal system, each piece of data would be entered only once and be available to any system in the information network that needs it. High-frequency, routine data input tasks should be fully automated, with oversight on a periodic basis by skilled systems optimizers, such as planning or logistics personnel. In a similar manner, high-frequency information flows should be fully automated and transmitted in standard formats with common protocols.

Much evidence is available that this ideal information system integration is not evolving within industry supply chains:

- Manual data entry is widespread, even when machine sources are available; critical information is often manually reentered at many points in the chain.
- Interventions from purchasing clerks, order processors, and expediters are required to maintain supply-chain information flows.
- The use of translators to convert data from one format to another is almost universal, even between systems that are nominally compliant with established protocols.
- Organizations of all sizes and across industry tiers use “informed” estimates rather than actual or production plan data in scheduling, materials management, and expediting.

[1] It is the implementation of these Internet-based information systems that is most often referred to as SCI, even though EDI and telephone/fax are also ways of integrating supply chains.

- Large numbers of firms, especially in the lower tiers, simply operate without essential data.

The business case for better integration has been evident in the automotive industry for several years and for more than a decade in the electronics sector. As a result, a number of companies in these industries have made efforts to provide partial or total solutions, almost all resulting in either inefficient or incomplete integration. Under *inefficient integration*, systems are put in place to automate information inputs and flows, but the unavailability of a suitable standards infrastructure leads to excessive capital investment, duplication of effort, higher than optimal staffing and support levels, and inadequate organizational flexibility. In the case of *incomplete integration*, key elements of a comprehensive system are missing, or improved systems are only implemented for a subset of supply-chain partners. In the latter case, the supply chain as a whole still experiences costs well above optimal levels, and many of the gains from integration remain unrealized.

3 MARKET FAILURES IN THE PROVISION OF INFRASTRUCTURE

From the standpoint of public economics theory, the efforts of private businesses are likely to lead to inadequate standards infrastructures for at least two reasons. The first arises from the public goods nature of these standards, which inevitably leads to a free-rider problem[2] and resultant under-investment in provision of these infrastructures. The second reason is coordination failure, in which asymmetric incentives lead participants to pursue investments that are suboptimal for the industry as a whole.

Resolving these public-goods and coordination failures requires intervention from an organization outside of industry. Underinvestment can be partly corrected by government provision of research funding, by subsidies for private R&D efforts, and by agency participation in standards and infrastructure development efforts. Direct participation by a government agency can also help eliminate coordination failure, as long as industry participants are willing to accept its leadership.

[2] A free rider problem arises when firms can benefit from the actions of others in producing a public good, without themselves contributing, i.e., they may *free ride*. This gives every firm an incentive to under-invest in production of the public good. In the present case, the public good is an adequate standards infrastructure for SCI.

This study was initiated by the National Institute of Standards & Technology (NIST), an agency of the Department of Commerce whose mission includes supporting industry by helping to improve our country's technology infrastructure. The public good content of the infratechnologies underlying most industry standards often causes under-funding of needed research in the private sector. One of NIST's roles is to provide industry's standards-setting processes with these infratechnologies. Furthermore, NIST's expertise and unique research facilities can result in greater efficiency, and hence, cost savings in the development of the technical basis for standards.

Secondly, NIST’s role as a third party independent of the supply chain and its competitive constraints allows it to serve several vital coordination roles as well. NIST's status as a competitively-neutral third party permits its technical experts to seek timely solutions that are optimal for the entire sector, as opposed to the technically inferior or incomplete standardization that often results when competing private entities cannot agree on the public goods content that results in optimal standards. The collaborative process used by NIST ensures that all parties have the opportunity to be represented and involved, which is not always the case with trade associations or voluntary standards groups. A NIST-led process can reduce transactions costs through its competitively-neutral leadership role in coordinating consensus building.

4 SUPPLY CHAINS IN INDUSTRY

The U.S. manufacturing sector is the largest in the world; its 15.9 million workers produced $1.85 trillion in value-added in 2001, according to the most recent government data (U.S. Census Bureau, 2001). The success of the United States in efficiently producing consumption and investment goods has relied on the optimal management of the logistics of manufacturing (i.e., forecasting demand, scheduling production, and ordering and receiving raw materials). To that end, businesses have at various times

- vertically integrated to control as many materials and interfaces as possible,
- maintained large inventory buffers to protect their operations from risk, and
- installed sophisticated planning systems to speed key information to decision-makers.

4.1 The Automotive Supply Chain

The U.S. automotive supply chain is not easy to characterize. It consists of thousands of establishments ranging in size from 50 to many thousands of employees. In addition, many of the lower-tier suppliers also supply the aerospace and other transportation industries. The sheer size of the industry is overwhelming. Manufacturing employment in the motor vehicle and motor vehicle parts industry was 949,984, or about 6.5 percent of all manufacturing employment, in 2001. Shipments of motor vehicles and motor vehicle equipment amounted to almost $403 billion in 2001, or approximately 10 percent of the value of all manufactured goods (Census Bureau, 2003).

Further complicating an analysis of the automotive supply chain is the complexity of the relationships between customers and suppliers. OEMs design and produce only some of the 15,000 parts and accessories that make up an automobile; they procure others from first-tier suppliers. The first-tier suppliers can in turn outsource to subtier suppliers. A company's position in the supply chain may differ depending on the part and the customer. Thus, a company that is a first-tier supplier of transmissions to one OEM may be a subtier supplier of other parts to the same or other OEMs.

At the production stage of the product life cycle, most of the information exchanged between an OEM and its vendors concerns ordering and schedule requests, acknowledgements of messages received, ship notices, and order tracking. To assure on-time delivery, there is also information exchange with logistics functions (i.e., warehousing and shipping). Communication with logistics often means communication between the OEM and the supplier, but it could also mean communication with a third party to whom logistics has been outsourced.

4.2 The Electronics Industry

The electronics industry is an aggregation of several widely disparate product segments, from radar equipment to biomedical devices. A combination of factors, including mass customization, rapidly shrinking product life cycles, lean inventory practices, complex multisource supply chains, and rising global competition, have created a highly competitive industry. Electronics products are brought together by commonality in components, manufacturing technologies, or consumption patterns.

With almost $430 billion in sales in 2001, or approximately 10 percent of the value of all manufactured goods, and 1.6 million employees, electronics is the third-largest manufacturing industry, behind chemicals and transportation equipment (U.S. Census Bureau, 2003). Of total electronics sales, semiconductors and electronic components made up the majority of sales followed by computers and peripherals and telecommunications equipment.

5 METHODOLOGY FOR MEASURING COSTS

In this study, we modeled our analytical approach on ones used successfully by RTI in several previous economic studies for NIST, including an *Interoperability Cost Analysis of the U.S. Automotive Supply Chain*, an *Economic Impact Assessment of the International Standard for the Exchange of Product Model Data (STEP)*, and *The Economic Impact of Inadequate Infrastructure for Software Testing* (Brunnermeier and Martin, 1999; Gallaher and O'Connor, 2002; and RTI, 2002, respectively). We began by developing a task/cost matrix for the industry sectors being studied. This matrix identified the most important information flows for which excessive costs were likely being incurred. Representative case studies or in-depth interviews were then used to estimate excessive costs for each cell of the task/cost matrix. A large-scale survey was conducted to provide data that will allow us to estimate the incidence of these costs across the heterogeneous population of the entire industry. Finally, secondary data on industry sales and employment and wage rates allowed aggregation to industry-level impacts.

Primary data collection was necessary to inform the impact metrics developed during the conceptual phase of the study. As it would be difficult or impossible to design a single instrument to collect information from a cross-section of the industry's firms, much of the data needed was obtained from a small number of in-depth interviews. These structured conversations were similar to the case studies done in many qualitative analyses, although in this case the intent was to gather components of excessive costs borne by firms due to a lack of adequate information infrastructure. By summing these components of cost, we developed an estimate of the cost of inadequate standards for SCI.

6 RESULTS AND COST CALCULATIONS

The initial thrust our data collection for this study was the series of nine in-depth interviews we conducted during the summer and fall of 2003. Several of these firms have *traditional relationships* with their suppliers, indicating that they communicate primarily over the telephone and by faxing machine-generated documents. These firms required the highest levels of effort to accomplish their supply chain information tasks.

Firms with *incomplete integration* most often used EDI for their customer communications, and several reported using EDI with their larger, more sophisticated suppliers. In addition, the first-tier firms in this category were obligated to support one or more proprietary logistics systems by their customers. As a result, their costs were a combination of planning and coordination effort and information systems charges, including license fees, in-house software development, contract software costs, and charges for EDI translators.

Finally, we estimated these types of costs for firms we would characterize as having an *ideally integrated supply chain information system*. Despite their high degree of automation, they still experienced some costs of inefficient integration, mostly in dealing with suppliers with a low degree of e-capability and customers that required use of proprietary systems.

6.2 Large-Scale Survey Results

With the results of the in-depth interviews in hand, we proceeded with large-scale surveys of the two industry sectors. The automotive portion of the survey was fielded with an AIAG working group through an email list-serve announcement and was completed by logistics or information systems professionals actively working on supply chain integration issues. The survey posed questions about the degree of integration and labor effort required in each of the major supply chain processes, the number of software systems supported and their annual costs, and effort expended in several avoidance and mitigation areas. Results from the survey used in quantifying the cost of inadequate integration are summarized in Table ES-1.

In electronics, we were fortunate to be granted access to results from a RosettaNet survey conducted in the fall of 2003 by San Jose State University. Although we did not have influence on the questions posed in the survey, they were quite similar to the core questions in our survey and yielded a reasonable profile of the degree of integration of electronics firms in the process areas we had identified in the in-depth interviews. The results from this survey used in quantifying costs are summarized in Table ES-2.

Table ES-1. Relative Use of Different Communication Methods by Representative Automotive Firms

	With Suppliers (%)	With Customers (%)
XML/Internet	22.6	22.5
EDI	45.2	45.1
Paper/Fax	32.2	32.4

Table ES-2. Relative Use of Logistics and Accounting Process Integration by Electronics Firms

	Traditional (%)	Incompletely Integrated (%)	Ideally Integrated (%)
Customer Logistics	46	32	22
Customer Accounting	43	34	23
Supplier Logistics	51	14	35
Supplier Accounting	52	20	28

Note: Logistics refers to communications about and coordination of production schedules, inventory levels, shipment information, etc.

6.3 Aggregating Costs to Industry Level

With complete information on estimated effort levels, degree of integration by process, and industry data on sales and wage rates, it was possible to estimate the total annual costs to U.S. firms of inadequacies in their supply chain infrastructures. Using the methodology described above, we estimated total costs for the automotive industry slightly in excess of $5 billion per year, which equates to about 1.25 percent of total value of shipments. In electronics, the figures equate to almost $3.9 billion per year, or an almost identical 1.22 percent of the value of shipments. In both industries, roughly 50 percent of the total costs were in dealings with suppliers, while nearly 40 percent arose from interactions with customers, figures which were roughly constant along the supply chain.

In order to put these figures into perspective, it may be helpful to consider the costs of operating under each of the integration scenarios to a typical firm in the automotive and electronics industries. Using data from the most recent Economic Census reports, we calculate that the value of shipments for the average automotive parts establishment was $30 million in 1997. Had such a facility operated with traditional supply chain systems, its managers could expect to incur almost $500,000 in annual costs for the logistics and accounting functions described above. Investing in incomplete integration would lower that figure to about $400,000 per year, while implementing an ideal integration strategy would result in a total of $150,000 in annual costs.

In the electronics industry, the average value of shipments for a semiconductor facility is $71 million per year, while a typical computer maker produces about $55 million in annual shipment value. Using the summary data from Table 7-7, we can estimate that a semiconductor facility operating traditionally would incur annual expenses of $1.15 million, while a computer maker would see logistics and accounting costs of about $900,000. Once again, incomplete supply chain integration would lower costs only slightly. Implementation of an ideal system, however, would reduce these expenses substantially – to slightly more than $350,000 for a semiconductor establishment, and to $280,000 for the slightly smaller computer facility.

7 IMPLICATIONS OF THE STUDY

In this study, we have described how the emergence of low cost communications and information processing has made it possible for manufacturing firms to fundamentally change the way they manage their supply chains. Our quantitative analysis suggests that the total cost of managing supplier-customer inventory and schedule information exceeds $5 billion per year in the automotive industry, and almost $4 billion in the electronics sector. Almost all of this cost could be eliminated if firms implemented true interoperability, which we have termed 'ideal supply chain integration'.

A handful of firms in both automotive and electronics industries have come close to achieving this ideal state with some or most of their supply chain partners. Industry-wide adoption of interoperability will require significant investments in standards and other critical infrastructures that are not in place today. The evidence from our study strongly suggests that businesses in these two key sectors have not made sufficient infrastructure investments to capture the benefits from interoperability. The public goods nature of these infrastructures, along with possible coordination failures, suggests that government involvement is needed to support the optimal level of investment.

NIST's expressed purpose in commissioning this study was to determine if there was evidence of market failures in the creation of the critical infrastructures required to create effective integration. A secondary objective was to gather data that would enlighten potential roles taken by NIST's Manufacturing Engineering Laboratory (MEL) and Electronics and Electrical Engineering Laboratory (EEEL) in industry-wide consortia working on improving supply chain information systems. In the judgment of the present authors, the study's results provide support for both of these aims.

1 Introduction and Scope of Study

The emergence of low-cost communications and information processing has made it possible for firms to revolutionize the way they operate internally, especially in distributing information throughout their organization on new and existing products, production and shipping schedules, engineering and technical requirements, and costs of manufacturing and distribution. Through the use of Manufacturing and Enterprise Requirements Planning (MRP and ERP) systems, they can operate with lower levels of inventory, can respond more quickly to changes in customer requirements, and can eliminate or outsource costly accounting functions.

However, companies have made much less progress in improving the efficiency of routine and exceptional communications between their facilities and those of their suppliers and customers, along what is known as their ***supply chain***. A lack of universally accepted and implemented standards for the format and syntax of messages that flow between supply chain partners reduces the potential for inventory and expense savings, as well as leading to duplication of effort, maintenance of redundant systems, and investment in non-ideal information processes.

In this study, we examine the current state of ***supply chain integration*** and identify opportunities for governmental organizations, such as the National Institute of Standards and Technology (NIST), to provide infrastructures that will improve the efficiency of supply chain communications. First, we will describe conceptual issues related to communications within and across supply chains, detail the types of market failures that may lead to suboptimal levels of private investment in information technologies, and explore the changing nature of global supply chain operations.

Next, we present detailed information about supply chain integration in two key manufacturing sectors in the United States: the automotive and electronics industries. We use a methodology that we have developed in previous studies to estimate the cost to the nation's economy of the current inefficiencies in supply chain structures in these industries. Finally, we describe the results of a major data collection effort that attempts to inform the metrics identified in the methodology. The report concludes with some implications of our results for firms in the two targeted industries and for the future actions of NIST, both for the continued support of U.S. supply chains and for helping domestic firms deal with emerging global organizational structures.

1.1 SCOPE OF THE STUDY

In this study, RTI International has estimated the costs associated with an inadequate standards infrastructure for supply-chain integration (SCI) in the automotive and electronics sectors, including the portion of those expenditures due to incomplete or inefficient integration. Although our study restricts the focus of these costs to two industry sectors, the implications could be extended much further. The magnitude of these socially wasteful expenditures across all industries represents the size of government's opportunity to contribute to the nation's economic growth by helping U.S. industry create and use improved standards infrastructures.

Our work has included performing extensive literature reviews, conducting in-depth interviews with industry stakeholders, and surveying several groups to help determine the average costs incurred as a result of inefficient and incomplete supply chains. The final results are a combination of qualitative examples and quantitative impact data because both types of data are necessary to inform those making policy decisions related to government involvement in supply change integration.

1.2 DEFINITION OF A SUPPLY CHAIN

According to Ganeshan and Harrison (1995), a supply chain is "a network of facilities and distribution options that performs the functions of procurement of materials, transformation of these materials into intermediate and finished products, and the distribution of these finished products to customers." Many supply chains have been significantly altered over the past decade, but this core definition remains unchanged.

Made up of a group of firms linked together in a series of customer-supplier relationships, every supply chain eventually results in the delivery of finished products and/or services. Over time, firms have increasingly looked to improve the efficiency of their supply chains by reevaluating two key types of transactions:

- **Physical flows** of material connect members of a supply chain, moving “forward” from suppliers to customers in each link of the chain.
- **Data flows** move “backward” from customers to suppliers, as orders are placed and payments are made for materials, services, parts, and supplies.

To facilitate these goods/services and financial transactions, information flows throughout the supply chain, with the highest volume and frequency of data moving between adjacent links in the chain. Firms continue to look for ways to improve each piece of this web of relationships.

1.3 CONCEPTUAL DISCUSSION OF SUPPLY-CHAIN INFORMATION FLOWS

In this section, we describe an ideally integrated supply chain and compare it to less efficient types of integration. Firms engaged in a supply-chain relationship, as customers, suppliers, or providers of services, need to share a great deal of information in the course of their interactions. These diverse data include descriptive information such as quantities, prices, dates, technical specifications, and quality attributes, and significant contractual and legal transactions, such as purchase orders, shipment authorizations, receipt acknowledgment, and payment processing. To understand the types of information flows, it is most convenient to break them down into functional categories. Many different types of information must be exchanged for the supply chain to function efficiently, including

- product descriptions, specifications, and prices;
- purchase order information such as quantities, required shipment dates, and addresses;
- planned and actual production, shipment, and delivery dates/times and status against such schedules;
- technical and engineering data on products, components, and equipment;
- accounting information such as prices, discounts, allowances, and account numbers; and

- product quality data, such as test results, performance measurements, and warranties.

Over the years, companies have managed these information flows in a number of ways, including telephone calls, letters, telex, faxes, and electronics data interchange, known as EDI.[3] Often firms will have several systems in place simultaneously, perhaps more sophisticated ones for normal, high-volume exchanges and manual systems for communicating schedule changes, quality problems, needs for expediting deliveries, canceled orders, or other emergencies. Redundancy is often built in to stop a system failure from leading to a business disaster, such as a plant shutdown or shipment of poor-quality product.

Most large first- and second-tier suppliers and original equipment manufacturers (OEMs), along with a smaller fraction of firms in the lower tiers, have installed EDI between each customer-supplier pair for handling high-volume, routine communications such as transactions processing, accounting entries, and billing activities. EDI is also at the heart of most automated inventory control systems, including continuous replenishment (CRP) and vendor-managed inventory (VMI). With effective EDI, human intervention is not required to initiate or operate the periodic communication of information, leading to a low marginal cost of data transmission. Significant fixed-cost investment in high-cost expertise is typically needed to develop and install the systems, to upgrade or troubleshoot each script, and often to translate the EDI data streams into alternate formats required by other information systems within each firm.

Finally, firms are increasingly using the power of the Internet to create XML-based transmission protocols for machine-to-machine communication of the same high-frequency data now handled by EDI. These flexible XML implementations have the potential for lower up-front engineering costs more than can EDI and require lower levels of support in use. They also can be modified much more easily for use with other customers or suppliers by the target firm. Most importantly, the nature of Web-based architecture and protocols offers the potential for better scalability—the degree of effort and cost required to expand coverage to an entire supply chain. Here, scalability is proportional to the number of firms involved, rather than to the much higher number of customer–supplier pairs, as is the case with EDI.

[3] EDI is described in greater detail in the next section.

1.3.1 Electronic Data Interchange (EDI)

If machines are going to communicate, they need a common vocabulary that can be universally understood, and messages must be structured in a standardized way so that they can be properly interpreted and acted on. In the case of EDI, most companies in the United States have adopted ANSI X12 as a common language, whereas, in Europe, Edifact is the accepted standard. With one of these systems, computers at each end of a message can be programmed to understand the letters (bits) of the data stream. Furthermore, computers need to know how the message will be formatted (i.e., the exact order of elements, how bits of information will be separated, and what real piece of information each letter or word represents). For example, if the message is a purchase order, the pieces must be properly arranged and coded to ensure that a part number is not misinterpreted as a quantity or a delivery date as a shipment address.

Because of the requirements for exactness in each EDI transmission, the diversity of business relationships and communications needs has led to a large number of similar but distinct EDI protocols and formats in the industry sectors we are studying. Each newly established link between a customer–supplier pair is a custom installation; the particular business and technical needs at the time mean that each link may be slightly different, using nonstandard syntax, unique variables, or reordered transmission. So invoicing and billing systems, vendor-managed inventories, and production schedules shared between an OEM and an important Tier 1 supplier may all use different EDI formats.

The complexity of the automobile and electronics sectors' supply chains increases this confusion. Firms with an extended network of customers and suppliers may be forced to support a large number of mutually incompatible EDI implementations. The resources needed for support and the risk of errors from mix-ups increase with the complexity and diversity of EDI protocols installed.

As an example, if an OEM like Ford inadvertently sent a high-priority purchase order to Johnson Controls (JCI) in the EDI format used for communications with Visteon,[4] JCI's information systems might not be able to correctly interpret the order. A great deal of additional effort would be required by both parties to make sure the proper products were

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[4]JCI and Visteon are tier-one automotive suppliers.

made and delivered on the timing required. In the absence of this additional manual effort, it is likely that Ford's needs would not be met.

1.3.2 Extensible Markup Language (XML)

A standardized XML implementation offers the opportunity to address many of these issues. One extremely flexible feature of XML is that it is self-referencing: the label attached to the bit of data describes the type of information contained within. For instance, in an EDI purchase order, the receiving computer may be programmed to interpret the third bit string in the message to be a part number and the fourth an order quantity for that part. If these strings are sent out of order, or if an extraneous word is added, the recipient will not be able to interpret it correctly. An XML-based purchase order could have a piece of data labeled “1stpart#” and a second one labeled “1stpartqty.” The instruction that contained the label and associated numerical data could be located anywhere within the XML data stream, and the computer would interpret the instruction correctly. As a result, XML messages can be easily expanded or modified to meet specific needs.

Although the emergence of XML offers opportunities for flexible, adaptable implementations, it does not reduce or eliminate the need for standardization. Vocabularies must be established and adopted, labels need to be assigned agreed-upon meanings, and change-control procedures must be established. As we describe in the next several sections, the most likely outcome of pure private-sector SCI is the creation of a number of competing, incompatible systems, each one adopted incompletely within industry sectors. NIST and RTI have identified the excess costs of this type of outcome in the communication of engineering design information in the automotive and other industries, in both a prospective study (Brunnermeier and Martin, 1999) and a recently completed analysis of the STEP initiative (Gallaher and O’Connor, 2002).

1.4 A DESCRIPTION OF IDEAL AND SUBOPTIMAL SUPPLY-CHAIN INTEGRATION (SCI)

A perfectly efficient supply chain information structure does not exist in most industries today, and it is extremely unlikely that a fully optimized system could be implemented in any industry in the future. Nonetheless, it is useful to describe such a system to estimate the excess costs experienced in current operations, if for no other reasons than to quantify the size of the opportunity and allow more informed decisions about public and private investment in this area. In the following sections, we describe conceptually what forms ideal integration should take and then discuss how the current state of affairs is both inefficient and incomplete.

1.4.1 Perfectly Efficient Supply-Chain Integration

Supply chain information systems require a great deal of data input, both from automated sources (numerically controlled machines, scanned bar codes, sensors, analytical instruments) and manual interactions. In an ideal system, each piece of data would be entered only once and subsequently made available to any system in the information network that needs it. High-frequency, routine data input tasks should be made fully automated, with oversight on a periodic basis by skilled systems optimizers, such as planning or logistics personnel. In a similar manner, high-frequency information flows should be fully automated and transmitted in standard formats with common protocols.

Ideally, each firm would expend resources primarily on its own data, as well as on contributing to the maintenance and improvement of the standardized backbone. Information from supply-chain partners should “arrive” as needed (or be made available for query), without additional cost to the receiving firm. A set of agreements should exist to identify and empower the system optimizer, often the OEM, who would initiate the major changes to which other members must adjust.[5] These unusual events include the launch of new products or services, product termination decisions, production acceleration or slow-down, and sourcing changes.

In today’s competitive environment, many medium and large firms set internal goals to approach this ideal state; integrated enterprise resource planning (ERP) and internal networks can come close to this state within the boundaries of a multidivisional firm. Extended to the entire supply chain, however, this level of sophistication rarely occurs. A proper goal of supply chain integration, then, would be to extend these concepts to inter-firm interactions across the entire chain of industries. A piece of information is entered at the source and is instantly available to all members of the supply chain who need it, information flows to points of use without manual intervention, and standard protocols obviate the need for translation.

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[5] It is not necessarily the case that the OEM acts as the system optimizer. As we described later in this report, firms at a number of different places within a supply chain can play the key optimizing role.

1.4.2 Inefficient and Incomplete Integration

Much evidence is available that this ideal information system integration is not occurring within industry supply chains:

- Manual data entry is widespread, even when machine sources are available; critical information is often manually reentered at many points in the chain.
- Purchasing clerks, order processors, and expediters are widespread within the automotive and electronics sectors, and their manual interventions are critical links in supply-chain information flows.
- The use of translators to convert data from one format to another is almost universal, even between systems that are nominally ANSI X12 or Edifact compliant.
- Organizations of all sizes and across industry tiers use “informed” estimates rather than actual or production plan data in scheduling, materials management, and expediting.
- A lack of system integrity creates a continuing need for verbal or written authorizations to protect against costly errors or even catastrophic failures.
- Large numbers of firms, especially in the lower tiers, simply operate without needed data.

As an example, the business need for better integration has been evident in the automotive industry for several years and for more than a decade in the electronics sector. As a result, a number of companies in these industries have made efforts to provide partial or total solutions, almost all resulting in either inefficient or incomplete integration. Under *inefficient integration*, systems are put in place to automate information inputs and flows, but a lack of a suitable standards infrastructure leads to excessive capital investment, duplication of effort, higher than optimal staffing and support levels, and a lack of organizational flexibility. In the case of *incomplete integration*, key elements of a comprehensive system are missing, or improved systems are only implemented for a subset of supply-chain partners. In the latter case, the supply chain as a whole still experiences costs well above optimal levels, and many of the gains from integration remain unrealized.

1.4.3 Example—Invoice Payment Authorization

A simple example involving authorization and payment of a supplier invoice will help illustrate the contrast between optimal, inefficient, and incomplete integration. After a product has been shipped to a customer from one of its suppliers, the supplier will submit an invoice for payment, which must be approved and subsequently paid. This transaction is one of the last steps in the order management process and feeds directly to both firms' accounting systems. As such, the information flows here involve both informational and contractual issues between the firms.

In an optimal information system, record of a shipment by the supplier (perhaps generated by optical scanning of a bar code in a warehouse vehicle loading system) would trigger a request for an automatic payment of the amount described in the purchase order requisition. The requisition may have been generated automatically through a CRP or vendor-managed inventory process. Receipt of the shipped items, perhaps also recorded via an optical scanner, would generate invoice approval, and subsequently the seller's account would be credited and buyer's account debited. Aside from the supervision of the loading and unloading process and the physical transportation of the products themselves, no manual intervention is required for the steps outlined above.

Inefficient integration would require additional effort and use costly resources. Suppose that the supplier and customer use EDI systems for such transactions, but their formats differ slightly. In this case, recording the shipment triggers the generation of an invoice, which is immediately translated from the seller's format to the buyer's format, using a piece of customized software. The EDI system then transmits the invoice, which is subsequently processed in the customer's payments system and approved when the receipt is recorded. The customer's accounts are then updated, and a record of the automated payment is transmitted back to the seller. Finally, the record of payment is translated back into the seller's format, and the supplier's accounts are updated.

With incomplete integration, lower tiers in the supply chain may be using almost completely manual systems for this process. To handle this same event, a shipment notification (with information transcribed from a bill of lading, perhaps) is faxed to the supplier's own invoice processing department, where an invoice is prepared and authorized manually. This invoice is then mailed or faxed to the customer's purchasing agent, who confirms delivery through its internal information system. The invoice is approved for payment, at which point an accounts-payable clerk updates the customer's accounting system and wires (or even mails) payment to the seller's accounts-receivable department. The accounts-receivable clerk, in turn, verifies payment and updates the supplier's accounting system.

1.5 ROLE OF STANDARDS AND NEED FOR EFFECTIVE STANDARDS INFRASTRUCTURE

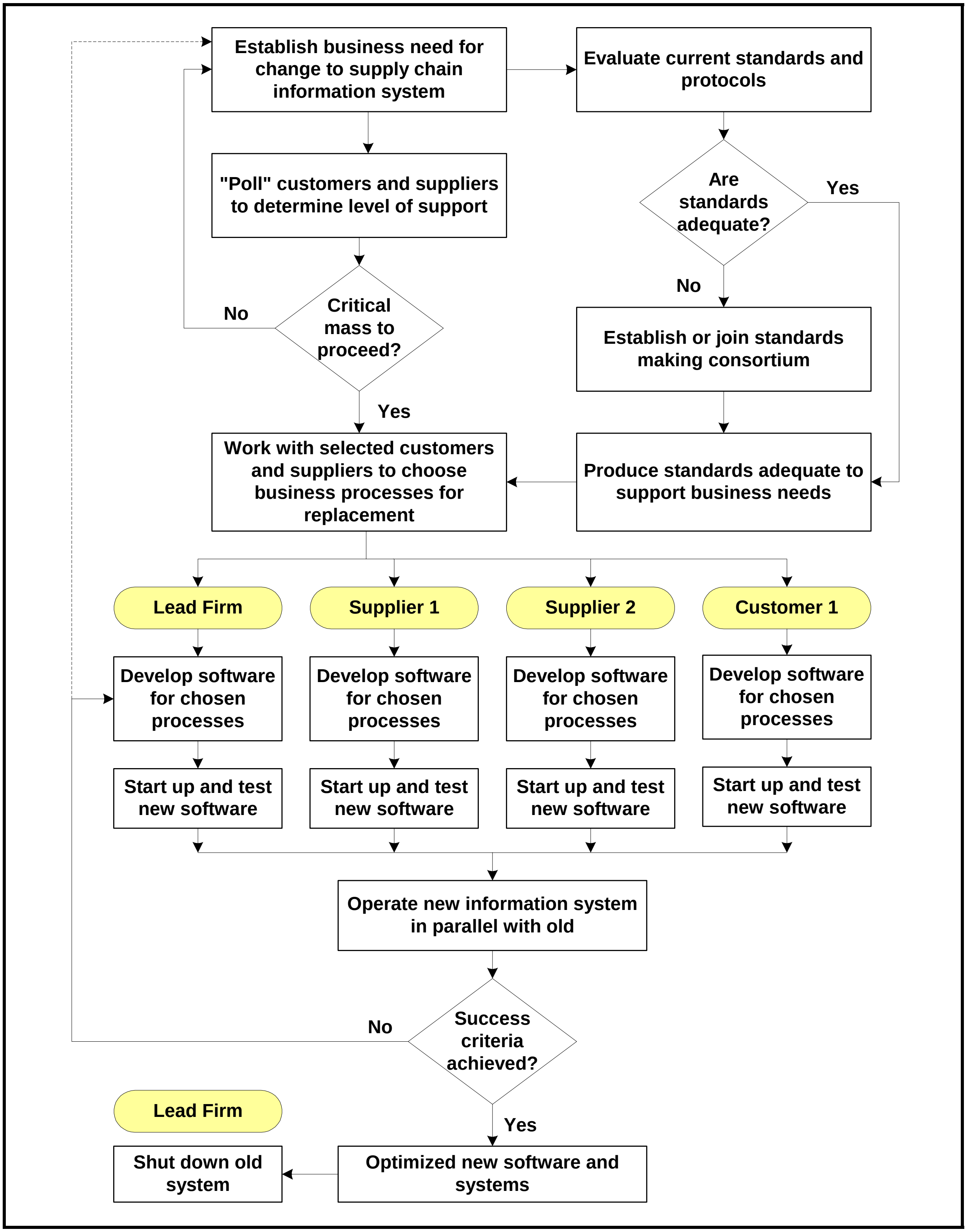
The discussion and example in the previous section clearly suggest that various standards are needed to support ideal implementation of SCI in the automotive and electronics sectors. At the lowest levels of communication, semantic and syntactic standards are needed so that data elements can be understood without the need for translation or interpretation. The content and format of high-frequency transactions also must be standardized so that modifications by one supply-chain partner do not require manual intervention at the other end. The wide variety of information flows and the diversity of customer–supplier interactions make the standards infrastructure very complex, resulting in a large absolute number of standards. For example, the RosettaNet consortium has identified more than 100 separate business processes for which standard protocols, called Partner Interface Processes (PIPs), are necessary within the electronics sector.

1.5.1 Conceptual Description of SCI and Standards Development Process

Although the detailed process for integrating supply-chain information systems is likely to depend on particular technologies and business conditions within each industry sector, the overall flow of events should have many similarities. Figure 1-1 shows a conceptual diagram that attempts to illustrate the development process. Although this figure depicts the improvements being led by a single firm, other approaches are also feasible, as the next section discusses.

Initially, firms that will participate in the process must establish a business need for the systems change and determine whether sufficient support is available within the supply chain. At the same time, an assessment of the current state of the standards infrastructure will typically lead to efforts to produce needed standards and protocols for the information system improvement. The quality of effort at this point will have a major impact on whether the new standards will be effective and efficient. After a decision to proceed, the firms involved will identify the business processes for replacement and initiate development work.

Figure 1-1. SCI and Standards Development Process



Next, the lead firm, along with key suppliers and customers, will develop software and operational procedures for the improved process, typically with the help of third-party vendors or consultants. When development is complete, each firm will start up and test the new software and make a decision to proceed with the conversion. After running old and new systems in parallel, if the project's success criteria have been achieved, the new system will be accepted and old systems will be shut down. If a subset of the supply chain has been involved in developing the new information process, the final step is to roll it out to remaining members of the supply chain.

It is important to note that the involvement of a lead firm and key business partners is not sufficient to create efficient integration. Companies not participating in the initial process may choose to adopt different standards or protocols or to implement totally incompatible improvements. Firms may be unable or unwilling to convert to the new process or may lack critical skills in adopting the new technology. A mismatch between the incidence of costs and financial benefits may distort the incentives of supply-chain participants. These issues are covered as a part of the market failure discussion in Section 1.6.

1.5.2 Industry Approaches to Standards Development

Firms within an industry can put needed standards infrastructures in place to support integration efforts in several ways, and each approach has implications for the efficiency and completeness of the resulting systems. If the industry is dominated by a single firm (usually an OEM) or if a statutory monopoly exists, that firm can create standards and impose them on the rest of the industry. AT&T took this role in telecommunications during the era of regulation and developed and implemented most of the standards used within that sector. In the case of personal computer operating systems, Microsoft's dominance has allowed it to set standards that hardware and software firms alike are obligated to support. The U.S. Department of Defense has forced all military contractors to use its procurement specifications and procedures since shortly after its creation in the 1940s.

In an alternative scenario in imperfectly competitive markets, each large OEM can develop its own standards and insist that its suppliers comply to enjoy continued business. This has long been the practice in the automotive sector, in which General Motors, Ford, and DaimlerChrysler have routinely imposed their unique standards on direct suppliers. Many of the Tier 1 firms in turn require the lower tiers to comply as well. Because many of these Tier 1 firms supply products to all three OEMs, as well as to many Japanese-owned domestic facilities, there are inevitably excessive costs under this regime from duplication of effort and lack of interoperability.

Potentially, many or all of the firms in an industry can work together to create a mutually beneficial infrastructure for integration, either by forming a consortium through an industry trade or technical association, or with the help of one or more standards development organizations. Antitrust concerns have receded sufficiently over the past 20 years so that firms in an industry can meet to develop standards without risk of adverse governmental attention. Still, it is difficult to manage power and influence issues within consortia and other voluntary organizations, and success in creating efficient standards is not assured. In addition, incomplete representation of entire industry supply chains within these groups means that important suppliers and customers may be left out of the process.

1.6 MARKET FAILURES IN THE PROVISION OF STANDARDS INFRASTRUCTURES

From the standpoint of public economics theory, all of these approaches are likely to lead to inadequate standards infrastructures for at least two reasons. The first arises from the public goods nature of these standards, which inevitably leads to a free-rider problem and resultant under-provision of the good. The second reason is one of coordination failure, in which asymmetric incentives lead participants to pursue investments that are suboptimal for the industry as a whole. Each of these market failures is discussed briefly below.

1.6.1 Underinvestment Due to Public Goods Externality

According to standard microeconomic principles, goods and services can be classified as rival if one buyer’s consumption reduces the amount available for purchase by others. Goods and services are considered excludable if the owner(s) can prevent consumption by others. Public goods are defined as those that are neither rival nor excludable, and economic theory tells us that the market, left to its own devices, will not provide the optimal level without outside intervention. This is because each participant can obtain much of the benefit from the public good based on the prior investment of others (i.e., to act as a free rider).

Because many or all market participants have similar incentives, an insufficient level of investment will result.

Scientific and technical knowledge, along with other forms of human capital, have long been considered at least quasi-public goods. Knowledge is clearly not rival, in that its use does not diminish the amount of it available to others. In fact, learning by doing and network externalities make the opposite more likely. With the exception of trade secrets and the limited exclusivity granted by patents and copyrights, knowledge is also largely non-excludable. Tassey (1997) has demonstrated that investments in standards, along with other generic technologies and infratechnologies, have this quasi-public goods nature and are therefore underprovided by private markets.

1.6.2 Coordination Failures in Development of Standards

Coordination failures arise from asymmetries in incentives between market participants, either among competitors or among levels in a supply chain. In the competitive case, firms acting in their self-interest may invest in standards or other forms of human capital that are not optimal for the industry as a whole. This is especially critical in imperfectly competitive markets, where strategic interaction is important. As an example, the separate and incompatible systems created by the automotive OEMs for the exchange of technical data (e.g., computer-aided design [CAD], computer-aided manufacturing [CAM], computer-aided engineering [CAE]) are a direct result of the focus on private optimum among the oligopolistic Big Three.

A second type of failure may occur between customers and suppliers along the supply chain, especially if the size and technical capabilities of the partners are quite different. Small firms in the lower tiers may have an interest in improving their information infrastructure but may lack the financial resources or technical capability to make it happen. Their incentives to invest are further reduced if they believe that any cost advantages they obtain from increased efficiency will be quickly competed away through lower prices. The larger upper-tier firms might more easily take on the burden of developing improved information systems. If, however, most of the initial benefits will accrue to their suppliers, these Tier 1 and OEM corporations may conclude that their investment might not pay out over their required time horizon.

1.6.3 Government's Role in Correcting for Market Failures in Standards Provision

If private markets are unlikely to provide the optimal level of these critical standards infrastructures, then there is the potential for government to intervene in economically beneficial ways. This involvement could take the form of increasing the overall level of investment in standards development, providing financial and logistical support for standards organizations or consortia, and helping industry participants coordinate their activities in producing flexible, interoperable systems. In the case of the present study, NIST requested that we estimate the magnitude of the potential market failures in automotive and electronics supply chain integration, and identify potential roles NIST could play in alleviating these failures.

In our judgment, the NIST Laboratories are ideally suited to help correct both the public goods and coordination failures outlined above. The provision of government funding for the highly complex and time-consuming tasks involved in creating the new information systems software and processes raises the overall level of investment, alleviating the potential public goods failure. The expertise of NIST personnel ensures that the critical human capital applied to standardization efforts is effective in supporting and/or leading the private-sector efforts. NIST's efforts can lower overall costs of development and adoption because of the expertise of its personnel.

Secondly, NIST's role as a party independent of the supply chain and its competitive constraints allows it to serve several vital coordination roles as well. Its status as an uninvolved third party permits its technical experts to seek solutions that are optimal for the entire sector, rather than those that would favor one or more powerful OEMs. The collaborative process used by NIST ensures that all parties have the opportunity to be represented and involved, unlike the situation of a trade association or voluntary standards group. Finally, if NIST takes a leadership role in the development process, it can coordinate mutually beneficial outcomes both vertically and horizontally, without concerns of collusion or anticompetitive practices.

2 Overview of Manufacturing Supply Chains

The U.S. manufacturing sector is the largest in the world; its 15.9 million workers produced $1.85 trillion in value added in 2001, according to the most recent government data (U.S. Census Bureau, 2001). The success of the United States in efficiently producing consumption and investment goods has relied on the optimal management of the logistics of manufacturing (i.e., forecasting demand, scheduling production, and ordering and receiving raw materials). To that end, businesses have at various times

- vertically integrated to control as many materials and interfaces as possible,
- maintained large inventory buffers to protect their operations from risk, and
- installed sophisticated planning systems to speed key information to decision-makers.

The following section presents an overview of the structure of manufacturing supply chains, traces the evolution of organizational structures and optimization strategies, and discusses the complex interrelationships between organizations and their supply chain activities.

2.1 STRUCTURE OF MANUFACTURING SUPPLY CHAINS

To make and deliver products that meet consumers' needs, manufacturing firms must manage relationships with complex supply systems that involve movement, transformation, and legal transfer of physical materials and information. These systems have been envisioned as *supply chains*, virtual supplier-customer links that connect upstream suppliers of basic materials, intermediate products, and associated information to the final consumer. In reality, the system will likely be more complicated than the chain analogy suggests, with cross-linkages and reverse flows being common occurrences.

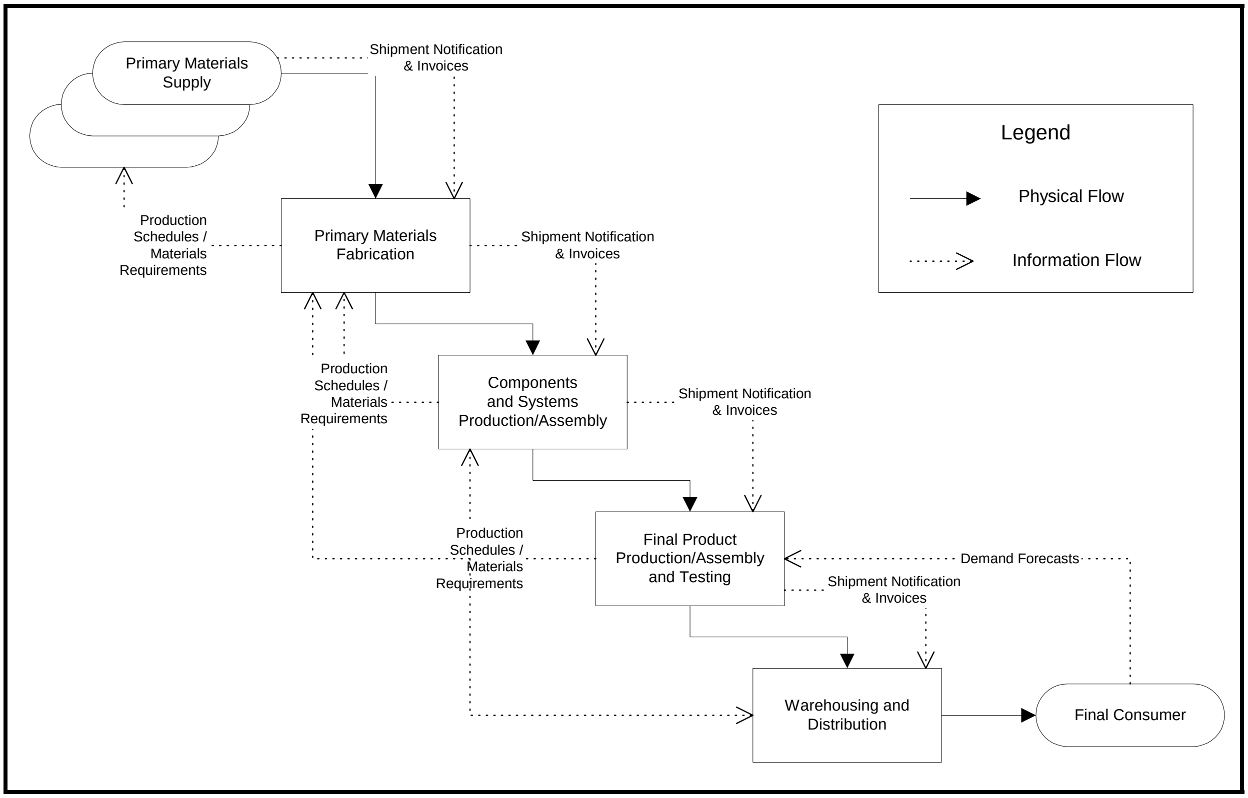
Nonetheless, for description and analysis, it is helpful to present a simplified model of the most significant components that illustrates the vital physical and information flows. Figure 2-1 presents a simplified supply chain schematic for a discrete parts product. (Note that the term "*discrete parts"* indicates that the products are made and sold in individual units. By contrast, homogeneous, or "*bulk products*" such as agricultural goods, chemicals, and primary metals, are most often sold in pounds or tons.)

As Figure 2-1 indicates, the physical flows in a supply chain move from raw materials to intermediate components and assemblies to finished products, with value added at each step of the process. Finished products most often enter a distribution system, which may include wholesalers, jobbers, retailers, and other services before reaching the final consumer. In a supply chain, information flows in several directions, with a great deal of it being controlled at the location where the finished product is made. In many of the most important manufacturing sectors, the organization that controls this last step is known as an *original equipment manufacturer*, or OEM. The term OEM is used whether or not the firm in question actually owns and operates the facilities where final production or assembly takes place.

Each link in the supply chain has its own information and logistics needs, although some information (e.g., long-range sales and production forecasts) is needed by all links for capacity planning and procurement. Each supplier in the chain must know its next-in-line customer's materials requirements, including quantities needed, delivery dates, and shipping instructions. Each customer needs to factor its suppliers' shipment schedules into its own planning, and must receive shipment notification, quality specifications, and invoices as products are delivered.

Most forms of supply chain organization and information transmission work adequately if forecasts and schedules seldom change and production dynamics are predictable and stable. However, events such as production problems, shipment delays, order cancellations, and forecast revisions at any step in a supply chain may interrupt physical

Figure 2-1. Supply Chain Process Flows: Discrete Parts Manufacturing



and information flows. These interruptions pressure suppliers to adjust their business plans. For example, a small problem at one of the primary materials suppliers may propagate through the chain and shut down final assembly for weeks. A reduction in a sales forecast may result in idling facilities all the way up the chain. A quality defect may cause costly rework at several plants.

OEMs and various firms in the supply chain have a number of options to protect themselves from these types of risks. A vertically integrated firm (described in more detail in Section 2.2) may be able to coordinate logistics activities over the entire supply chain and rapidly respond to any unexpected situations. Stocks of intermediate or finished goods, usually called *inventory buffers*, can protect both suppliers and customers from small interruptions or system failures; however, the cost of holding this inventory must be set against the benefit of risk reduction. Finally, the firms in the supply chain, led by OEMs, can integrate their operations through real-time sharing of vital information, thus minimizing the cost of changes and errors. This last option requires significant investment in information technology, and realizes its major impact through reducing the need for large inventory buffers or vertical integration.

2.2 EVOLUTION OF ORGANIZATIONAL STRUCTURES AND SUPPLY CHAINS

Firms that emerged in the first few decades of the 20th century, including those in the emerging automotive and electrical products industries, were very concerned about the performance of their supply chains. One of the most common organizational strategies was *vertical integration*, in which the entire supply chain was brought within the firm's ownership structure. Henry Ford built such an integrated company in the 1920s and 1930s, owning not only automobile parts production and assembly, but also car dealerships, steel mills, iron ore mines, and even rubber plantations (Nevins and Hill, 1957).

The advantages of vertical integration in centralizing decision-making and maintaining coordination across the supply chain were sufficient to make it an organizing strategy of choice throughout much of the 20th century. There were disadvantages as well, however. Firms often found themselves running operations in which they had little expertise, such as Ford's rubber plantations. These noncore businesses were likely to have inferior technology and thus higher costs than more focused competitors. Vertical integration often raised antitrust concerns, especially if the industries in which the firm operated were highly concentrated. In addition, the divisional structures adopted by most firms after World War II tended to defeat the close coordination that vertical integration was intended to foster—two divisions of the same corporation might have as much difficulty communicating and managing logistics as separate firms in a similar supplier-customer relationship.

During the 1960s and 1970s, corporations invested heavily in information technologies to manage intrafirm planning and logistics. Given sufficient vision and adequate investment, information systems could be developed to control and optimize the entire production chain, from raw materials to customers. The development of Materials Requirements Planning (MRP) and its successor models, along with dramatic decreases in the cost of computing and internal networking capacity, helped firms retain the benefits of vertical integration.

Over the past 20 years, U.S. firms have undergone a radical change in their approach to integration. During the last period of corporate consolidation in the late 1970s and early 1980s, firms integrated both horizontally and vertically and combined into multimarket conglomerates. The rationale behind these mergers was that larger firms may benefit from economies of scope and scale in financing, production, distribution, and marketing.

The trend toward integration began to reverse by the mid-1980s. Faced with rapid technological change, increasing global competition, and accelerating quality improvement expectations, many large enterprises found their agility in the marketplace hampered by the rigidity of their corporate structure. To concentrate on leveraging “core competencies,” firms began to spin off subsidiary operations. This process began with a slow reversal of many conglomerate mergers, and the benefits noted above were overwhelmed by issues of communication, coordination, and corporate focus.

The necessity of developing core competencies, along with the arrival of low-cost computing and communication via the Internet, catalyzed the beginnings of *vertical disintegration*. With external communication and data transfer costs decreasing, much of the rationale for vertical integration began to erode. The potential emerged for a chain of firms, each focused on its own areas of expertise, to cooperate to provide products and services for final consumers. These factors have altered the strategic choices available to firms regarding the set of activities they choose to perform and the inputs they purchase in the market. The result of these and other developments has been to encourage new forms of organization that leverage modern information/production technologies (see Besanko, Dranove, and Shanley, 1996). A critical need for ensuring success in these organizations is the creation of interfirm information systems, embodied in ERP software or SCI systems.

These systems look at the entire supply chain as a virtual enterprise that may include a global network of suppliers, factories, warehouses, distribution centers, retailers, and service centers. The virtual enterprise acquires raw materials, transforms them into products, markets and delivers products to customers, and services products over their lifetime. Supply chain functions must operate in a coordinated manner to optimize performance. In a dynamic marketplace and a changing economic environment, the supply chain management system must coordinate the revision of plans/schedules across supply chain functions. The efficiency of the production system is ultimately determined by the agility with which the supply chain is managed at the tactical and operational levels to enable timely dissemination of information, accurate coordination of decisions, and management of actions among people.

2.3 INFORMATION TECHNOLOGY'S IMPACT ON CURRENT SUPPLY CHAIN INTEGRATION

This section provides a more in-depth look at the current state of affairs in supply chain integration and, in particular, firms' options for coordinating activities across supply chains and minimizing risks.[6] The three major benefits of supply chain optimization are improved customer service, improved internal operating efficiency, and reduced inventory costs. The key objectives of supply chain optimization are to manage uncertainty and dependency. The tighter and more complex the dependencies, the greater the criticality of suffusing supply chains with dependable coordinating mechanisms.

We begin by articulating the trade-off between two ways to manage uncertainty—using inventory as a buffer or relying on information to predict requirements. We then extend the information/inventory perspective to explain coordination between trading partners. Then, we present the pros and cons of two approaches to supply chain optimization—local optimization in the form of improving the interfaces between companies in adjacent tiers and overall optimization of the supply chain as a whole. Finally, we argue that improved communication is the most promising tactic for improving supply chains, and that improved interoperability is the most promising way to improve communication.

2.3.1 Inventory and Information as Ways to Manage Uncertainty with Customers

One way to look at supply chain management is to see it as a set of interorganizational arrangements whose purpose is to manage uncertainty. Uncertainty is defined in terms of the probability of an event either occurring or not occurring. Each member of a supply chain has a core commitment to deliver particular goods to a particular place at a particular time, and these fundamental commitments become ever more difficult to meet as uncertainty increases in suppliers' capacity or customers' needs. One way to manage uncertainty is with inventory as a

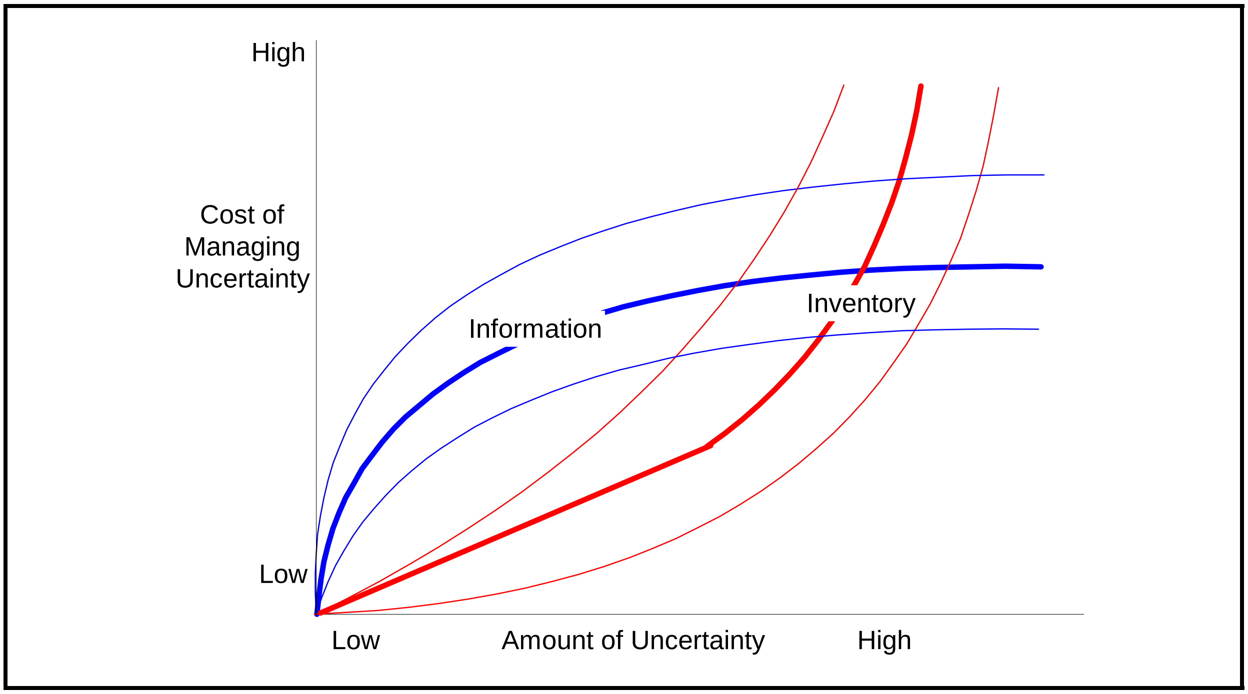
[6] Jenny Morell and Tom Phelps, of Altarum, developed much of the material for this section of the report. Portions of their contributions also appear in Morell and Phelps, 2001.

hedge against the vagaries of supply sources and fluctuations in demands from customers.

A second tactic for managing uncertainty is to keep inventory low, while maintaining good information on what suppliers can deliver and what customers will demand. Both approaches have costs. The critical question is what the inventory/information combination should be, given specified targets for internal efficiency and customer service. Real-world decisions about inventory levels are more complex than portrayed here because hedging against uncertainty is only one of several factors used to make decisions about inventory.

Also important is the overall cost structure of production, because it may be cheaper to run a plant at full capacity and maintain inventory than to keep inventory low. (For instance, in screw machine production, set-up costs are high relative to the cost of material and operation.) Also, inventory may support a business model, as would be the case if a company's reputation depended on fast response to low-probability changes in customer needs. Figure 2-2 illustrates the trade-off between information and inventory.

Figure 2-2. Managing Uncertainty with Inventory and Information



Assuming that a choice can be made to rely *exclusively* on either information or inventory, two lines can be drawn that show how the *cost* of managing uncertainty changes with the *degree* of uncertainty. The actual shapes of curves that define the relationship are highly dependent on the specific supply chain context. With respect to inventory, we believe that the line is straight through most of its length, with an upward swing when uncertainty is very high.

For the most part, as the goods increase, so does the investment, in direct proportion to the size of the inventory. At very high levels of uncertainty, we believe that a series of factors may combine to result in a nonlinear increase. For example, at some point in time, a new warehouse may be needed, with all its attendant building, maintenance, and personnel costs. Also, as inventory increases, it becomes progressively more likely that larger amounts of goods would spoil or age. As these factors come into play, expected costs increase at a faster rate. While these dynamics are present in any industry, they are more acute in some than in others. For instance, desktop computer manufacturing is subject to product life cycles measured in months. In this time context, both raw and finished goods can become obsolete very quickly.

Information technology (IT) investment behaves in the opposite way. An IT infrastructure must be built early in the supply chain implementation process. For example, it may be necessary to establish workable systems for accounting, production control, inventory management, and forecasting. However, once this investment is made, costs rise at a decreasing rate as more functionality is added.

In the real world, uncertainty is managed through a combination of inventory and information. For any given setting, an acceptable solution may involve a greater investment in one method and a corresponding decrease in the other. In a particular business context, the shape of the trade-off is determined by several relevant factors, including

- the degree of uncertainty for the business,
- how critical are accurate projections,
- how tight the time deadlines are on production and delivery, and
- the cost of material needed for an adequate hedge.

On-Time Delivery Requirements

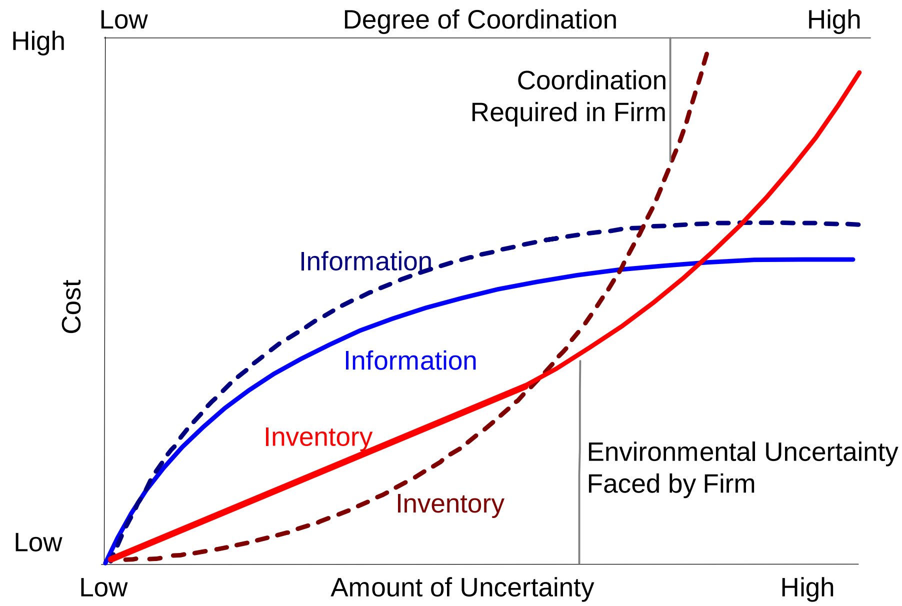
So far, we have dealt with supply chain management as a tool for improving a company's internal efficiency. However, supply chain management is also a tool for achieving on-time delivery, which is critical to maintaining customer satisfaction. Obviously, cost and quality are major factors with respect to customer satisfaction, but timing is the critical factor in the context of optimizing the functioning of a supply chain. After all, on-time delivery is what the customer needs to minimize uncertainty and associated costs. On the other hand, on-time delivery requires coordination across the supply chain, and this coordination has a cost. These costs can be calculated in terms of the labor and technology investment needed to assure that a supplier can deliver to a customer within an agreed-upon time frame.

Requirements for coordination may shift supply chain choices away from the most cost-effective balance of inventory and information; this situation is depicted in Figure 2-3. Just as managing uncertainty can be plotted against cost, so too can coordination. Two sets of "Information x Inventory" curves are shown. One set (solid lines, using the bottom horizontal axis) shows the relationship depicted in Figure 2-2, "uncertainty against cost." The second set (dashed lines, using the top horizontal axis) shows the "coordination against cost" relationship. As in Figure 2-2, these are hypothetical plots drawn to illustrate general relationships.

The vertical gray lines describe the dilemma faced by a manufacturer. Given the uncertainty that the firm faces, a relatively low-cost, inventory-based solution is the most promising option. However, a higher-cost, information-based solution is needed to meet customer expectations.[7] Depending on how the manufacturer can manage relations with its customers, the company must find a solution somewhere between the lower-cost choice sufficient for uncertainty reduction, and the higher-cost solution required for customer satisfaction.

[7] In this context, "customer satisfaction" refers to customer needs such as product quality, on-time delivery and personal relationships. The latter two can be solved with more information but not higher inventory. In our example, such requirements have interfered with what might otherwise be the most efficient activities for the company.

Figure 2-3. Costs of Uncertainty and Coordination



2.3.2 Local versus System-Wide Optimization

Almost all supply chain management involves information flow and coordination between a company and its customers and direct suppliers, and these relationships are bound together by contractual obligations. Thus, “supply chain optimization” usually means a series of local optimizations. Because many trading partner relationships are far from optimal, improving one-to-one coordination would result in much improved supply chain functioning.

However, a collection of local optimizations may not result in optimization at the system level. Dynamics along the supply chain may create perverse system-level distortions even in cases where each of the customer-supplier relationships in the supply chain is functioning well. These distortions can include:

- amplification of variance in the order stream as purchase orders move further away from the end-use customer, a phenomenon known as 'cracking-the-whip';
- spurious correlations in the order stream that can lead to unstable amplification of order signals; and
- persistence of demand disturbances long after a change has been made in the system.

Agent-based simulations of these phenomena and detailed descriptions of their operation can be found in Parunak (1998) and Parunak, Savit, and Riolo (1988). The authors of these studies conclude that because these problems are so sensitive to timely and accurate information, a multi-tier communication system is highly desirable.

The desirability of system-wide optimization calls for supply chains that are characterized by groups of companies across multiple tiers who interact as a group, rather than as a collection of individual trading partner relationships. Table 2-1 summarizes the pros and cons of local and system-wide optimization. However, making collective business models work is extremely difficult; this difficulty is both business-related and technological.

Table 2-1. Pros and Cons of Local and System-Wide Supply Chain Optimization

	System Level	Direct Relationships Only
Pros	• Fast transmission to people with a need to know. • Promotes multi-company collaboration. • Opportunity to deal with system-level phenomena.	• No radical change in traditional business processes. • The familiar traditional business case can be used. • Amendable to implementation support through existing organizations (e.g., AIAG).
Cons	• Messy. Difficult to know who gets what information, or what the information can be used for (e.g., information only, instructions to act). • Difficult to implement—requires major changes in how business is traditionally done. • No existing industry force is up to facilitating the change.	• Communication is relatively slow up and down the chain. • Does not promote multi-company collaboration.

Under present conditions, there is a very well-defined sequencing of parts flow through a supply chain. Further, responsibility and authority in that flow are very well defined. Companies know who can make demands on them and the allowable limits of those demands. When data flow between companies, the meaning of those data is clear. All parties know if the data are to be used for information and planning, or interpreted as a command to act, or taken as a query that demands a response.

However, when many companies interact as a group, authority, responsibility, and the interpretation of messages become much more difficult to negotiate and track. Argyres (1999) shows that information technology and agreement over technical standards can play a vital role in helping multi-company collaborations function, and his research highlights how organizational dynamics and business forces make tight multi-company cooperation extremely difficult to establish and maintain.

The most difficult technological issue is the multiplicity of communications methods, protocols, and formats that exist among trading partners. Consider all of the elements of communication that might move within an extended enterprise—part descriptions, manufacturing specifications, requests for bids, purchase orders, ship notices, price and availability of information, sequencing instructions, and order status, to name a few. Even with our existing methods of interoperability—EDI, XML, IGES, STEP, and specially negotiated trading partner agreements—there is a low probability that any pair of companies in the enterprise could communicate with each other in an unambiguous fashion without considerable groundwork and oversight.

2.3.3 Interoperability as an Approach to Optimizing Supply Chains

Morell and Phelps (2001) define interoperability as “the flow of information from one system to another without the need for human intervention.” Interoperability is one of the most important factors to improving supply chain functioning because communication in supply chains must be limited and precise to be efficient. Small improvements in interoperability can produce disproportionately large improvements in supply chain function.

Business process change might make the greatest contribution to improving supply chains. Unfortunately, new forms of business relationships can be extremely difficult to design and implement. When one-to-one relationships are to be developed, the difficulties center on the tighter relationships (see Figure 2-3) that require extended negotiation, complex dependencies supported by contract and trust, long-term commitments, mutual interdependence, and shared assets. When multilateral relationships are involved, difficulties are even greater because business models have to be developed that proliferate communication pathways; provide the benefits of greater certainty and coordination; and continue to assure unambiguous authority, responsibility, interpretation, and security of messages. Because these changes are so difficult, we see them as rare events.

Communication alone will not rationalize supply chains because communication has no value without a business context. Still, lowering the cost of communication can provide business with expanded choices in designing a business process. One way to see this expansion is to consider the “information” curves in Figures 2-2 and 2-3. Because of the lack of interoperability discussed above, effective communication can be a large component in the information costs. Thus, more facile communication would lower the information curves, thereby increasing the amount of certainty and coordination that trading partners could afford.

While interoperability can help with both one-to-one and multilateral approaches to supply chain optimization, its greatest potential contribution is in multilateral situations. This is true even though multilateral change is extremely difficult, because even small improvements in a complex supply chain can lead to major improvements in the chain’s overall performance. Parunak, Savit, and Riolo (1988) and Parunak (1998) show how this “butterfly effect” emerges in supply chains. Communication delays and inaccurate information lead to inventory fluctuations, which in turn lead to higher costs. Because of this leverage, interoperability improvement should be one of the highest priorities when it comes to pursuing supply chain optimization.

3 Supply Chain Optimization in Practice

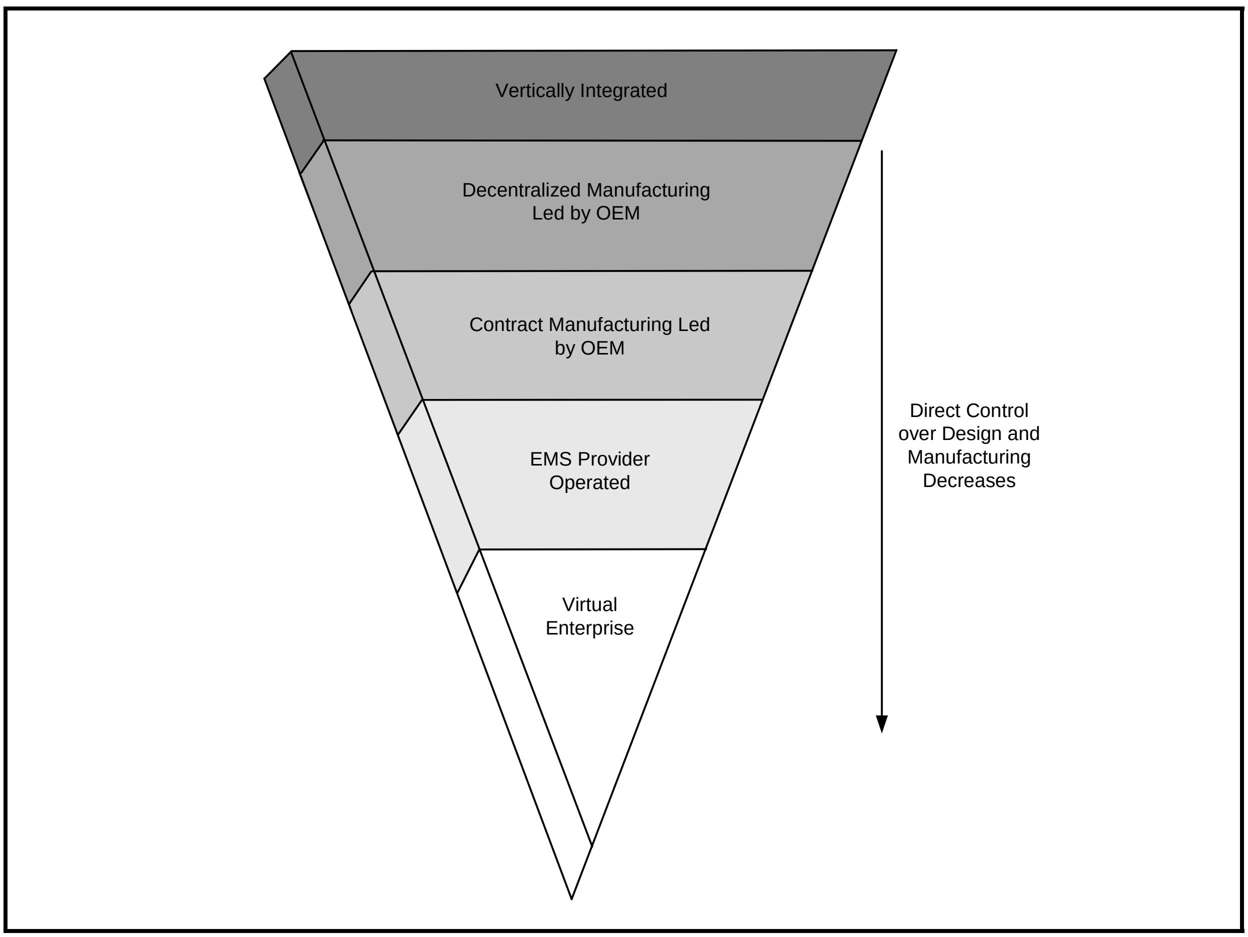
Although the focus of this report is on the automotive and electronics industries, this section provides a summary of current supply chain activities throughout the world economy, with a focus on U.S. activities. We first introduce several conceptual supply chain models. Next we give an overview of supply chain activities over the past several years and provide an analysis of the recent trend toward globalization. Finally, we use three companies as examples of supply chains that have excelled in specific areas.

3.1 CONCEPTUAL DESCRIPTIONS OF CURRENT SUPPLY CHAIN MODELS

In today's economy, we see a number of different approaches to supply chain management, which leads to a wide variety of organizational structures. Several of these structures can be thought of as existing along a continuum characterized by the degree of control by the OEM. At one extreme lies the traditional vertically integrated firm, in which a single corporation directs and operates facilities at every step of the supply chain, and at the other is the "virtual enterprise," in which the OEM plays no part in the supply chain aside from product design and sales and marketing functions. Figure 3-1 presents a visual comparison of the distribution of control in each extreme supply chain structure. Each of these models is described below.

The *vertically integrated (VI) firm* manages all supply chain activities, from raw materials to final customers. This type of firm manufactures most or all key component parts, assemblies, and finished products in-house, purchasing only less critical parts and commodity items from outside vendors. In some industries, historical practice or legal restrictions may separate distribution and final sale from VI manufacturers; for example, in the automotive industry, franchise laws in many states prevent OEMs from selling their vehicles at retail. Nevertheless, these firms manage all of the information needed to support the supply chain, although vertical integration does not guarantee efficient management. The use of multiple incompatible information systems is common among the vertically integrated OEMs in the automotive industry. One large, vertically integrated Tier 1 automotive business reported having more than 20 home-grown planning systems in their plants, none of which could interoperate with the others.

Figure 3-1. Conceptual Supply Chain Models: Changing Control



In *decentralized manufacturing led by the OEM*, the OEM owns and operates the final assembly and processing steps, but most steps in the supply chain are in the hands of independent suppliers. Operationally, this may have cost and/or quality advantages, as each firm is able to focus on its core competencies. However, information sharing must now cross corporate boundaries, so contractual and legal complexities are added. The OEM has less control than in a VI organization and must rely on information or inventory to protect itself. The OEM may keep control of product performance and quality by providing component design, process engineering, and facility tooling. All of these functions can be transferred to another supplier if necessary, but effective control resides with the OEM. Most of the automotive industry operates in this way today; for example, Arnaldo Camuffo (2002) writes, “In Ramos Arizpe, Mexico, General Motors has recently used modular assembly for the new Pontiac Aztek. Modules—preassembled groups of parts—account for about 30 percent of the vehicle and are shipped to the plant and bolted together.”

Another model is *contract manufacturing led by the OEM*. In this structure, the OEM turns over operation of all production, including final assembly, to other firms; this allows the OEM to focus on product design and sales and marketing functions, which it may consider to be its core competencies. The OEM turns over production to a firm that specializes in the necessary skills to be successful in this arena; these skills might include shop floor supervision, employee (and perhaps union) relations, risk management, maintenance, and repair. Outsourcing can permit OEMs to be more flexible because they no longer have responsibility for employees or production management, and if the product fails to meet specs, they merely cancel the contract. In 2002, Asyst Technologies developed a relationship with Solectron Corp. to manufacturer many of its electronic products so that they could use the expertise of Solectron and presumably reduce overhead costs for labor and facilities (Chappell, 2002).

OEMs initiating contract manufacturing may achieve better business results through the resulting management focus. However, OEMs cede more control than in previous structures and can no longer directly control the quality and performance of the finished products. In most cases, OEMs still maintain control over design, engineering, and tooling; in electronics contract manufacturing, OEMs often purchase all capital equipment. Information flows are critical in this structure to avoid costly errors. In one well-publicized case, Cisco was forced to write off $2.25 billion in unsaleable products made by contract manufacturers in 2001 (Barrett, 2001).

Electronics manufacturing services (EMS) providers enable another supply chain structure. If OEMs are willing to cede control over design and engineering as well as manufacturing, they may contract with EMS providers to manage the entire process. In this case, the OEM's name will still appear on the product, and the OEM will still handle marketing and sales functions, but most of the supply chain will be controlled by the EMS provider. From the latter's perspective, the resulting supply chain will look like one of the structures above; all of the complexity, information needs, and risk have now shifted to the EMS firm, although quality defects, supply disruptions, and perhaps cost overruns may injure the OEM as well. For these reasons, the OEM remains in nominal control (specifies designs) and must be able to manage all of the supply chain information generated by the EMS provider and other firms in the chain.

In the *virtual enterprise supply chain,* a service provider controls and manages the entire supply chain, while the firm that will put its name on the product and contribute sales and marketing effort is entirely disconnected. In this last step in the continuum, the service provider actually functions as the OEM and has the same information needs as an EMS provider or traditional OEM. The "brand name" firm becomes a spectator in the production process and exerts no control at all; its role is limited to marketing. Li & Fung represent the quintessential example of a virtual enterprise; they manufacture products for companies such as Coca-Cola and Levi & Straus; however, these firms have no control over operations.

In distinguishing among the five manufacturing models, the tradeoff between process control and the advantages of distributing responsibility among levels of a supply chain (degree of specialization) is value added. Although specialization may increase the total value added for the supply chain as a whole due to production efficiency gains, the OEM in the virtual enterprise model relinquishes significant control.

Thus, for any degree of vertical disintegration, choices must be made among alternative supply chain management techniques. In weighing the respective costs and benefits of alternative techniques, each firm must decide which is best. Several factors could impact this decision:

- **Production Type**—Whether a company produces small or large components can drastically affect supply chain management possibilities, such as transportation costs, and if products are commonly specialized or customized, timing becomes more of an issue.
- **Target Markets**—The geographical and societal characteristics of a company's market can drastically affect SCM choices; for example, international markets might necessitate manufacturing goods in another country to expedite time-to-delivery.
- **Technology Infrastructure**—Firms will be affected in their plans by their current IT infrastructure and how they are able to use IT to solve SCM problems; they could additionally be affected by the level of IT used by their customers and suppliers.

Based on these factors and others, firms must decide what type of supply chain model will enable them to perform most efficiently. In the next section, recent supply chain integration activities are discussed.

3.2 SUPPLY CHAIN INTEGRATION DEVELOPMENTS

At the end of the last decade, software makers touted the efficiency and cost savings that companies could expect from buying and implementing new supply chain software. Venture capitalists invested millions and U.S. companies spent billions purchasing new software expected to increase efficiency, but most reported very few benefits. In November 2003, a *Wall Street Journal (WSJ*) article on the status of B2B electronic commerce suggested that only one-third of the B2B Internet startups operating in 2000 were still in business by the end of 2001; approximately 1,350 companies went under during this period. The *WSJ* piece went on to say that as start-ups were trying to profit by charging transaction fees on billions of dollars in trading, many companies initiated their own B2B programs, often with great success. The market for supply chain management software is alive and well; last year, U.S. companies conducted approximately $482 billion in business using online transactions, an increase of 242 percent from 2 years prior (Angwin, 2003).

As companies make efforts to increase supply chain efficiency, they are taking few risks in purchasing software after the overspending that typified the late 1990s. Software makers are more aware of what companies are looking for and thus products are less expensive, easier to integrate into their internal software, and simpler to use; additionally, customers are seeing a return on their investment (ROI) more quickly.

Many companies continue to use EDI systems and SCM products are still selling; however, and total solutions are becoming increasingly popular.[8]

New individual and “total solution” products are being developed and sold by software titans such as Oracle, PeopleSoft, and SAP, but other companies are entering the market as well. IBM has been developing its On Demand service offering, and HP and Microsoft are working on supply chain solutions. Some companies, such as Dell and Intel, are integrating software programs such as i2’s TradeMatrix and supply chain standards such as RosettaNet, which can be individualized for each company but enable interoperability with other firms. Additionally, as companies need more customization to allow SCM programs to interoperate with internal software, smaller companies can gain some market share. Some companies even outsource the management of these systems to companies such as Li & Fung (see Section 3.4.2).

As these supply chain software packages for companies become more sophisticated, companies are looking for ways to use this new-found power. One way to improve efficiency is to perform more statistical analysis of their internal operations using software packages such as Six Sigma or SAS. Radiofrequency identification, or RFID, chips are a more recent example of a technology that can help SCM. Beginning in January 2005, Wal-Mart will require that its 100 top suppliers use RFID tags, which will allow Wal-Mart to track information such as the origin of each product, a perishability date if applicable, and the movement of items both within a store and as they move out the door. Subsequently, Wal-Mart could save between $1.3 to 1.5 billion (Shim, 2003). As Wal-Mart pushes the demand for RFID chips, more retailers could be forced to begin using the tags to be competitive.

Additionally, firms are looking for ways to cut costs. Today, popular supply chain models being adopted by companies relinquish more control to contract manufacturers, such as Solectron, and electronics manufacturing services, which specialize in locating and using the most efficient supply chain components to make the lowest-cost products (see Section 3.1). From manufacturing plants to service centers, companies are hiring process management firms and consulting groups with

[8]Supply Chain Management (SCM) software includes program types such as Enterprise Resource Planning (ERP), Customer Resource Management (CRM), and Product Lifecycle Management (PLM). These programs are both supplier-side and customer-side applications.

expertise managing and operating complex activities. Although many companies are using supply chain software and Internet-enabled solutions, others have benefited by redefining the roles of the players in their supply chain as well as by leveraging the knowledge of supply chain experts. Some companies have found that moving certain processes abroad has enabled them to cut costs and become more competitive; the following section addresses motivations and inhibitors to globalize supply chains.

3.3 INCREASED GLOBALIZATION OF SUPPLY CHAINS

The proliferation of free trade agreements, increased membership in the World Trade Organization (WTO), and historic increases in the volume of cross-border trade all indicate that the trend towards internationalizing business will continue.[9] David Ricardo's law of comparative advantage has proven that it is more efficient for countries to specialize in a few products rather than produce many goods at a high opportunity cost. As companies around the world continue to learn of the cost savings involved in moving certain job functions and process facilities to the most cost-effective location, outsourcing will increase.

The growth in the globalization of business will inevitably be accompanied by growth in the internationalization of supply chains. The implications of this growth transcend scaling problems that attend normal supply chain expansion. Rather, particular sets of problems become salient in the international context. The question is not whether supply chains will continue to internationalize but how to manage the process to the best advantage of domestic industries. To succeed, it is necessary to first define potential globalization practices.

First, a distinction needs to be made between moving an entire level or industry (e.g., manufacturing) in a supply chain offshore and moving one phase of an industry's activity (e.g., R&D, service, or production). The majority of outsourcing being implemented today concerns specific activities within an industry. For example, over the past several years, numerous U.S. companies have built customer service call centers and "programming plants" in Asia, most often in India. Recently, some

[9] A December 17, 2003, *Star-Telegram* article entitled "U.S. Reaches Central America Trade Deal" discusses the progress of several free-trade agreements currently being debated by the U.S. administration. To view the article, go to <http://www.dfw.com/mld/dfw/7513520.htm>.

companies have moved R&D activities overseas as a way to combine manufacturing and R&D activities or reduce costs in some cases.

The next sections discuss motivations and inhibitors that drive decisions about the internationalization of supply chains.

3.3.1 Motivators to Internationalizing Trade

For an individual company, many factors might lead to the globalization of its supply chain. However, four main factors consistently motivate companies to move operations overseas:

- access to complementary assets,
- cost savings,
- marketing necessity, and
- trade regulations.

By *access to complementary assets*, we mean that if a certain resource (e.g., raw materials) is located in a particular country, then a company would be more likely to perform other activities (e.g., manufacture products) in that country if other circumstances are not prohibitive. As an alternative example, a company might decide to move R&D activities overseas because they want to ensure that employees working on manufacturing and R&D are located in the same geographic vicinity; if manufacturing is less costly in a certain country, R&D personnel could follow for strategic and/or coordination-related reasons.

The most common reason for sourcing overseas is the cost of components. In many cases, decreased production costs outweigh any added cost due to longer, more elaborate, or more unpredictable logistics. In general, the greater the contribution of labor to product cost, the greater the appeal of sourcing in low wage-rate countries. Prime examples of such industries are apparel, textiles, and electronics.

Anther reason for sourcing in multiple countries is the sales and marketing advantage that can accrue to having a presence in, and making a contribution to, local economies. This consideration is likely to be important in industries characterized by low volumes and high product prices, a set of conditions that requires global sales for business success. Aerospace is a good example of such an industry.[10]

[10]A GE Aircraft Engines Press Release in February 2002 discusses a new plant in Thailand that was opening to support GE aircraft in Japan, Korea, China, Taiwan, Australia, and New Zealand. To view the article, go to

Local trade restrictions may also cause firms to expand their supply base to additional countries. In recent conversations with several manufacturers of measurement equipment, we learned that unique country and/or trade-bloc approval systems created the need to maintain separate supply chains in Europe and the Americas.

3.3.2 Inhibitors to Internationalizing Trade

Mitigating the advantages of global sourcing is a set of factors that increase risk and cost. While few of these factors are solely a function of international sourcing, the greater the international dimension of a supply chain, the greater the likelihood that these factors will be important. Increasingly global supply chains will bring

- increased system heterogeneity,
- increased political complexity,
- decreased legal security,
- more transportation modality changes,
- greater delivery times and higher volumes, and
- new geopolitical concerns.

As uniformity decreases, there is a corresponding increase in the cost of maintaining and coordinating multiple systems. Systems are affected by laws, regulations, business culture, currency, and data and communication standards. Each of these can be unique to individual countries (or trading blocs). Thus, one consequence of international sourcing is that each new location carries the burden of accommodating several new systems. The multisystem coordination problem may compound in a nonlinear fashion because each new locale results in many new interfaces among multiple systems.

Political boundaries bring requirements that touch on how business can be conducted in a locale and on the activities needed to transport goods across borders. With respect to conducting business in a particular country, examples of relevant issues include laws requiring the use of local supplies for manufacturing in a particular country, labor and environmental regulations, or export/import laws. Dell provides a perfect example for us; before China joined the WTO in 2002, Dell decided not to build a plant there because government leaders indicated that they would maintain control over Dell's operations (Frahm, 2004).

<http://www.geae.com/aboutgeae/presscenter/services/services_20020228.html>.

As firms enter new territory, they are often faced with legal systems that do not adequately support the security needs of many business activities. For example, the laws in some countries do not enable firms to apply for patents or protect previously developed intellectual property. One *Industry Week* article on the effects of globalization on manufacturing noted that despite China's membership in the WTO, "manufacturing executives say China still does not offer the kinds of protection for know-how, patents and other sorts of intellectual property that are common in the U.S., Canada, and Europe" (McClenahen, 2003).

With respect to transportation across borders, critical factors are customs requirements, documentation of export/import regulation compliance, and advance notification of shipment content. The data management burden resulting from these requirements can be very high, particularly in this age of increased security vigilance. As international sourcing increases, the need for overseas transportation will follow, thus requiring goods to move from a ship or an airplane to a truck or train. Each transition increases cost, time, and the possibility of loss or damage. TT Club, the mutual-insurance provider for the international cargo container industry, estimates that as many as 5 percent of container movements in the world develop problems during transit (Machalaba and Pasztor, 2004).

Additionally, international sourcing usually involves increased delivery times and high numbers of units per shipment. Both are attributable to reliance on sea transportation, a mode of transport that is slow and most economical with large volumes. These requirements are not conducive to business tactics such as vendor-managed inventory, just-in-time delivery, or mass customization.

Global sourcing requires dealing with the vicissitudes of political, social, and economic conditions. In the short term, these conditions may affect delivery and production schedules. In the longer term, they may undermine business plans based on assumptions about assured supply and predictable costs. Oil is a primary example of these kinds of uncertainties, as evidenced by recent interruption in supplies from Venezuela; a protest against President Hugo Chavez in Venezuela in December 2002 brought oil production in the country to a stand-still and marked the 2-year high of world oil market prices, as the uncertainty inherent in the oil supply chain increased dramatically (Banerjee, 2003). Another example is the problem of critical materials whose sale is caught up in regional conflict, as is the case of coltan, a dull metallic ore that is a critical component in the electronics industry that is found in plentiful supply in the Democratic Republic of Congo.

A second dimension to geopolitical concerns in sourcing is the need for government-to-government agreements as part of sourcing decisions. For instance, weapons systems are often developed by international consortia and require not only agreements among the many companies involved but also negotiated agreements among the countries in which those companies reside. In cases like these, the transaction costs of establishing business relationships can be extremely high. One reason the expense may be justifiable is the need to sell globally. Another reason, though, is that governments may see these agreements as instruments of foreign policy.

Building on the understanding that today's business climate is driving companies towards more efficient supply chains and often more global supply chains, next we will identify several case studies.

3.4 SUPPLY CHAIN INNOVATORS

This section describes the operations of three companies that are leaders in supply chain management innovation. Through focusing on internal optimization, external relationships, and inventory management, each was able to improve their supply chain role.

3.4.1 Business on Demand—The Evolution of IBM

Over the past 10 years, International Business Machines (IBM) has gradually transformed its business practices to improve supply chain efficiency, and today the company exemplifies a combination of many of the features described in Section 2.2. In the early 1990s, IBM started consolidating its business hierarchy and used advances in technology after company data processing costs reached three times the industry average. Largely based on a more efficient and widely adopted supply chain infrastructure, IBM cut IT spending by 31 percent even after incurring large investment and growth costs.

With a self-reported $14.5 billion in benefits achieved from a $4.7 billion investment over 9 years, IBM exemplifies the benefits of IT-based integration of a supply chain. More specifically, IBM has deployed extensive middleware to reduce repetition in data entry and ease access to the company's vast information resources (IBM, 2003). The company has leveraged the use of many third-party solutions, such as SAP for

Enterprise Resource Planning (ERP), Siebel for Customer Relationship Management (CRM), i2 for Supply Chain Management (SCM), and Ariba for procurement. However, IBM believes that its *value chain* ideology has allowed a symbiotic relationship to form with many of its suppliers. This value network is defined by an IBM white paper as "a group of trading partners, focused on core competencies and connected via web-enabled technology, collaborating to provide total solutions to customers" (IBM, 2001).

Today, IBM's supply chain R&D efforts are exemplified by its On-Demand Supply Chain Research Laboratory at Penn State. In collaboration with faculty and students at Michigan State, Arizona State, and University College Dublin, IBM's supply chain projects will enable the company to continue to work toward a value network with maximized efficiency. The work at these labs is intended to help IBM build more dynamic supply chains that can automatically anticipate and respond to customer demands and changes in the market (Penn State, 2003).

3.4.2 Understanding Demand—The Li & Fung Virtual Enterprise

According to their Web site, Li & Fung is "one of the premier global consumer products export trading companies managing the supply chain for high-volume, time-sensitive consumer goods, including garments, fashion accessories, toys, sporting goods, promotional merchandise, handicrafts, shoes, travel goods, and household items." In the United States, Li & Fung subsidiaries have regularly stocked the shelves of Wal-Mart, JC Penny, Kohl's, and Meijer. In 2002, Coca-Cola partnered with the Asian company, and Levi Strauss proposed a licensing agreement with them in August 2003 (Li & Fung, 2002; 2003). Amazingly, Li & Fung's success has been achieved without either manufacturing or supplying any real product; they rely totally on selling their expertise in managing supply chains.

By 1997, the Internet had begun to transform the American economy and Li & Fung was forced to reevaluate its operations. In response, they decided to focus on new technology as a primary means of maintaining competitive advantage. Li & Fung used new Internet capabilities to develop a CRM system in which information could flow quickly and seamlessly.

Dedicated Internet sites are developed for Li & Fung's 10 largest customers. From these sites, customers are able to

- access past orders and billing information,
- track current orders,
- initiate a new order, and
- identify products being manufactured for other clients (and "piggyback" if desired).[11]

Li & Fung's Electronic Trading System, known as XTS, is linked to customers' internal networks, enabling very quick transfer of order and production information. Depending on the technology available, some Li & Fung offices can access central databases and share design and production images in seconds. For example, Microsoft's Biztalk software enables seamless data transfers, which increase the efficiency of supplier-side interactions and thereby decrease the time from receipt of an order to initiation of the processing stage.

Despite the continuing evolution of Li & Fung's order management capabilities, many interactions still occur in traditional ways, through phones, faxes, and personal visits. Li & Fung has excelled at finding extremely low-cost labor and raw or processed materials and then identifying the most efficient manufacturers. Figure 3-2 displays the complex nature of Li & Fung's business model. Although their supplier relationship mechanisms are not as sophisticated as their customer-side interactions, Li & Fung is able to coordinate the production of high-quantity, low-complexity products at extremely low prices. According to William Fung,[12] "We're actually the bridge between low-cost, labor-intensive manufacturing of consumer goods in the developing world and the consumers of those products, who are primarily in large, developed economies" (Hostein, 2002).

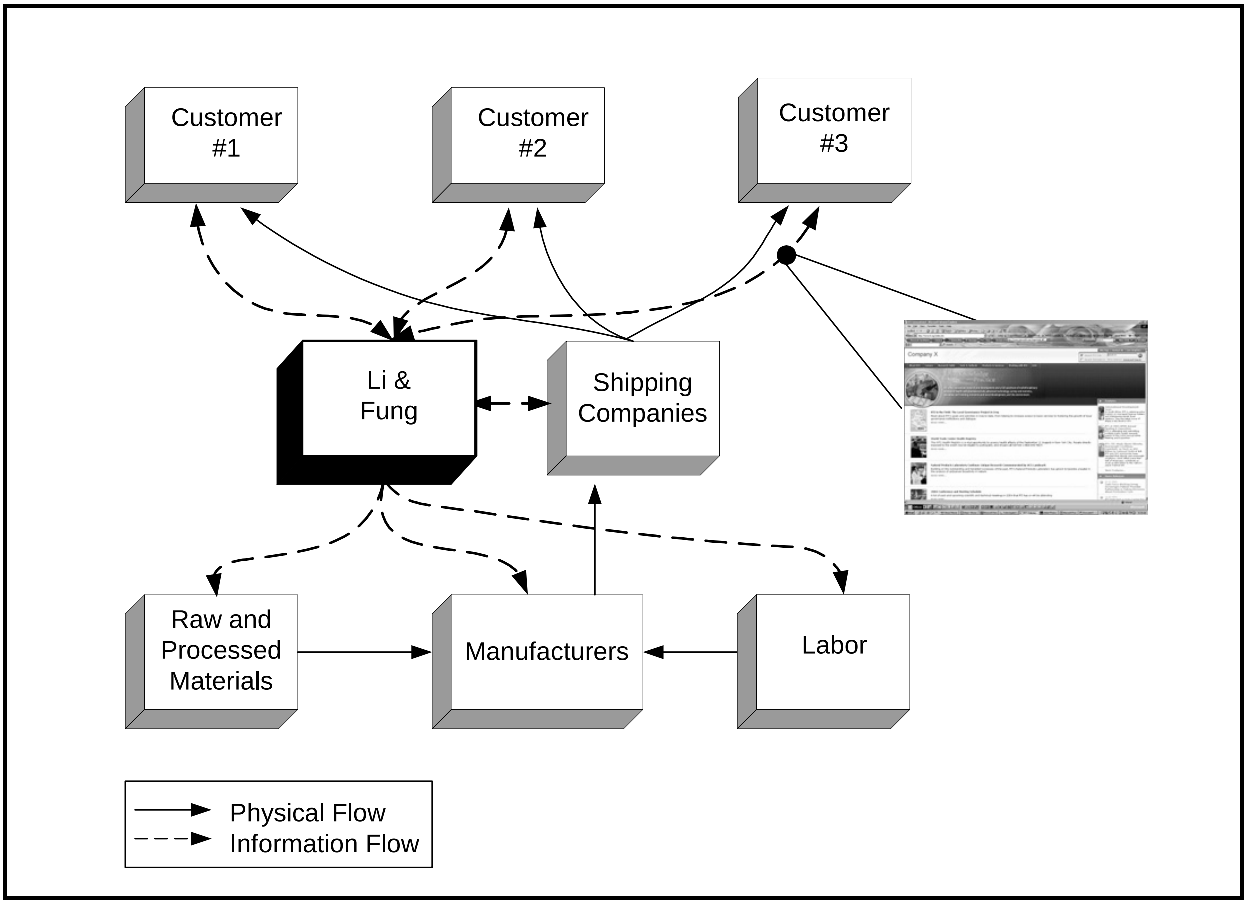
3.4.3 Build to Demand—The Dell Model

In 1994, Dell was a company struggling to keep afloat in the intensively competitive PC market, but one decision set Dell on a course to eventually become the number-one computer systems company in the world in 2001. The management team at Dell decided to adopt a new supply chain operations model based on a "build-to-order" procedure. By eliminating the costs associated with holding inventory, Dell was a pioneer in just-in-time delivery.

[11] Although Li & Fung does not actually manufacture any products, they coordinate the manufacturing of products for companies. If Li & Fung has contracted a product to be manufactured for one company, another company can see these products through their customized Web site and order more of, or "piggyback" on, the same product.

[12] William Fung is the current group managing director and CEO of Li & Fung.

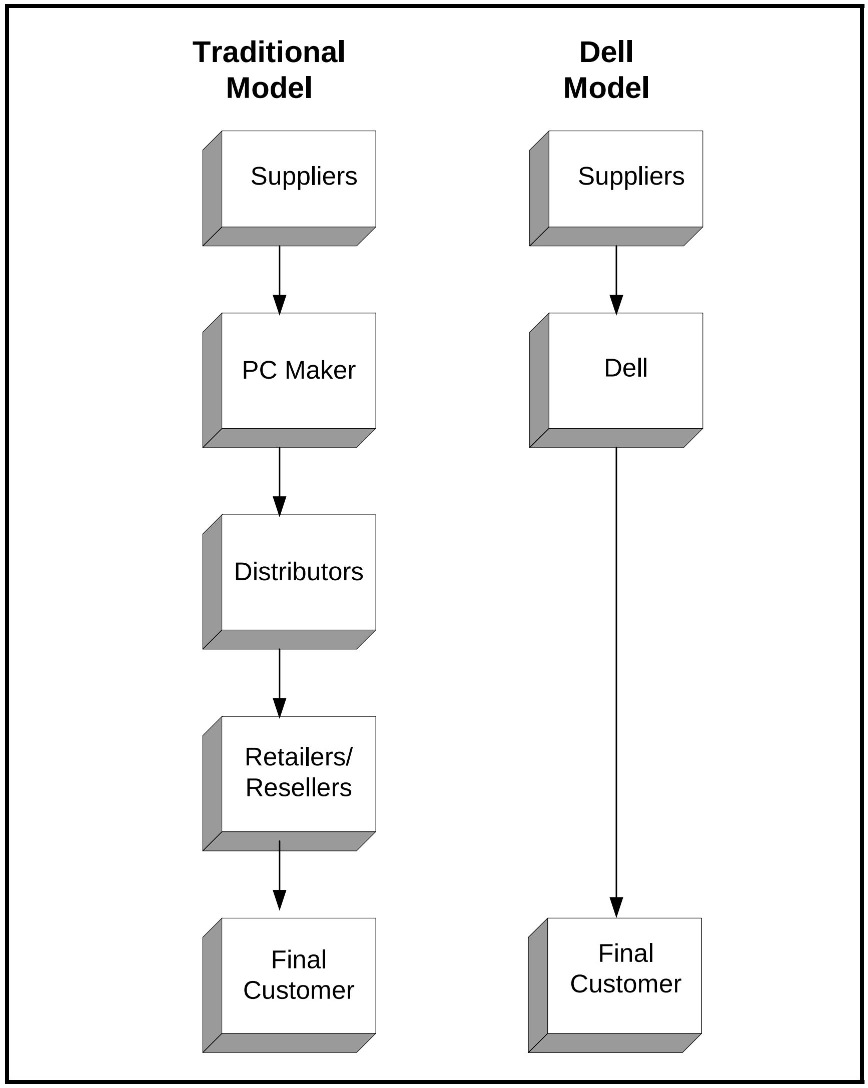
Figure 3-2. Li & Fung Supply Chain Model



Supplier and customer relationships were the key to the success of the "Dell Model." By finding stable companies interested in consistently high-quantity supplies and large IT-based customers interested in routine PC upgrades, Dell was able to successfully implement its business model. In addition, the company started a Web site, Dell.com, which allowed PC buyers to purchase computers designed to their personal specifications (Copacino and Byrnes, 2001).

Unlike competitors such as Apple, IBM, and Compaq, Dell sold directly to customers and thus eliminated the need for distributors and retailers or resellers, who completed the supply chain in the more traditional model (see Figure 3-3). Dell was able to have a direct relationship with its customers, enabling more targeted service and the ability to promote repeat or additional sales. As a result of good management and a well-defined business model, Dell's stock price appreciated over 40 times from 1994 to 1999 (Dedrick, Kraemer, and Yamashiro, 1999).

Figure 3-3. Dell Model vs. Traditional Model of Distribution



For Dell to keep a manageable balance between supplier deliveries and customer orders, it has relied heavily on the use of software programs and other IT processes that enable very efficient transfers of information. As Dell grew its global supply chain model, the use of IT continued to expand as new technology was developed. In the mid-1990s, the most important component of Dell's IT was its Information to Run the Business, or IRB system, which enabled the optimization of production, quality, and distribution both globally and locally (Dedrick, Kraemer, and Yamashiro, 1999). Dell continues to update its IT capabilities; in 2001, Dell deployed i2's TradeMatrix Supply Chain tools to gain a "cost-effective, flexible solution… to sustain a global, 24x7 manufacturing operation" (Dell, 2001).

4 The Automotive Supply Chain

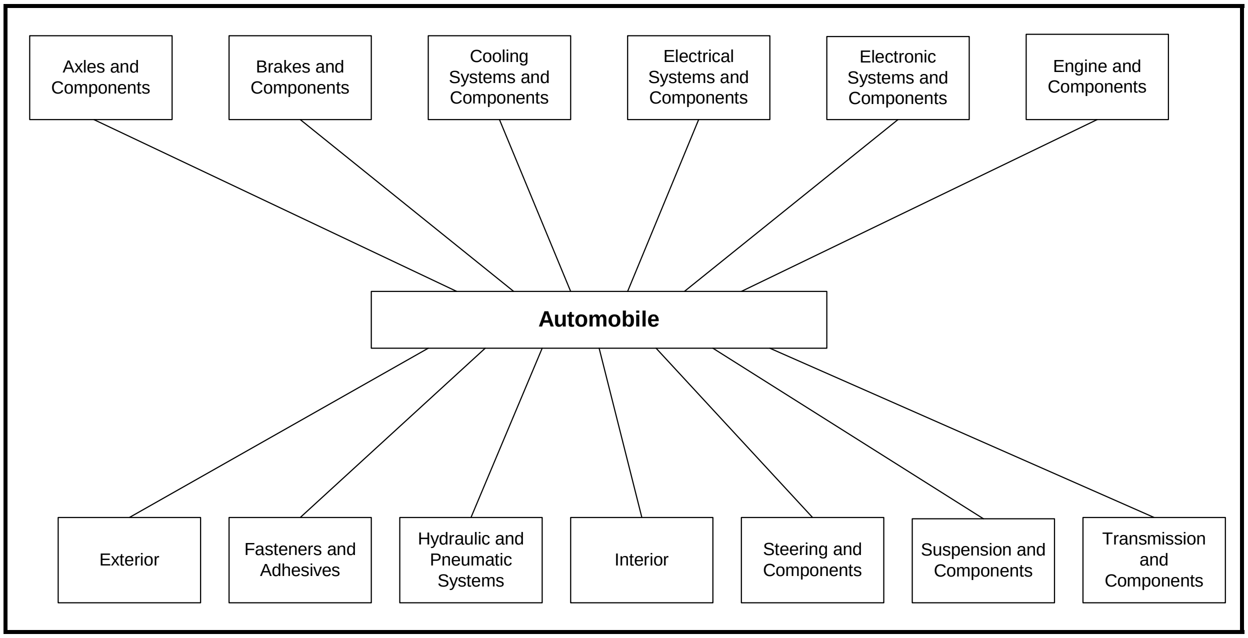
The production of an automobile requires interaction and coordination among many functions and industry participants. An automobile consists of a large number of components, parts, and accessories that must function together as an integrated unit. Consequently, the development and manufacturing process is also complex, requiring a number of iterations among the steps for different vehicle components. Because these components are typically designed and manufactured by many companies that are part of a complex supply chain, these companies must coordinate their activities to ensure that the components they manufacture are compatible with other components.

This section is divided into five parts. The first discusses the anatomy of an automobile and the basic theory behind automobile assembly. Building on the concepts described therein, we then present the actual process through which components and parts are assembled into a motor vehicle. Next we describe the corporate and industry structure of the U.S. automotive supply chain, followed by a discussion of current trends in supply chain integration and interoperability issues faced by the industry.

4.1 THE ANATOMY OF AN AUTOMOBILE

The structure of an automobile is extremely complex. A typical motor vehicle consists of approximately 15,000 parts and accessories that must be designed to be compatible. As shown in Figure 4-1, an automobile comprises several major systems, each of which contains many subsystems, components, and interfacing parts (e.g., bearings, crankshafts, filters, gears, pistons, pumps, and valve trains make up the engine, and their design must be compatible). Similarly, other systems,

Figure 4-1. Automobile Systems and Components



Source: Research Triangle Institute. March 1999. *Interoperability Cost Analysis of the U.S. Automotive Supply Chain*. Prepared for the National Institute of Standards and Technology. Research Triangle Park, NC: Research Triangle Institute.

such as axles, suspensions, transmissions, bodies, seats, and instrument panels, consist of many parts that must work together. Manufacturers must coordinate these systems to enable the successful final assembly of the vehicle.

4.1.1 Automobile Platforms and Models

Most motor vehicles are built under the platform concept. A platform is typically defined as the vehicle's basic mechanical structure. Different vehicles based on the same platform commonly share several structural elements, such as the floor plan and door pillar (*Automotive News,* 1997). Automakers typically offer several car models per platform. For example, the soon-to-be discontinued Chevrolet Lumina, Chevrolet Monte Carlo, Pontiac Grand Prix, Buick Regal, and Buick Century all share the same platform. In addition, these cars may be offered in several body styles, such as a two-door coupe, four-door sedan, and four-door hatchback.

The platform concept is becoming increasingly important as automakers seek to reduce costs by designing and producing more vehicles from common platforms. The number of platforms is an important measure of the annual design and engineering effort of each company. Models built on common platforms carry over a large percentage of parts and production processes, and the engineering and tooling for the vehicle's basic structure account for the majority of total product development and launch costs (Womack, 1989). Thus, the potential savings from using an existing platform for a new model are considerable. Ford estimated that when they develop a new model on an existing platform, development and engineering costs fall by 15 to 20 percent (*Automotive News Europe*, 1997). In addition, components and subassemblies may be interchangeable within groups of platforms, thereby reducing the total number of parts that OEMs must procure.

4.1.2 Production by Platform

Maximizing unit production and sales per platform is an important industry strategy for decreasing design and development costs over the next decade (Auto and Auto Parts, 1997). In 1997, the most popular platform grouping, Chevy S/K pickups and utilities, produced over 1 million, while some of the less popular platform groupings produced only 100,000 or less.

Industry's current strategy of consolidating on fewer, more flexible platforms is a response to an opposite longer-term trend. Over the past 20 years, the unit sales per platform have declined for the U.S. OEMs. In addition, more frequent model renewals are required to keep pace with faster changes in style and taste. An analysis of the OEM plans for major and minor redesigns shows that 12 platforms undergo major redesigns and 8 undergo minor revisions in an average model year (IRN, 1997). Each revision may affect the engineering and geometry of automotive components; this information must be transmitted throughout the supply chain to ensure proper physical and electrical compatibility between the platform and automotive components.

4.2 THE AUTOMOBILE PRODUCTION PROCESS

Automotive production in the United States has changed significantly over the last few decades. These changes have contributed to development and production complexity while simultaneously shortening automobile development and production timelines and improving product quality. Prior to these changes, U.S. automakers considered new automobile development a linear process that took 5 or more years to complete. Automakers proceeded sequentially from concept design through product design, product engineering, and component sourcing to final assembly (Womack, 1989).

4.2.1 Engineering and Manufacturing Philosophies

U.S. automakers were compelled to rethink their linear approach to the vehicle development and production process in the face of stiff competition from Japanese automakers. In the 1980s, Japanese auto companies completed the automotive design process, from initial conception to delivery to consumers, in 43 months, on average; their U.S. counterparts took 63 months (Womack, 1989). Thus, Japanese automakers were able to introduce novel design changes that met customer demand more quickly and at less expense, which accounted, at least in part, for their rising market share.

Concurrent engineering, which integrates design, manufacturing, and support processes to provide early manufacturing input into the design process, is a fairly recent phenomenon in the U.S. automotive industry. The design of the GMC CK pickup in the early 1970s marked the first time in the U.S. auto industry that manufacturing engineers formally worked with design engineers. This early effort at concurrent engineering was very successful and eventually led to its further acceptance in the auto industry.

Concurrent engineering has enabled lean manufacturing, a manufacturing philosophy that "focuses on delivering the highest quality product at the lowest cost" (Liker and Wu, 2000). The system focuses on value streams, where all steps in the production process include only those steps needed to convert raw materials into end products. According to Liker and Wu, any steps that fail to do this are considered wasteful. Included in their assessment of wasteful activities is the transportation of parts from suppliers to OEMs located at significant geographical distances. To mitigate this waste, OEMs and suppliers have adopted the Japanese concept of just-in-time (JIT) delivery—getting the right part to the right place at the right time. Under JIT, manufacturing operations are coordinated so that the quantity of parts produced and shipped by suppliers to OEMs meets their demand requirements at that particular time. The goal was primarily to reduce inventories and ancillary expenses, and the process has had the dual effect of deepening supplier-OEM relations.

As a result of these efforts, lead times for U.S. automakers have been falling since the mid-1980s and continue to fall. Buchholz (1996) reports that Chrysler's average lead time was 54 months in 1987 and about 29 months in 1996. The Dodge Durango, first sold in 1998, was developed in 23 months; the shorter lead time was attributable to heavy borrowing from the Dakota pickup (Brooke, 1998). The late 1990s Concorde and Intrepid redesigns took about 31 months (Jost, 1998). GM has recently reported that its cycle time has fallen from 36 months in 1995 to about 24 months in 1998 (Martin, 1998). It now takes the auto industry 9 months to convert raw materials into a vehicle in the driveway (Piszczalski, 1998).

The remainder of this section discusses the process through which the automobile supply chain takes design information and brings a final product to market. The discussion is divided into two components: process and factory design and assembly.

4.2.2 Process and Factory Design

Once an OEM has identified a need in the marketplace and designed a vehicle to that end, it proceeds with production procurement and design decisions for the body, power train parts, and other components. In parallel, a factory and process are designed for the parts that will be produced in-house. The plant floor layout is determined, and tooling and fixtures are designed or procured. These activities are mimicked by the suppliers that will produce the design's constituent pieces.

The degree of design activity conducted by suppliers varies along a continuum. At one extreme, suppliers simply manufacture parts based on the specifications and designs provided by the OEM. At the other extreme, the supplier is responsible for the component or system design, responding only to high-level specifications from the OEM. In the intermediate case, detailed design may be a collaborative process involving engineers from both supplier and OEM.

In any event, the OEM contracts with suppliers to procure the parts and subassemblies that will comprise the final product. Suppliers themselves may contract with subtier suppliers for the components needed to fulfill their contracts. In this way, the entire supply chain coordinates the process through which the final product is brought to market. This process requires the efficient exchange of information within and between processes among OEMs, suppliers, and subcontractors. Information exchanges include design and engineering data, financial data, and scheduling information. Interoperability problems can interrupt this process causing delays and increasing costs.

4.2.3 Assembly

The process through which raw materials are converted to the constituent pieces of a motor vehicle is a complex one. The intricacies of automotive design and production call for an array of materials and systems, very few of which are low value-added products. Even the simplest of components may be composed of engineered materials produced through a complex process. What is more, these materials and components are sourced from a diverse variety of industries. These two factors combine to inhibit a concise description of the production process. With this limitation in mind, what follows is a general description of the automotive assembly process. It also important to keep in mind that the transition from one activity to another may also entail a shift in geographic locale and a change in production agent as components move through the supply chain.

As mentioned earlier, motor vehicle parts include thousands of both finished and semifinished parts that are later assembled into 100 major components (e.g., suspension systems, transmissions, and radiators). These components and systems are eventually transported to a plant for assembly. In the past, these parts were traditionally composed of iron and steel. Demand for more fuel-efficient vehicles in recent decades has altered the overall material composition to include plastics and aluminum. On average, 70 percent of the materials in a car are ferrous metals, 9 percent are nonferrous metals, and 21 percent are nonmetals, such as plastic, rubber, glass, and textiles (EPA, 1995).

The manufacturing processes used to produce the thousands of discrete parts and accessories vary depending on the part design and the material used. Different processes may be employed for the production of metal components versus the production of plastic components (EPA, 1995). Most processes, however, include casting, forging, molding, extrusion, stamping, and welding. Once a part has been produced it is either incorporated into a subassembly, a larger component, or directly incorporated into the final product (see Figure 3-1).

Although components and systems assembly occur at many points along the supply chain, final assembly occurs solely at the OEM’s plant. Here, all the parts produced by suppliers are combined into the final product. Body parts are assembled on platforms and move through various painting operations. Afterwards, the body moves along production belts during which time the remaining systems are installed, including power train, engines, interior components, and electrical systems. Next, the assembled vehicle is checked over for defects and flaws. If none are detected, it is tested and readied for shipment. Otherwise, the automobile is returned to the production area to have its faults corrected and then joins other vehicles being readied for shipment.

4.3 THE U.S. AUTOMOTIVE SUPPLY CHAIN

The U.S. automotive supply chain is not easy to characterize. It consists of thousands of establishments ranging in size from 50 to many thousands of employees. In addition, many of the lower-tier suppliers also supply the aerospace and other transportation industries. The sheer size of the industry is overwhelming. Manufacturing employment in the motor vehicle and motor vehicle parts industry was 949,984, or about 6.5 percent of all manufacturing employment, in 2001. Shipments of motor vehicles and motor vehicle equipment amounted to almost $403 billion in 2001, or approximately 10 percent of the value of all manufactured goods (Census Bureau, 2003).

Further complicating an analysis of the automotive supply chain is the complexity of the relationships between customers and suppliers. OEMs design and produce only some of the 15,000 parts and accessories that make up an automobile; they procure others from Tier 1 suppliers. The Tier 1 suppliers can in turn outsource to subtier suppliers. A company's position in the supply chain may differ depending on the part and the customer. Thus, a company that is a Tier 1 supplier of transmissions to one OEM may be a subtier supplier of other parts to the same or other OEMs. Furthermore, these companies, especially the subtier suppliers, often supply parts to customers outside the auto industry.

Production infrastructure, such as hardware, tooling, robots, and software, is also an important part of the supply chain (Fine and Whitney, 1996). The supply chain in the automobile market, therefore, comprises a long, dynamic, and complex network that involves the OEMs, Tier 1 suppliers, subtier suppliers, and companies that provide infrastructure.

Finally, the relationships between the customers and suppliers are changing over time as competitive pressures force changes on the industry. In response to Japanese competition, U.S. automakers are reducing the time it takes to develop a concept into a final product by adopting the philosophies of core competence, concurrent design, and JIT delivery. The adoption of these philosophies is forcing significant changes in the relationships between the OEMs and their suppliers (Flynn et al., 1996).

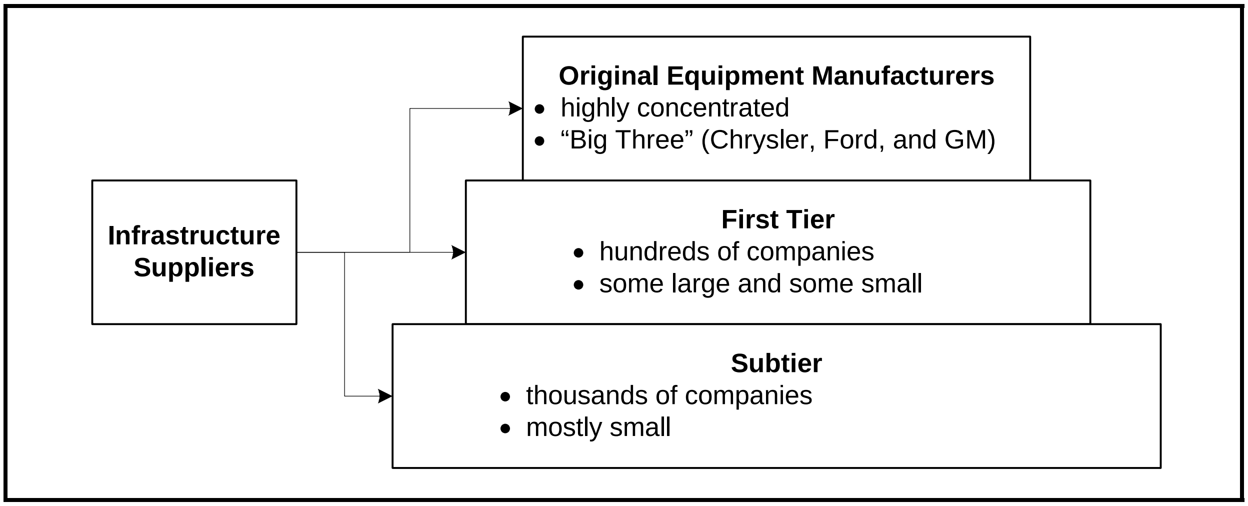
All of these factors complicate the task of clearly identifying and describing the different components of the automotive supply chain. Analysts have proposed two competing characterizations of the supply chain. The first identifies a company's position in the supply chain based on its customers. If a company directly supplies the OEMs, it is a Tier 1 supplier; a subtier company supplies the Tier 1, and so on. However, this definition is difficult to operationalize in today's business scenario because a supplier can simultaneously serve multiple customers. As noted earlier, the same company can act as a Tier 1 supplier on one project and a subtier supplier on another project.

An alternative characterization identifies a company's position in the supply chain based on its products and its role in production. The Tier 1 suppliers are responsible for integrating systems, while the subtier supplies modules or subsets of systems, and the next subtier contributes components and basic material (Phelan, 1997; Flynn et al., 1996).

Despite the limitations of both characterizations, it is useful to choose one to facilitate a discussion of the industry's structure. We use the first method for characterizing the industry. Figure 4-2 provides a simplified view of the overall industry structure. The OEM market is highly concentrated: a few large firms dominate the market. The Tier 1 market is more competitive. There are hundreds of Tier 1 suppliers, some of which are very large with sales of billions of dollars. The subtier market is even more competitive and consists of thousands of smaller companies in addition to a few large companies. Some Tier 1 suppliers also operate on the subtier by either vertically integrating or by supplying parts to their rivals on the Tier 1. Infrastructure suppliers often supply software, hardware, tooling, and robots to all levels of the supply chain. Some of the major players at each level of the automobile supply chain are characterized below. Information on the current trends in integration among these companies and tiers follows.

Figure 4-2. U.S. Automotive Supply Chain

The U.S. automotive industry is less concentrated and more competitive in downstream segments of the supply chain.



4.3.1 OEMs

The "Big Three"—DaimlerChrysler, Ford Motor Company, and General Motors Corporation (GM)—are the major U.S. auto OEMs. As illustrated in Table 4-1, the three OEMs produced over 11 million cars and light trucks in 2002 in North America. They generated over $503 billion in total revenue and employed over 1 million people in 2002.

Table 4-1. "Big Three" Production, Sales, and Employees

GM is the largest U.S. OEM in terms of production and sales.[a]

OEM	2002 North American Production (Cars and Light Trucks) (thousand)	2002 Global Total Revenue ($million)[b]	2002 Global Number of Employees (persons)
DaimlerChrysler	4,999	156,839	365,571
Ford Motor Company	3,928	162,586	350,321
General Motors Corporation	2,288	184,214	350,000

[a]The Production and Revenue numbers come from "Standard and Poor's Auto and Auto Parts Industry Survey" dated December 25, 2003, by Efraim Levy. The employees numbers for Ford and General Motors are from Hoovers Online, 2004, and DaimlerChrysler's figure is from their annual report.

[b]Includes revenue from financial services, insurance, and other revenue.

In an attempt to become more globally competitive, the OEMs are restructuring to cut costs and speed vehicle development. They are increasingly focusing on parts and services in which they possess a clear competitive advantage and are outsourcing other work. In 1997, GM, Ford, and DaimlerChrysler were already outsourcing 30, 50, and

70 percent of their vehicle content, respectively (*Auto and Auto Parts*, 1997). With GM's recent spin-off of Delphi Automotive Systems, GM's percentage of outsourced work will climb to levels more comparable to those of Ford and DaimlerChrysler. Successfully transferring the design and manufacturing of many components to their supplier base requires concurrent design processes that demand effective EDI and interaction between the OEMs and their many tiers of suppliers.

4.3.2 Tier 1 Suppliers

The Tier 1 of the supply chain consists of several hundred companies. Each supplier, depending on its size and diversity, can produce anything as minor as a part for a major system (fasteners for the brake system) or as integral as the entire axle assembly. Many of the larger companies have several divisions and sites and are responsible for producing several parts, systems, components, and accessories. Many suppliers are also increasing their input into designing and manufacturing complete modules or systems rather than just building simple component parts based on OEM specifications. Therefore, sharing data throughout the product life cycle has become an important feature of a Tier 1 supplier's operations.

While OEMs are becoming less vertically integrated, many Tier 1 suppliers are purchasing subtier suppliers to become more vertically integrated. Suppliers are becoming system integrators by combining related components into a single product to provide increased value to the OEM. Many suppliers, eager to deliver a larger share of the content of a vehicle, have become large system integrators by acquiring competitors and related-parts assemblers and operations, giving them the resources, financial strength, and the capacity to serve several manufacturers globally. For example, Lear Corporation purchased Automotive Industries in 1995 and acquired Masland, a maker of carpet and trim, in 1996. Similarly, Johnson Controls, Inc., recently acquired interior components manufacturer Prince in 1996, and Magna International purchased Douglas and Lomason, a seat manufacturer, in the same year (Flynn et al., 1996). Companies pursuing a niche in the system integration market know that they must communicate efficiently to compete effectively.

Tier 1 suppliers often work for multiple OEMs. For example, TRW conducts 23 percent of its business with Ford and 10 percent with GM. Johnson Controls earns 11 percent of its revenues from Chrysler and

10 percent from Ford (NIST, 1997). Table 4-2 lists a few of the largest members of the Tier 1 of the automotive supply chain, their auto industry revenue, and their primary products. The total sales of the top 150 U.S. OEM parts suppliers to North American OEMs in 2000 were $85.5 billion (*Automotive News*, 2001).

4.3.3 Subtier Suppliers

The subtiers of suppliers consist of thousands of smaller companies that work with OEMs only indirectly via other suppliers. An exception would be some of the Tier 1 suppliers that also operate on the subtier by supplying parts to their rivals on the Tier 1. An example is Dana Corporation, which directly supplies Ford (18 percent of its revenue) and Chrysler (11 percent of its revenue). Dana also acts as a subtier supplier to Eaton, which, in turn, supplies Ford. The subtier companies that have no direct OEM business are relatively smaller companies that supply integral components or modules to the Tier 1 without having much interaction with the OEMs. Table 4-3 lists a few of the larger subtier suppliers and their total sales (including nonauto sales).

4.4 TRENDS IN U.S. AUTOMOTIVE SUPPLY CHAIN INTEGRATION

As discussed earlier, the predominant manufacturing and engineering philosophies adhered to by the automobile industry, such as Lean Manufacturing, necessitate efficient communication across entities that produce automotive parts. Supply chain management (SCM) activities are now as integral to operations as manufacturing; efficient management of the chain can reduce costs and delays that may add thousands of dollars to end product prices and eat away at corporate profits. Three basic categories of SCM activities are currently being pursued by OEMs and suppliers: business-to-business (B2B) exchanges and markets, long-term relationships and alliances, and real-time communications links.

Business-to-Business Exchanges and Markets. The Internet plays an essential part in current SCM activities, improving time-to-market cycles, lowering inventories, and reducing costs (LaLonde, 2000). It has done so in two ways: B2B exchanges and real-time communications.

Table 4-2. Characteristics of Prominent Tier 1 Suppliers
Tier 1 suppliers vary in terms of their size and the range of parts and components they produce.

Company	North American OEM Auto Sales 2002 ($millions)	Worldwide OEM Auto Sales 2002 ($millions)	Primary Products
Delphi Automotive Systems	19,656	25,527	Brakes, steering, suspension, cockpit components, wire harness
Visteon Automotive Systems	12,168	16,900	Steering, chassis, electrical, energy and engine management, interior, electronic components
Lear Corporation	9,504	14,400	Interior systems, seats, instrument/door trim panels, overhead, flooring and acoustic systems, electronic/electrical systems
Johnson Controls, Inc.	7,687	13,653	Seats, interior trim, batteries
Magna International, Inc. *(NOTE: Acquired Donnelly Corp. in October 2002)*	7,650	12,172	Interiors, exteriors, body and chassis systems, seats, mirrors, closures, electronics, engines, transmissions
Dana Corporation	5,340	7,315	Structural, engine, chassis, sealing, brake and fluid system products
TRW, Inc.	4,950	9,900	Steering suspension, braking, engine components, fasteners, occupant restraint systems, electronic safety and security
Robert Bosch Corporation	4,390	19,085	Safety systems, break systems, fuel injection systems, electrical and electronic equipment
Denso International America, Inc.	3,769	15,348	HVAC, electrical and electronic components, filters, fuel management systems
American Axle & Manufacturing Holding, Inc.	3,341	3,480	Chassis and driveline systems, forged products
ThyssenKrupp Automotive AG	3,171	6,218	Body systems, chassis modules, powertrains, suspensions, steering systems, drivetrains
Collins & Aikman Corp.	3,147	3,886	Cockpit modules, instrument panels, flooring and acoustic systems, fabrics, trim, convertible top systems and accessory mats
DuPont Automotive	2,700	5,400	Engineering polymers, fibers, refrigerants and finishes
Valeo, Inc.	2,372	8,787	Electronic/electronics, thermal systems, transmissions
GKN Automotive, Inc.	2,348	4,733	Constant velocity products, powdered metal components, traction systems

Source: *Automotive News*. "Top 150 OEM Parts Suppliers to North America." Detroit: Marketing Services Inc. As obtained on January 19, 2004. <http://www.autonews.com/images/dataCenter/1448.pdf>.

Table 4-3. Characteristics of Prominent Subtier Suppliers
Subtier suppliers tend to be smaller and supply various parts to Tier 1 suppliers.

Company Name	1999 Worldwide Sales ($millions)	Primary Products
Textron Automotive, Inc.	463.1	Plastic products and custom injection moldings; ABS components, sensors and actuators, solenoids, valves, and controls
Intermet, Inc.	956.8	Aluminum and magnesium die-cast parts
Lectra Systems, Inc.	250 to 500	CAM systems, CAD systems, design hardware, design software
Illinois Tool Works, Inc.	9,333.0	Batteries and parts, door systems and trim, molded components, filtration products
Amtec Precision Products	90.5	Wire splices, assembly material, ignition components
Auburn Gear, Inc.		Axles, differentials, transfer cases, gears, and linkages
Veridian Engineering	225.0	Design hardware, engineering design, and prototyping
Cascade Die Casting Group, Inc.	60.0	Dies, molds, tools and equipment, filters (air, oil, fuel, pumps, tubings, hoses, and fittings)
Breed Technologies, Inc.	1,395.3	ABS components, airbag components, antitheft systems, sensors and actuators

[a]Estimated by Gale Research Inc. (1997) based on prior year data.

Sources: Gale Research Inc. 1997. *Ward's Business Directory of U.S. Private and Public Companies*. Detroit: Gale Research Inc.

Information Access Corporation. 1998. Business Index [computer file]. Foster City, CA: Information Access Corporation.

Chilton Company. 1997. Automotive Industries Annual Source Guide. <http://ai.chilton.com>.

B2B electronic commerce market exchanges in automotive parts have been in rapid development since the late 1990s. Several are currently functioning, including Free Markets and Covisint, the latter having the backing of North American OEMs and a handful of Japanese and European automakers. These online marketplaces are not just bazaars for parts and products, but also are portals through which companies can see a clear picture of the supply chain's needs at any time (Memishi, 2000). By participating in these marketplaces, companies hope to reduce inventories and speed up the process through which parts and vehicles are designed. The benefits are perceived to lie not in the contracting of parts, but rather in the development of new products and better management of manufacturing and distribution. Analysts at Morgan Stanley estimate that the cost savings could reach as high as

$2,750 per vehicle for companies that participate fully in these exchanges (Memishi, 2000).

The goal of these B2B initiatives is for the industry to create efficient supply chains that can produce a car in 20 days. It is still unclear, however, if the industry will be able to reach that goal and if so, how (Kiesel, 2000; Sedgewick, 2001). Although these initiatives, particularly Covisint, have both policy and financial backing from the major automakers, suppliers are wary of participating. For example, Covisint was developed and will likely remain controlled by large automakers, a fact that does not sit well with some suppliers. These suppliers have two additional concerns: first, they fear that these markets, which employ reverse auction techniques, will eat into their profits. Second, many have already invested heavily in establishing EDI and PDM links with long-term customers; they are wary of investing in another system that may not contribute significantly to their profits.

There is no question that B2B exchanges will be employed by the industry to facilitate supply chain collaboration, but there are questions about their short-term penetration and adoption, particularly in an environment of preexisting real-time communications links and emphasis on alliances and long-term relationships.

Long-term Relationships and Alliances. Long-term relationships and alliances are becoming increasingly common in this industry as manufacturers see the benefits of close, long-term ties with their suppliers. By forging stronger ties, companies work together to refine parts and components, and can more easily and quickly respond to shifts in demand and unclog bottlenecks (Landry, 1998). Companies participating in alliances deepen their ties beyond the contractual level, developing common interests and business goals and becoming more comfortable with information sharing. Companies within alliances are more likely to share business and production information through integrated systems than companies that work together on a contract-by-contract basis. An example of this would be DaimlerChrysler's Extended Enterprise policy through which the automaker works closely with parts makers on future vehicle programs and establishes long-term supply relationships (*Automotive News*, 1998).

Real-Time Communications Links. Many OEMs and suppliers have invested in automated supply chain technologies that make important business data visible to suppliers, distributors, and customers. These systems are viewed as being essential to maintaining a firms' competitiveness in the industry. Examples of the communications tools include EDI systems, PDM systems, electronic mail, and direct links between corporate information systems.

4.5 INTEROPERABILITY ISSUES IN THE AUTOMOTIVE INDUSTRY

This section provides an overview of interoperability issues affecting manufacturing systems in the American automotive industry. For this study, we focus on interoperability associated with the production phase of a vehicle's life cycle, a time when engineering design has been completed, vendors have been chosen, and contracts put in place.

At the production stage of the product life cycle, most of the information exchanged between an OEM and its suppliers concerns ordering and schedule requests, acknowledgements of messages received, ship notices, and order tracking. To assure on-time delivery there is also information exchange with external logistics functions (i.e., warehousing and shipping). Parallel to all this product-oriented data is a flow of financial information that drives accounts payable and receivable, which in turn drives payments and clearing transactions with banks.

The supply chain network in the automotive industry is quite complicated, with significant differences in business practices above and below the first tier. First tier suppliers do almost all their business within the automotive sector, which means they have a relatively small number of OEM customers. Suppliers to the first tier, however, deal with a large number of customers, who operate both inside and outside the automotive industry. Thus, as you move further away from the customer in the automotive supply chain, dependence on automotive business decreases while the complexity of information flow increases. Supply chains in other industries that produce complex discrete products, such as aerospace and major appliances, are generally similar.

4.5.1 Customer–Supplier Interoperability

From the point of view of understanding automotive interoperability, two different scenarios are important. In the first scenario, the customer and supplier exchange high volumes of information, a situation found between OEMs and their most important first tier suppliers, as well as between first tier firms and their larger second-tier suppliers. In the second scenario, the volume of information exchange is low. This situation occurs often in customer-supplier interactions in the lower tiers as well as between OEMs and minor suppliers.

The OEMs have insisted on the use of EDI by all of their suppliers, regardless of the transactions volume, and will likely continue to do so in the foreseeable future, for three main reasons. First, OEMs have large legacy systems that are integrated into EDI applications. Switching costs would be very high. Second, the OEM's IT personnel have much experience with optimizing EDI systems. This human capital is valuable. Third, for high-volume communication, EDI requires less bandwidth for the OEMs than XML.

First- and second-tier firms have been much less insistent on pushing EDI into their supply base, especially for suppliers that produce a low volume of information exchange transactions. In these instances, EDI's high installation costs may make it uneconomical to deploy, and some other means is found to communicate between customer and supplier. One solution is for the first- or second-tier customer to translate its data streams into plain English and send the information via e-mail or fax. A second solution is for the customer to direct the data stream (in EDI format, perhaps) to a third-party that does such translations. A third possibility is for the supplier to purchase a low-end EDI system that can receive messages and output them in plain text.

Another option is developing that within a few years *may* improve interoperability in low-volume situations. In this scenario, EDI- and XML-formatted messages are translated into one another during transmission over a secure internet link or through a web portal. This option would allow customers to send and receive information in EDI format and suppliers to send and receive messages in XML format.

To affect interoperability under these conditions, the *cost/benefit* ratio for interoperability must be lowered to a point where individual companies can make a business case for implementing whatever changes would be required to achieve system interoperability with their trading partners. XML represents such a solution. In terms of cost, XML does not require large investments in new hardware, software, or human capital.

4.5.2 Interoperability with Third-Party Logistics Companies

It is common in the automotive industry for warehousing and shipping to be handled by third parties who specialize in logistics. One reason for this trend is cost. It is often more cost-effective to outsource services to specialists. A second reason is that third-party logistics firms can provide value-added services that cannot exist with direct shipping between suppliers and customers. One common service is “cross docking.” In this case, a logistics firm picks up parts from multiple suppliers and reorganizes the loads so that the right mix of parts goes to the OEM. One advantage of this technique is cost reduction resulting from more fully loaded trucks. Another advantage is that the right mix of parts arrives, at the right time, at the OEM’s loading docks. Taking cross docking one step further, logistics companies also provide “sequencing” services. Here, different parts are arranged so that a particular combination of components can move together, from a truck into the assembly process. This frees the OEM from the effort of reorganizing parts that come off a truck as those parts move through vehicle assembly.

While the inclusion of third parties and value-added services complicates data flow, the basic issues of interoperability mirror that of direct communication between supplier and customer. Logistics companies working between Tier 1 suppliers and OEMs have sophisticated systems that are compatible with the “local” standards their customers use. EDI communication is used to coordinate all the necessary activity. However, logistics below the Tier 1 level usually do not justify EDI-based communication. While some Tier 2 companies are EDI-capable, most are not. Fewer and fewer EDI-capable companies appear below the Tier 2 level. As with direct suppliers to customer communication, system interoperability in this domain will require the development of XML-based communication standards.

4.5.3 Emerging E-business Trends in the Automotive Industry: Implications for Interoperability

Two developments in e-business may have consequences for interoperability. The first is electronic catalogues (e-catalogues). This development is important because the move from paper to bytes can change how business is done. Customers can check prices and availability from a larger pool of potential suppliers. Because publishing lags are eliminated, information on price and availability will be current. A greater variety of complex information can also be provided and accessed. For instance, companies are now including AutoCAD files as a part of their e-catalogues, thus allowing customers to easily incorporate a part into a design. As with EDI and XML, the impact of e-catalogues differs from the Tier 1 up and from the Tier 1 down. Above the Tier 1, contracts tend to be long term. It is uncommon for an OEM, in the middle of a production run, to shop for a new supplier. In any case, the industry's emphasis on buying complex components limits the number of potential Tier 1 suppliers available to an OEM. As a result, the impact of digitizing catalogues is, and will likely remain, small.

Below the Tier 1, however, contracts are likely to be shorter term, and any potential customer will have a relatively wide choice of suppliers. As a result, e-catalogues may very well affect who gets automotive business and on what terms. However, the power of e-catalogues can only be realized if customers can query a wide variety of catalogues. Complicating the problem is that the best value for a buyer may come from outside of its traditional industrial buying base. As a result, either standards or trustworthy translation systems are needed to allow catalogue searching across a very wide range of companies and industrial sectors. In essence, to capitalize on the potential of e-catalogues, a high level of interoperability is needed for e-catalogues and e-catalogue searching systems.

The second important development is the rise of industry portals. These are becoming commonplace in many industries, and efforts to develop portals that can serve the automotive industry are well under way; however, the much hyped Covisint was recently bought by Compuware after marginal success. From the point of view of interoperability during the production phase of the life cycle, portals are interesting because of their potential to consolidate data flow and, thereby, perhaps change demand for interoperable systems; however, demand must be used as a barometer for startups.

Without a unified portal, communication between trading partners is negotiated by those partners. Whether EDI, XML, or a proprietary format, each trading partner pair decides on its own how to communicate. True, partners will probably use an industry standard, but no matter how good the standard, variation will always creep in to each individual decision. And each company involved has to make that decision with each of its trading partners. With a portal, however, the situation changes. Now each company makes an information format decision *with only one entity*, the portal. The greater the number of tiers at which the portal operates, the greater the degree of data uniformity within the industry. The greater the uniformity, the lower the cost of interoperability. We do not know if automotive industry portals will succeed or to what degree. We know, however, that the cost of interoperability is inversely related to the success of a uniform portal. We believe that lower costs for interoperability may change business practices, but we cannot predict how. In any event, the success of portals and their impact on interoperability should be watched carefully.

4.5.4 Engineering Changes

An inevitable part of production is dealing with engineering changes (ECs). These are the formal product changes that are instituted in response to some officially recognized need for a change in the product. An EC may be initiated because of a request from the end user, the manufacturing floor, marketing, or any other interested party. The common element is that each EC must be at least approved by the engineering staff overseeing the product. Then the EC must be approved by others and distributed to all affected parties, which, depending on the affected product, will include such groups as customers, suppliers, tooling design and manufacture, the manufacturing floor, inspection (quality control), and so on.

Interoperability is an issue for ECs because they now nearly always include electronic data, especially CAD data defining the geometry of the part. Other controlling data may also be provided electronically, such as effective dates, approvals, and existing completed parts disposition. ECs are relatively rare compared to the business data described above. They are usually generated at unpredictable intervals, although the rate is normally much higher in the time surrounding a product's early production. The data they contain also tend to be much more complex and unstructured than business data. Hence exchange methods are substantially different from the EDI or XML approaches.

5 The Electronics Supply Chain

5.1 OVERVIEW OF THE ELECTRONICS SUPPLY CHAIN INDUSTRY

The electronics industry is an aggregation of several widely disparate product segments, from radar equipment to biomedical devices. A combination of factors, including mass customization, rapidly shrinking products and product life cycles, rapid inventory depreciation, complex multi-source supply chains, and rising demand, have created a highly competitive industry. Electronics products are brought together by commonality in components, manufacturing technologies, or consumption patterns. Because of this diversity, the report will focus on two product segments—personal computers and communications equipment (i.e., routers)—that have made a more pronounced effort to develop integrated supply chains throughout their manufacturing cycle. The interoperability section focuses only on computer production; however, the issues in the computer industry are similar to the problems found in integrating the networking equipment supply chain.

With almost $430 billion in sales in 2001, or approximately 10 percent of the value of all manufactured goods, and 1.6 million employees, electronics is the third-largest manufacturing industry (behind chemical and transportation equipment) (U.S. Census Bureau, 2003). Table 5-1 lists 1997 computer and electronics product sales and employment by industry groups. Of total electronics sales, semiconductors and electronic components made up the majority of sales followed by computers and peripherals and telecommunications equipment. The NAICS codes separate the electronics market into six different product sectors. The following is a brief description of each category and the products included in each sector.

Table 5-1. U.S. Electronics Sales by Industry Group

NAICS Code	Industry Group	2001 Sales (10^6)	2001 Number of Employees
3341	Computer & Peripheral Equipment	89,528	193,109
3342	Communications Equipment	102,004	301,732
3343	Audio & Video Equipment	8,942	27,142
3344	Semiconductor & Other Electronic Components	124,215	566,864
3345	Navigational, Measuring, Medical & Control Instruments	97,169	468,114
3346	Manufacture & Reproducing Magnetic & Optical Media	7,612	41,805
334	Total Computer and Electronic Products	429,471	1,598,766

Source: U.S. Census Bureau. January 2003. 2001 Annual Survey of Manufacturers. Washington, DC: Government Printing Office. Available at < http://www.census.gov/prod/2003pubs/m01as-1.pdf>.

Computer and peripheral equipment manufacture is the third-largest sector of the computer and electronics industry, consisting of over 20 percent of the total value of shipments. This grouping includes personal computers, servers, workstations, and other peripheral equipment, such as monitors and scanners. This industry sector is further discussed in Section 5-2.

Similar in size to computer and peripheral equipment, communications equipment manufacturing consists of such industries as telephone unit manufacturing, equipment for radio and television broadcast, and both wireless and non-wireless networking. This sector claims almost 24 percent of total computer and electronics product sales and is discussed in Section 5-3.

The audio and video equipment sector includes firms manufacturing audio and video products such as televisions, camcorders, VCRs, and DVD players. Most production of audio and video equipment takes place overseas, reducing production of domestic audio and video equipment to roughly 2 percent of total computer and electronics products sales. This report does not focus on audio and video equipment because of the predominance of overseas manufacture and the relatively small size of the market.

The semiconductor and other electronic components sector contains firms engaged in the production of printed circuit boards (PCBs), transistors, transformers, integrated circuits, and other electronic components. At over 28 percent of total shipped value, the semiconductor and other electronic components sector makes up the largest percentage of electronics sales. Semiconductors and electronic components are used across the electronics sector, and a significant portion of components go into telecommunications and computers and peripherals. For this reason, this sector will be included in the supply chain analysis as well.

The navigational, measuring, medical, and control instruments sector is a grouping of various products including biomedical products, automatic environmental control, watch/clocks and components, measuring and controlling devices, and industrial process and control instruments. The wide diversity and lack of commonality with other segments has led us to exclude these products from our study, despite its significant share of 22 percent of the computer and electronics products sales.

The manufacture and reproducing magnetic and optical media sector includes firms engaged in record, tape, compact disk (CD), and software reproduction, as well as magnetic and optical recording. Manufacturing and reproduction of magnetic and optical media account for only about two percent of total electronics sales.

Because of the diversity of the computer and electronics products industry, a coherent analysis requires focusing on one or two specific sectors. In addition, the computer and peripheral and communications categories have made significant strides in integrating their supply chain in an attempt to create a virtual "company." For these reasons, this report focuses on the computer and peripheral and communications businesses in the computer and electronics products sectors, as well as the semiconductor industry that acts as a key supplier to both businesses.

5.1.1 Brief History of the Electronics Industry

Until the invention of the microprocessor in 1971, computers were discrete pieces of equipment used primarily for data processing and scientific calculations. They ranged in size from minicomputers to mainframe systems. The microprocessor enabled computer engineers to develop smaller microcomputers that had enough computing power to perform many kinds of business, industrial, and scientific tasks. The large demand for microprocessors led to high-volume production and a dramatic reduction in cost, which promoted their use in many other applications (including household appliances and automobiles). Continued advances in integrated circuit technology gave rise to very-large-scale integration (VLSI), which substantially increased the circuit density of microprocessors. This technological advance, coupled with cost reductions from improved manufacturing methods, made feasible the mass production of personal computers (Britanica, 2001).

By the 1980s, microprocessors had stimulated computerization of a variety of consumer products, including programmable microwave ovens and thermostats, clothes washers and dryers, self-tuning television sets and self-focusing cameras, videocassette recorders and video games, telephones and answering machines, musical instruments, watches, and security systems. Since the 1980s, microprocessor-based equipment has also proliferated, ranging from automatic teller machines and point-of-sale terminals in retail stores to automated factory assembly systems, communications equipment, and office workstations (Britanica, 2001).

5.1.2 Electronics Manufacturers

Table 5-2 lists the largest electronics manufacturers. These firms generated almost $664 billion in total revenue and employed over 2.5 million people in 2003. The top five electronics manufacturers alone produced over $380 billion in total revenue and employed nearly 1.4 million people.

5.2 COMPUTER AND PERIPHERAL EQUIPMENT

The production of a personal computer (PC) requires interaction and coordination among industry participants throughout the manufacturing cycle. Computers consist of thousands of discrete components, systems, and accessories that must function together as an integrated unit. These components and subsystems are typically designed and manufactured by numerous companies that are members of a complex supply chain. The supply chain companies must coordinate their activities to ensure that the finished product functions according to design goals.

5.2.1 The Anatomy of a Microcomputer

A computer performs high-speed mathematical or logical calculations and assembles, stores, correlates, or otherwise processes coded information in accordance with predetermined software programs (Petska-Juliussen and Juliussen, 1996). The structure of a PC is complex. A typical PC consists of thousands of parts and peripherals (both interacting and external) that must be designed to be compatible

Table 5-2. Largest Electronics Firms

Company Name	2003 Total Revenue ($million)[a]	2003 Number of Employees
International Business Machines Corporation (IBM)	89,131.0	255,157
Siemens	86,467.0	417,000
Hewlett-Packard Company	73,061.0	141,000[b]
Hitachi	69,343.0	320,528
Sony	63,264.0	161,100
Matsushita Electric Industrial	61,681.0	288,324
Toshiba	47,191.8	165,776
NEC	39,788.4	145,807
Fujitsu	38,529.1	157,044
Koninklijke Philips Electronics N.V.	36,505.0	164,438
Intel	36,141.0	79,700
Motorola	37,068.0	97,000[b]
Lucent Technologies	8,470.0	34,500

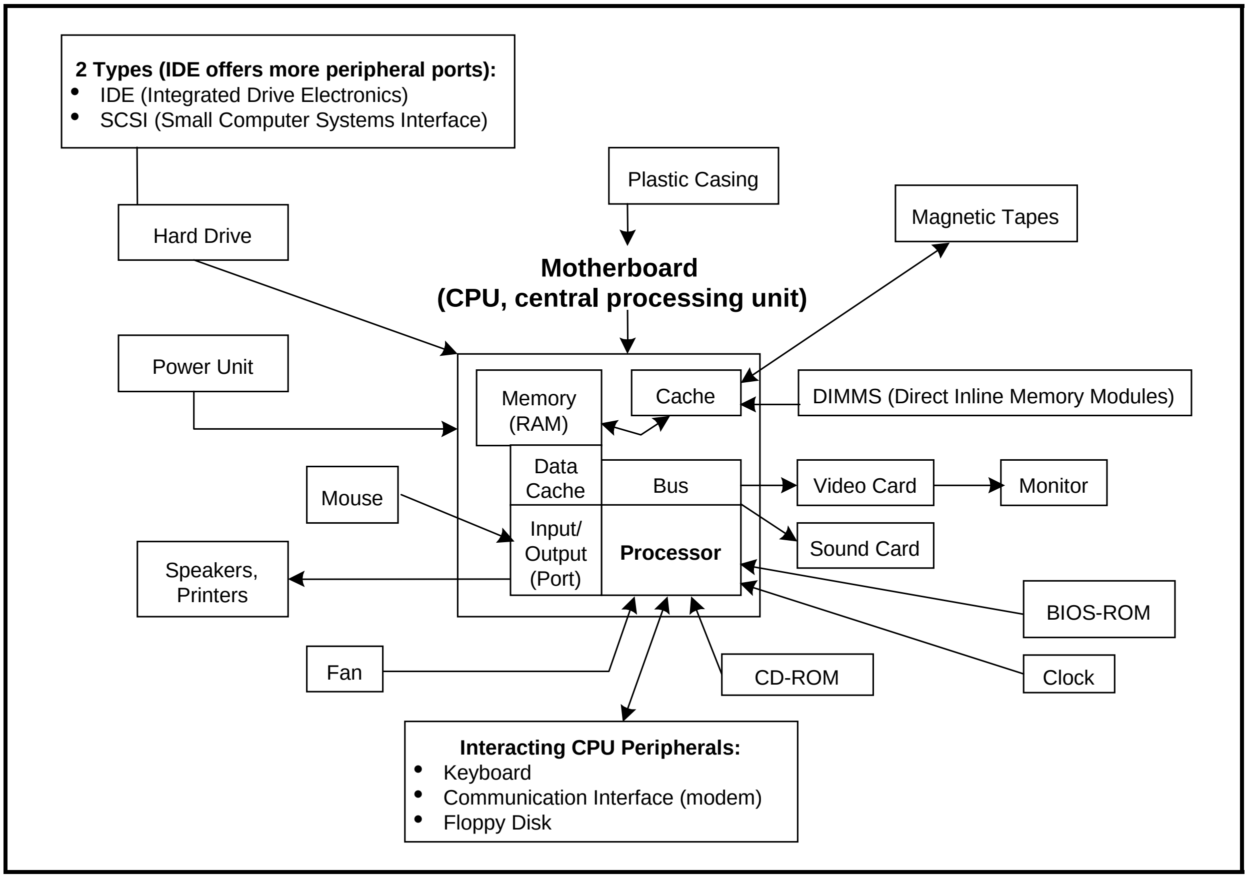
[a]Includes revenue from software sales and services.

[b]Revenue and number of employees in 2002 values.

Source: Hoovers Online. 2004. Available at <http://www.hoovers.com.

with other hardware and software drivers. There are three major types of computer peripherals: mass storage devices, output devices, and input devices. Mass storage devices store data, both temporarily and permanently, as well as software programs. Output devices display the results of computer calculations. Finally, input devices are used to enter data into a computer system. As shown in Figure 5-1, a PC comprises several major systems, each of which contains many subsystems, components, and interfacing parts (e.g., microprocessor ICs, memory ICs, discrete devices, and wires). Similarly, external peripheral devices, such as a mouse and monitor, consist of multiple parts and subsystems that must work together. Consequently, we view production of peripherals and their incorporation into a finished computer system as integral parts of the computer supply chain.

Figure 5-1. Computer Components

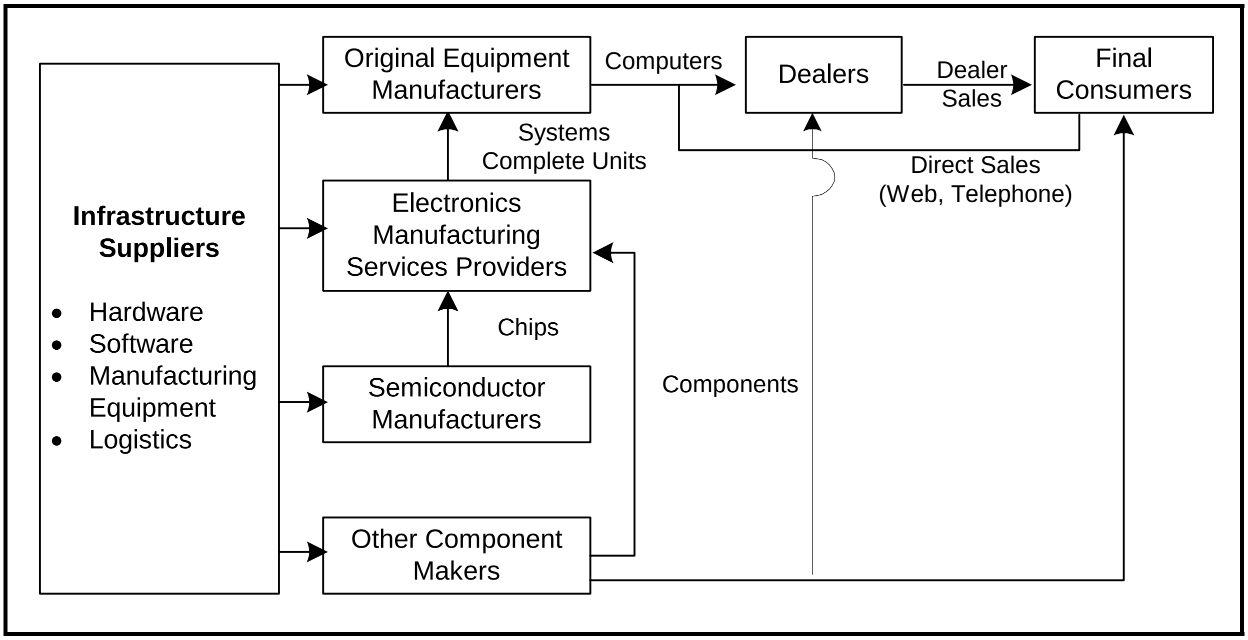


Source: Englander, Irv. 1996. *The Architecture of Computer Hardware and Systems Software*. New York: John Wiley & Sons, Inc. pp. 12, 170, 305.

5.2.2 Computer and Peripheral Products Supply Chain

The computer and peripheral supply chain maintains a complex network of relationships between customers and suppliers. OEMs design and produce only a few of the hundreds of parts and accessories that make up a finished product. Many OEMs contract out manufacturing and other functions to electronics manufacturing service (EMS) firms. Both OEMs and EMS firms procure most parts and accessories from Tier 1 suppliers. Tier 1 suppliers can in turn outsource to subtier suppliers. A company's position in the supply chain may differ depending on the part and the customer. A Tier 1 supplier of integrated circuits to one OEM may be a subtier supplier of other parts to the same or other OEMs or EMS firms. Figure 5-2 demonstrates a simplified representation of the computer industry supply chain.

Figure 5-2. U.S. Computer Manufacturing Supply Chain
A rapidly evolving supply chain leads from raw materials to the final consumer.



5.2.3 Computer and Peripheral Products Trends

The PC industry has been characterized for some time as a leader in very short product life cycles, rapid time-to-market, high material cost content, low margins, and increasing functionality. Widespread competition and widely available core technology means that no company can maintain a price advantage for long. In fact, sales prices for new PC models have typically dropped 1 to 2 percent per week after market introduction. The recent slowdown in the PC market implies that price erosion behavior is expected to continue for some time.

As a result of these characteristics, PC manufacturers have adopted one or more of the following manufacturing strategies:

- outsourcing to EMS firms, for manufacturing of printed circuit assemblies (PCA), assembly of finished systems (“box build”), or both;
- outsourcing to Original Design Manufacturer (ODM) companies that provide turnkey final assemblies (this outsourcing method is very common with notebook PCs, primarily through Asian ODM companies);
- build to order and mass customization;
- configure to order;
- global sourcing and supply; and

- inventory reduction (especially important in a business with high material content and significant price erosion).

Outsourcing. "PC companies" are increasingly focusing on services, such as advertising and product development, in which they possess a clear competitive advantage. There are essentially four outsourcing models in use today within the PC industry (see Figure 5-3). First, some of the large OEMs still maintain at least part of their PCA manufacturing internally (lower left corner of the diagram). Second, there is an increasing move to EMS outsourcing (lower right). Third, some firms prefer to keep manufacturing in-house while contracting design and/or sales operations. Finally, there have been many successful examples of outsourcing entire products to ODM companies (upper right). The supply chain implications for these three models are very different.

Figure 5-3. Outsourcing Models within the PC Industry

Design	Manufacturing: Internal	Manufacturing: External
External	• Contracted design, or sales of complete designs (e.g., Intel PC motherboards)	• ODM model for custom components or assemblies • Purchase of standard, off-the-shelf parts
Internal	• Traditional OEM manufacturing business model	• Traditional EMS model

Manufacturing

Outsourcing to EMS Providers. Many PC companies began operation with no internal PCA manufacturing (e.g., Dell, Gateway, and Micron Electronics) and have consistently used EMS firms for the supply of printed circuit assemblies PCAs. Recently, most of the other PC companies (e.g., Compaq, IBM, HP) have decided to follow the same strategy for at least part of their business. Cellular phone manufacturers (e.g., Motorola, Ericcson, Nokia) appear to be following the same path. In 2000, Bear Stearns projected that 70 percent of total value added would be outsourced by 2005 (Bear, Stearns & Co. Inc., 2004). A few of the important characteristics of this business model from a supply chain standpoint are as follows:

- The OEM usually maintains control of the design of the board, including the approvals for changes to the approved vendor list (AVL) for all components used in the manufacture of the board. Infrequently, the EMS provider is given approval to make changes to certain classes of components on the board without approval, but this has been generally limited to less expensive commodity components.
- The selection of the EMS manufacturer of the board is frequently made late in the design process, providing limited opportunities for the EMS provider to give recommendations on design for manufacturing (DFM) or design-for-supply-chain changes.
- Supplier management responsibilities are frequently split between the OEM and the EMS (they sometimes overlap).
- The manufacturing and test process is frequently designed, controlled, and maintained by the OEM, and then provided to the EMS company for execution. Production test hardware and software are routinely provided by the OEM. In fact, it is not uncommon to see fully dedicated lines within the EMS factories (i.e., these lines are only intended to build boards for one OEM customer).
- Ownership of defective products is not always clear, because it is not always easy to separate a design-related failure from a manufacturing execution-related one. Consequently, the OEM has much more interest in monitoring daily production defect rates than it would with another type of supplier.

These characteristics, as well as the fact that few standards exist, combine to create a supply chain environment that is exponentially more difficult to manage than the traditional internal manufacturing structures.

Outsourcing to ODM Companies. ODM outsourcing means that the ODM provider owns the product design, sourcing, assembly, and testing. These are custom products that are designed to match an OEM customer’s overall product specification. The specification usually remains at a form, fit, and function level, and decisions regarding how to achieve these results (either in product design, procurement, or in manufacturing) nearly always rest with the ODM.

The ODM outsourcing model has been used within the electronics industry for years, and is also common in other industries, such as automotive and defense. Within the PC industry, a few early examples of this outsourcing were in the areas of power supplies, option cards, keyboards, and displays. In the last 8 years, this outsourcing model has become increasingly common for entire PCs, especially notebook PCs.

All of the major PC manufacturers in the United States have adopted this practice for some or all of their notebook production.

The important characteristics of outsourcing to ODMs from a supply chain standpoint are the following:

- The ODM has virtually complete autonomy in decisions around the design of the product, the sourcing of raw material, the manufacturing, and the product testing. In fact, it is not unusual for the ODM to follow design or manufacturing practices that would not be allowed within the OEM customer's own design or manufacturing operations (or in their EMS outsourcing).
- The ODM is involved from the beginning of the development process, and owns all aspects of the product design and the manufacturing process. The ODM also owns most of the component supply chain, although certain components are occasionally selected and controlled by the OEM customer.
- The ODM exclusively handles supplier responsibilities.
- The ODM nearly always has complete control of the manufacturing and test process.
- Ownership of defective products nearly always belongs to the ODM. In terms of supplier quality management, the OEM generally treats the ODM as they would any other supplier.

Obviously, the ODM outsourcing model has a much simpler supply chain structure than the EMS outsourcing model. There are some indications that OEM companies are moving more toward the ODM model for products that had previously been built by EMS providers.

Build to Order, Configure to Order, and Mass Customization. To reduce levels of finished goods in the supply chain, PC companies have been implementing production systems in various versions of configure to order. Common terms for these systems are "build to order" (BTO), "configure to order" (CTO), "mass customization," and "postponement manufacturing." While these terms are frequently defined differently across the industry, the goal is the same—to reduce the inventory between the manufacturer and the end customer. In building standard Stock Keeping Units (SKUs) for the retail market, this would likely imply a strategy of building those standard units in small batches in a highly responsive manner (short lead times and dependable supply times). In building for a specific customer (e.g., in direct sales), this probably means building the final unit after the customer orders it, including customizing it to that specific customer's needs. The issues and opportunities associated with these strategies will be discussed in more detail in a later section.

Inventory Reduction. Given the combined pressures of short product life cycles, rapid time-to-market, and significant price erosion, effective inventory management is a critical success factor for the industry. Dell has set the standard in this area for years, and has recently dropped their total inventory to a low of 5 days.[13] In addition to improving the management of material within the manufacturing supply chain, companies are also focused on reductions in raw material through strategies such as supplier hubs and vendor-managed inventory (VMI). Companies are also focused on reductions in the distribution channel through strategies such as BTO, CTO, and direct sales to customers. For example, an OEM selling computers through traditional channels has an added burden of inventory obsolescence and price erosion in the channel (another 4 to 8 weeks of inventory)—a penalty that is not a factor for direct OEM sales to the end customer.

Global Sourcing and Supply. Given the characteristics already discussed, global sourcing and supply is a natural requirement. The general philosophy in the PC industry is to build as much of the product as possible in or near the target market. Additionally, developing regions of the world frequently offer much lower labor rates, as well as other financial investment incentives. Consequently, the large EMS companies have all undergone significant global expansion, and this trend is likely to continue. One implication of this global expansion is that applicable operating standards must be worldwide in scope.

5.2.4 Computer and Peripheral OEMs

The producers of finished products in computer and peripherals manufacturing, also called “boxmakers,” include IBM, Hewlett-Packard, Dell, Compaq, Sun Microsystems, Apple, and many others. As noted earlier, OEMs typically contract out manufacturing so that they can focus on product development and marketing. Table 5-3 illustrates the total revenue, revenue generated from hardware sales, and employment figures for several major U.S. computer and peripheral manufacturers in 2003.

[13] Dell Earnings Announcement, February 15, 2001.

Table 5-3. Major Microcomputer and Peripherals OEMs

OEM	2003 Sales ($million)[a]	2003 Hardware Sales ($millions)	2003 Number of Employees
IBM Corporation	$89,131	$27,456[a]	355,421[a]
Hewlett-Packard	$73,061	$59,230	142,000
Dell Computer	$41,444[b]	N/A	39,100
Cisco Systems, Inc.	$18,878	N/A	34,000
Xerox	$14,704	N/A	61,100
Apple Computer, Inc.	$6,207	N/A	10,912
Sun Microsystem	$11,434		36,100
3Com Corporation	$932.9		3,300

[a]2002 information used.

[b]2004 information used.

Source: Hoovers Online, 2004. Available at <http://www.hoovers.com>.

Tier 1 Suppliers. The Tier 1 of the supply chain consists of several hundred companies. Each supplier, depending on its size and diversity, produces a variety of products, including casing for electronics products, subassemblies, and peripheral equipment. Many of the larger companies have several divisions and sites and are responsible for producing several parts, systems, components, and accessories. Many suppliers are also increasingly manufacturing complete modules to OEM specification. Therefore, sharing data throughout the product life cycle has become an important feature of a Tier 1 supplier's operations.

The firms that provide electronics manufacturing services within the electronics industry have exploded in importance within the past 4 or 5 years. These largely unknown firms, including Solectron and Flextronics, consider their core competency to be management of high-volume, low-cost fabrication and assembly operations. Expanding out of an initial niche producing assembled, or "stuffed," printed circuit boards for OEMs, they have gained enough expertise and credibility to begin taking over the entire assembly process. In 1999, EMS firms sold services worth an estimated $28.1 billion (Lee, 2000); in 2003, the combined revenue of Flextronics, Solectron, and Sanmina-SCI was over $34 billion (Hoovers Online, 2004).

While OEMs are disaggregating many manufacturing processes, many contract electronics manufacturers are becoming more vertically integrated. For example, Sanmina acquired Hadco Corporation, Interworks, and Nortel Networks Enterprise Design Services Operations (Sanmina, 2001). Researchers have estimated that there were more than 100 mergers, acquisitions, and strategic alliances between contract electronics manufacturers and other companies in 1999 (Advanced Manufacturing, 2000). Many EMS providers have also begun to contract out portions or all of their manufacturing process, allowing them to focus on core competencies. Many EMS providers have also outsourced inventory management and flow to electronics distributors and other infrastructure contractors. These supply chain management programs are often employed by start-up manufacturers because they do not have the resources to manage components and inventory (Carbone, 2000). Table 5-4 provides a list of the largest EMS providers.

Table 5-4. Largest EMS Providers

EMS	2003 Total Revenue ($million)[a]	2003 Number of Employees	Primary Manufacturing Services
Flextronics International Ltd.	$ 13,378.7	95,000	Design, manufacturing, and distribution services
Solectron Corporation	$ 11,014.0	66,000	Product design and prototyping, printed circuit board and systems assembly, and repair services
Sanmina-SCI Corporation	$10,361.4	45,008	Multilayered printed circuit boards, backplanes, cables, and complete systems
Celestica Inc.	$ 8,271.6[b]	40,000[b]	Complex printed circuit assemblies and systems
Benchmark Electronics, Inc.	$ 1,630.0[b]	6,380[b]	Complex PCBs and other electronic subsystems
Plexus Corp.	$ 807.8	4,800	Product design and engineering, circuit board assembles, integrated circuits, memory chips, and other electronic components
IEC Electronics Corp.	$ 48.2	182	PCBs and electronic assemblies
Jabil Circuit, Inc.	$ 43.0	26,000	PCBs and other electronic components and systems

[a]Includes revenue from software sales and services.

[b]In 2002 values.

Source: Hoovers Online. 2004. Available at <http://www.hoovers.com>.

Subtier Suppliers. The subtiers of suppliers consist of thousands of smaller companies that work with OEMs indirectly via other suppliers. The subtier companies that have no direct OEM business are relatively small companies that supply integral components or modules to the Tier 1 without having many interactions with the OEMs. Table 5-5 lists a few of the larger subtier suppliers and their total sales, including nonhardware sales.

Subtier suppliers often work for multiple OEMs. For example, Intel supplies CPUs to virtually every microcomputer manufacturer, including Dell Computer Corporation, Gateway Inc., NEC Corp., IBM Corp., and Hewlett-Packard Company.

Semiconductor Suppliers. The integrated circuits that control computation (i.e., CPUs), display, memory, input/output, and other functions are the most expensive components. Further, their proper operation is the most critical for the performance of the finished computer system. The major suppliers of these semiconductor chips are large, economically powerful firms such as Intel, Motorola, and Texas Instruments. Maintenance of logistics and communications linkages between the semiconductor suppliers and EMS suppliers and/or OEMs is one of the key requirements of the computer industry's supply chain integration. Intel is the largest of the semiconductor suppliers, with about $30 billion in 2003 sales, but hundreds of smaller chips suppliers interface with the supply chain in the same way as the giants.

Other Component Suppliers. A computer is not nearly as complex a machine as an automobile; computers contain hundreds of unique parts versus thousands in the case of autos. Nonetheless, suppliers of internal drives, modems, transistors, diodes, power supplies, housings, and even knobs and lights are an important part of the supply chain. An unexpected shortage in production of any of these components could easily shut down production of finished computers, resulting in customer dissatisfaction and lost sales. Some component suppliers, such as data storage makers Seagate Technology and Quantum, are Fortune 500 companies, while many others are quite small in terms of sales and employment.

Infrastructure Suppliers. As is the case in the automotive sector, a number of infrastructure suppliers provide manufacturing equipment, hardware, and software to the various segments of the computer industry supply chain. The infrastructure suppliers may be focused on a single

Table 5-5. Characteristics of Prominent Subtier Suppliers
Subtier suppliers tend to be smaller and supply various parts to Tier 1 suppliers.

Company Name	2003 Worldwide Sales ($millions)	Primary Products
Intel	$26,764.0[a]	PC microprocessors, flash memories, embedded chips
Texas Instruments, Inc.	$ 8,383.0[a]	Digital signal processors, analog ICs, digital ICs, logic chips, microprocessors, microcontrollers
Micron Technology, Inc.	$ 3,091.3	DRAMs, flash memory, Rambus DRAM, Synchronous DRAM products
Advanced Micro Devices, Inc.	$ 2,697.0[a]	PC microprocessors, embedded chips, nonvolatile memories
Molex Incorporated	$ 1,843.1	Plugs and other connectors
Vishay Intertechnology, Inc.	$ 1,822.8[a]	Capacitors and resistors, diodes, optoelectronics, transistors
National Semiconductor Corp.	$ 1,672.5	Analog chips, SOC components
Amkor Technology, Inc.	$ 1,639.7[a]	Packaging and test services
AVX Corporation	$ 1,134.1	Passive electronic components
Winbond Electronics Corp.	$ 917.8[a]	Data communication, memory, microcontrollers, multimedia, PCs, speech, telephony, visual communication ICs
International Rectifier Corp.	$ 864.4	MOSFETs (metal oxide semiconductor field-effect transistors), diodes, and rectifiers
Creative Technology, Ltd.	$ 701.8	PC sound cards, graphics accelerator cards, MP3 players, PC multimedia upgrade kits
MEMC Electronic Materials, Inc.	$ 687.2[a]	Silicon wafers
KEMET Corporation	$ 447.3	Tantalum and multilayer ceramic capacitors
Technitrol, Inc.	$ 406.4[a]	Electrical contacts and assemblies
Methode Electronics, Inc.	$363.1	Connectors, current carrying distribution systems, and automotive electronic controls
DuPont Photomasks, Inc.	$ 323.1	Photomasks
Entegris, Inc.	$ 248.8	Wafer carriers, storage boxes, fluid management components, and transport systems
BMC Industries, Inc.	$ 248.1[a]	Aperture masks, photo-etched and electroformed products
Advanced Energy Industries, Inc.	$ 238.9[a]	Conversion and control products
FSI International, Inc.	$ 88.8	Microlithography systems
Kopin Corporation	$76.8[a]	Gallium arsenide wafers

[a]In 2002 values.

Source: Hoovers Online. 2004. Available at <http://www.hoovers.com>.

level in the chain, as is the case with semiconductor equipment manufacturers, or they may support components makers, EMS providers, and OEMs. With the rapid pace of technological change and short product life cycles that define the electronics industry in general, these firms must maintain close working relationships with both R&D and manufacturing functions in the firms they support. A great deal of commonality in technology across the electronics sector ensures that infrastructure suppliers work within many of the subsectors, as well as in less closely related industries.

5.3 COMMUNICATION EQUIPMENT INDUSTRY

The communication equipment industry comprises companies manufacturing wire telephone and data communications equipment, radio and television broadcast devices, wireless communications equipment, and other manufacturing communications equipment. An important focus of this study is the supply chain for the development and integration of routers and other computer network hardware, which are key components in communications equipment.

Communication equipment products may be stand-alone or board-level components of a larger system. In 2003, the value of shipments for communication equipment totaled $125 billion. Table 5-6 lists total value of shipments for the different sectors within the communication equipment industry. The two largest segments of this industry, communication systems and equipment and other telephone and telegraph equipment and components, constitute over 70 percent of the communications industry.

The largest segment of the industry is communication systems and equipment, accounting for 50 percent of total communication equipment sales. This sector includes equipment for amateur, meteorological, fixed, telecommand, telemetry, radionavigational and locational, and aeronautical communications; and mobile radio and microwave signals. Communication systems and equipment also includes antenna systems, fiber optics, and other carrier equipment. However, this industry tends to be more monolithic and less dynamic than other sectors in the communications equipment industry.

Table 5-6. Shipment Values for Communications Equipment Industry

NAICS Code	Description	2002 Shipments ($\$10^6$)	1997 Number of Employees
3342101	Telephone switching and switchboard equipment	7,368	26,268
3342104	Carrier line equipment and modems	4,730	22,334
3342107	Other telephone and telegraph equipment and components	17,648	52,961
3342201	Communication systems and equipment (except broadcast)	25,600	122,654
3342203	Broadcast, studio, and related electronic equipment	3,300	21,187
3342903	Intercommunications systems, including inductive paging systems (selective calling)	367	1,519
3342901	Alarm systems	2,993	13,790
3342902	Vehicular and pedestrian traffic control equipment and electrical railway signals and attachments	808	6,901
3342	Communication Equipment Manufacturing	62,813	267,614

Sources: U.S. Department of Commerce. 1999b. *1997 Economic Census*. EC97M-3342A through EC97M-3342C. Washington, DC: U.S. Government Printing Office.

U.S. Department of Commerce. 2003. *Current Industrial Reports. Communication Equipment*. MA334P(02)-1. Washington, DC: U.S. Government Printing Office.

Accounting for over 20 percent of total sales, the second-largest segment in the communication equipment industry is other telephone and telegraph equipment and components. Other telephone and telegraph equipment and components includes telephones, data communications, voice frequency and voice call message processing, facsimile communication, and other telephone and telegraph equipment. In 1999, data communications equipment[14] made up over 69 percent of total other telephone and telegraph equipment and components, and in the same year networking equipment sales grew 17 percent to $37 billion (U.S. Business Reporter, 2000). However, communication network manufacturers' shipments dropped approximately 23 percent between 1999 and 2002.

5.3.1 Definition of a Computer Network

A computer network is a group of two or more computer systems linked together. There are several different types of computer networks, including local-area networks (LANs) and wide-area networks (WANs). Computers in a LAN are geographically close together, whereas

[14] Data communications equipment consists of routers, gateways, bridges, terminal servers, concentrators, and other networking equipment.

computer systems in a WAN are farther apart and connected by telephone lines or radio waves. Computers connected to a WAN are often linked through public networks, such as the telephone system. They can also be connected through leased lines or satellites. The largest WAN in existence is the Internet. There are three types of networks: converged, wireless, and broadband. A converged network transmits voice, data, and video over a single network. Wireless networks transmit voice and data traffic over wireless networks. Broadband networks are primarily used to transmit data traffic through the Internet. Equipment for broadband includes cable modems, digital subscriber lines (DSL), satellites, and fiber optics (U.S. Business Reporter, 2000). Figure 5-4 illustrates a simplified network and some of the computer networking hardware involved.

Table 5-7 defines some of the hardware used in the computer networking industry. Routers, the largest segment of the industry, are specialized computers that determine the best route for data packets over a network and offer enhanced security for the data. Cisco Systems maintains 75 percent of the router market. Switches offer a faster alternative but lack the security features of a router. With the development of low-cost switching devices, the importance of routers in networking is waning (U.S. Business Reporter, 2000).

5.3.2 Computer Networking Current Trends[15]

From 1999 to early 2001, most major telecommunications hardware producers divested manufacturing to EMS providers. In 2000, Nortel Networks divested PCB assembly and repair services to Solectron. The 4-year supply agreement, valued at over $10 billion, is the largest outsourcing relationship to date (Nortel, 2000). At the same time, Nortel Networks switched from their traditional, in-house distribution process to third-party logistics and transportation contractors (Zuckerman, 2000). Other telecommunications hardware producers that have recently outsourced production include Lucent Technologies, CISCO Systems, and Nortel Networks.

[15] The information in the next few subsections was provided by Rodney Walker of Altus Consulting, a subcontractor to RTI on this project.

Figure 5-4. Network with Router

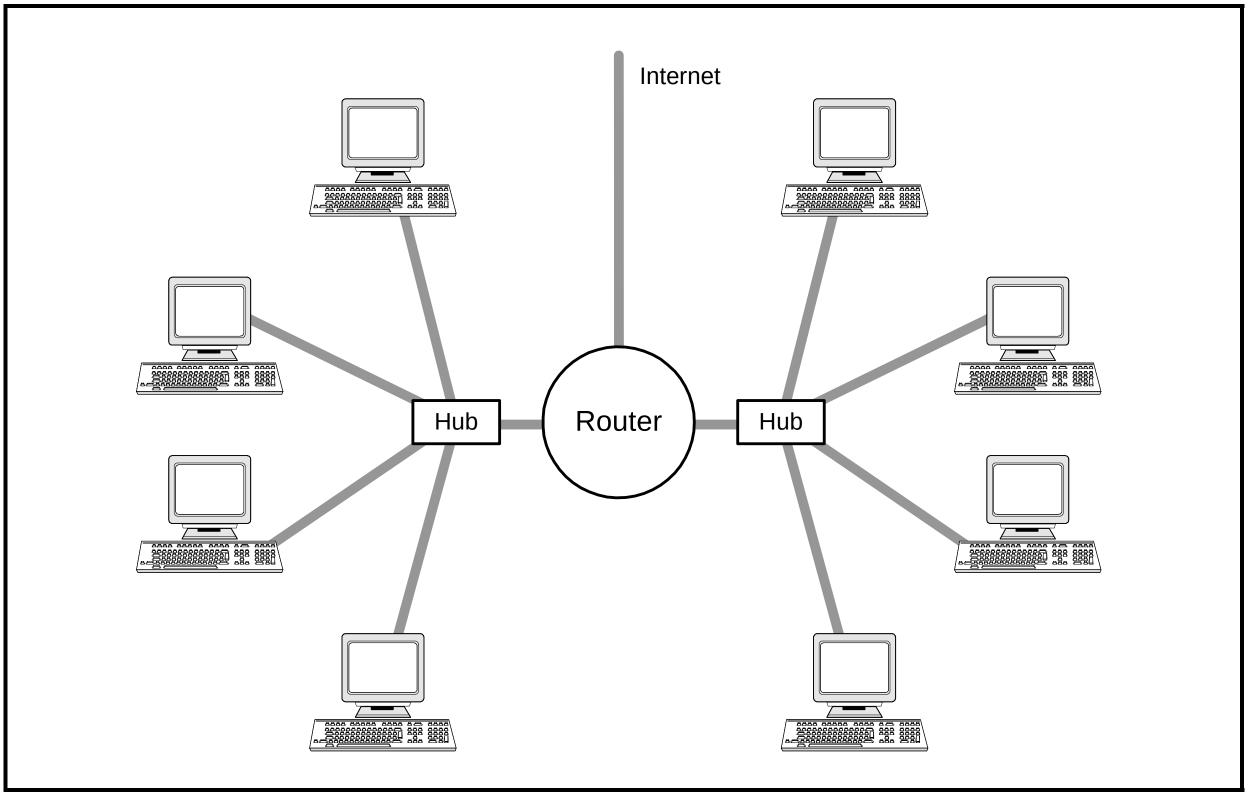


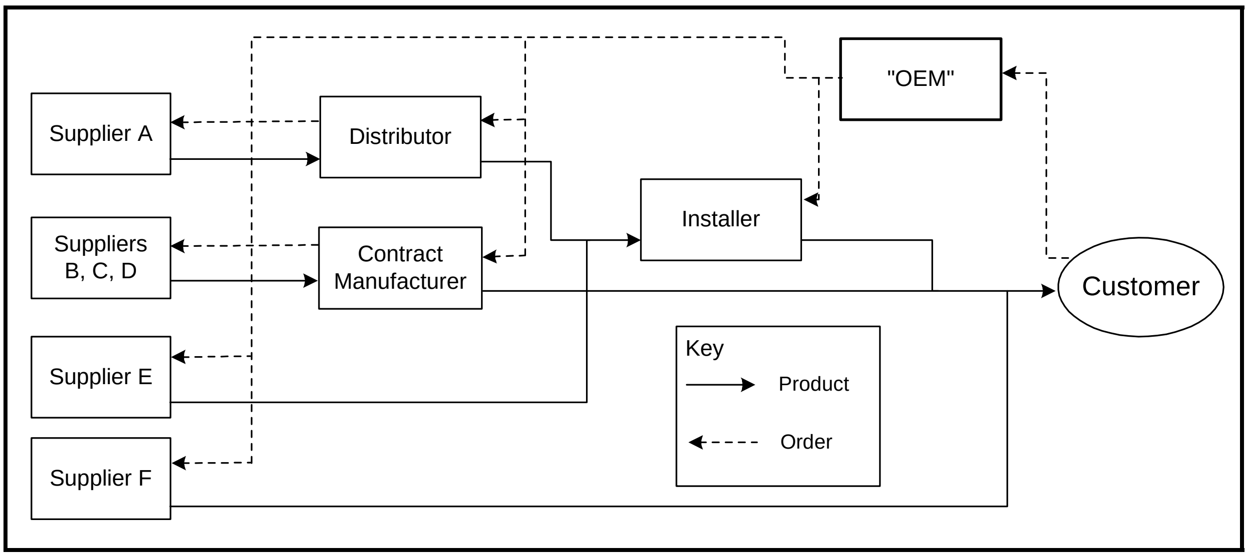
Table 5-7. Hardware Used in Computer Networking Industry

Hardware Type	Definition
Hubs	• Concentrate network signals from many devices • Track MAC addresses and route packets to destinations (intelligent hubs only)
Repeaters	• Connect similar types of networks together • Perform simple signal amplification takes place
Bridges	• Connect different types of networks together • Translate network packets from one network type to another
Routers	• Direct traffic to its destination • Implement delivery policies
Switches	• Filter and forward packets between LAN segments • Support any packet protocol

5.3.3 Computer Network Hardware Supply Chain

Most companies in the computer network supply chain divest most or all of manufacturing and logistics to EMS firms. The OEM's role is to define products and fulfillment processes, marketing, customer interfaces, research and development, and management of information flow across the supply chain. Figure 5-5 illustrates a simplified network hardware industry supply chain. In some cases, the OEM takes on the role of the installer.

Figure 5-5. Simplified Network Hardware Industry Supply Chain



Computer Network OEMs. Many of the computer networking equipment OEMs are the same as the computer and peripheral equipment OEMs. These OEMs generated over $45 billion in total revenue and employed 131,948 people in 2003; however, since 1999, sales figures have dropped by almost 35 percent and employment has decreased by 38 percent. Table 5-8 lists employment and sales figures for the largest computer network OEMs. The top five networking

Table 5-8. Large Computer Network OEMs

Company	2003 Sales ($$10^6$)	2003 Number of Employees
Cisco Systems, Inc.	$ 18,878	34,000
Nortel Networks Corporation	$10,560[a]	36,960[a]
Lucent Technologies, Inc.	$ 8,470	34,500
Avaya Inc.	$4,338	16,900
3Com Corporation	$933	3,300
Brocade Communications Systems, Inc.	$ 562[a]	1,332[a]
Juniper Networks, Inc.	$ 547[a]	1,542[a]
Adaptec, Inc.	$ 408	1,527
MRV Communications, Inc.	$ 253[a]	1,400[a]
Terayon Communication Systems, Inc.	$129[a]	487[a]
Total	$45,078	131,948

[a]In 2002 values.

Source: Hoovers Online, 2004. Available at <http://www.hoovers.com>.

hardware manufacturers produced $43 billion in total revenue and employed 125,660 people. Similar to the computer and peripheral industry, competitive pressures have led networking hardware manufacturers to outsource most of their subassembly and final product assembly to EMS providers. This outsourcing leaves computer networking hardware firms with R&D, market development, and sales functions, in addition to overall control of the supply chain.

Computer Networking Subtier Suppliers. Because of the similarities of the input parts and components of the PC and computer networking equipment, subtier suppliers are largely the same for both industries. Similarly, computer-networking equipment shares other subtier suppliers with the computer industry. For example, IBM produces ASIC chips used to produce Junipers routers. Table 5-5 provides a more complete listing of subtier suppliers for both industries.

5.4 INTEROPERABILITY ISSUES IN ELECTRONICS

The trends and challenges described earlier indicate a set of important interoperability issues within the PC industry's manufacturing supply chain. A few of the more important issues are

- inventory management in a distributed supply chain,
- time-to-market,
- efficiency,
- BTO/CTO support, and
- partnering vs. standards.

5.4.1 Inventory Management

The essential challenge of inventory management is having just enough material at the right time. The penalties of not having enough material are missed customer commitments, lost revenue opportunities, last-minute revisions to production plans, and overall reductions in factory performance. The penalties of having too much material are increased working capital requirements, write-downs in inventory value, and the increased potential for ultimate material obsolescence. Obviously, neither state is desirable, but companies generally operate under the belief that too much material is better than not enough. At the same time, OEMs have been trying for years to reduce their inventory levels. In the PC industry, the material cost is 60 to 80 percent of the purchase price of the unit. Small improvements in inventory management can create positive results at the bottom line.

As more OEMs have outsourced manufacturing to EMS companies, inventory management has become increasingly difficult, but no less important. A few of the key factors in this new environment are

- unique material,
- reduced visibility of the demand, and
- less capable information systems across the supply chain.

Many of these are well-known issues in inventory management, but the trends in the industry have increased their importance.

Inventory Management—Unique Material. At a board level within the PC industry, a large number of components (resistors, capacitors, connectors, etc.) are standard within the industry and among customers (see lower left quadrant of Figure 5-6). Standard inputs allow the EMS supplier to share inventory across multiple products. Unfortunately, although the majority of components on the board are fairly standard, the highest-cost components tend to be unique to either the customer or the customer’s specific product (top half of Figure 5-6). If the unique component is inexpensive, the logical strategy is to always over-buy.

Figure 5-6. Inventory Uniqueness

	Customer Standard—One They Are Likely to Use on Another Product	Customer "Special"—One They Are *Not* Likely to Use on Another Product
Industry "Special"—Custom and/or Proprietary	***Examples: Some ASICs; some PC motherboards; many option boards*** Risky for a supplier to hold, since it is unique to a customer. Risk mitigated some by the fact that other products could use the material. Information management important, especially for high-dollar parts.	***Examples: LCD panel on a notebook PC; some ASICs; raw PC board*** Extremely risky for a supplier to hold, since there are no other customers for the material. Good candidate for a BTO/CTO strategy at the suppliers. Critical information management requirements.
Industry Standard—One that Other Customers Are Likely to Use	***Examples: Many components, including commodity passive components; Intel processors and chipsets early in the cycle*** Low inventory risk—surpluses can be sold to other customers. Best candidate for vendor-managed inventory programs. Lowest IM criticality.	***Examples: Components that are near the end of their production life, such as last-generation processors and memory*** High inventory risk. Frequently managed through one-time "lifetime buys." Information management important, especially for high-dollar parts.

However, these components tend to be expensive, and they can become a significant liability for the manufacturer. Unused material at the end of the production life can sometimes be allocated for field service requirements, but the rest is scrap. Effectively managing this type of material has always been a challenge for the OEM, and it is worse in the EMS outsourcing environment, where the visibility is much lower.

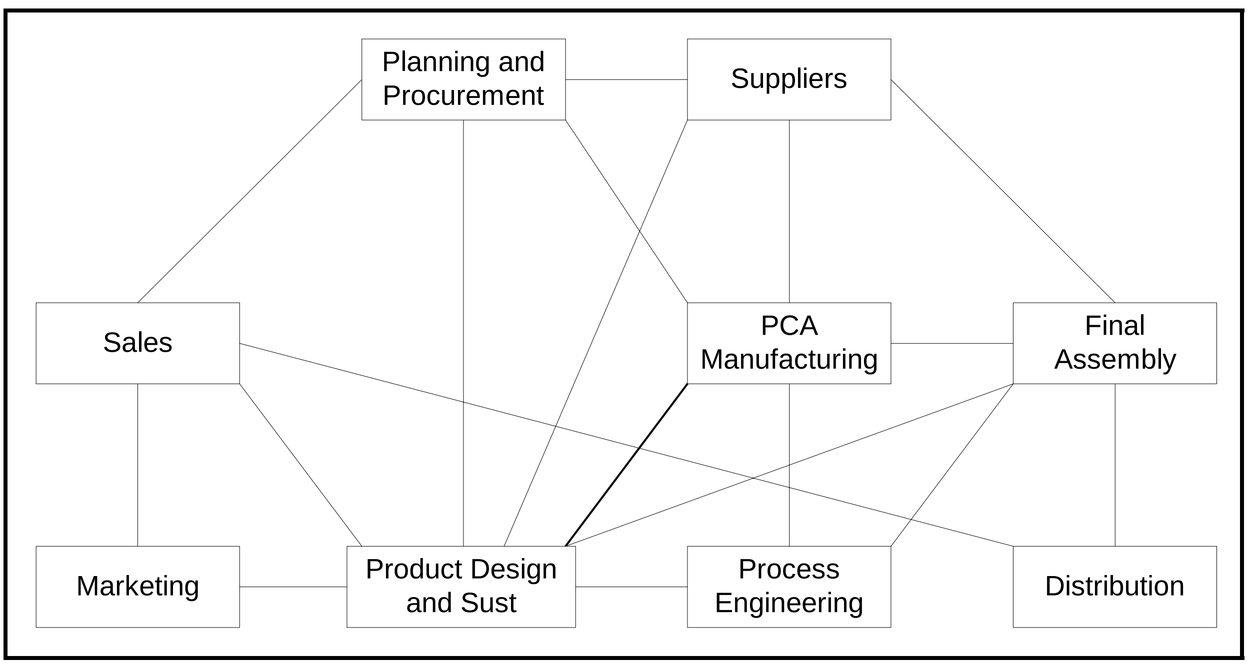
Inventory Management—Reduced Demand Visibility. Sales forecasts in the PC business are never accurate. There are examples of products that were never profitable just because the forecast was too high, and there are numerous examples of successful products that gave up a potentially dominant market position because the forecast was too low. For years, OEMs have worked to improve the accuracy of their forecasts, but it is still considered by most to be a significant issue.

Outsourcing has aggravated an already challenging situation. Within an OEM, improvement teams have focused on tactics such as shortening the forecast-to-execution loop (to reduce delays as well as to minimize the multiple levels of management judgment of the forecast), improving the information systems, and implementing VMI and BTO systems. One of the keys to making all of this work is an effective and well-connected information management system.

These systems have been challenging enough to implement within the large OEMs, and are more difficult to achieve with multiple EMS companies that are running on different systems.

Inventory Management—Less Capable Information Systems. Within the last 6 or 7 years, most large OEMs began projects to rebuild their internal planning systems using software from SAP, Baan, i2, Manugistics, and many others. The scope of these planning systems can be enormous, as shown by the diagram (Figure 5-7) of typical information flows. For the information flows that are within an enterprise, it can be a difficult but achievable project to define the desired business processes, system transactions, and reporting. It can be much more difficult for flows that go outside of the enterprise, as in the case of outsourcing PCA manufacturing to multiple EMS companies. Fortunately, much work has already been done in the areas of EDI among suppliers, manufacturing, and distribution.

Figure 5-7. Typical System Information Flows



It is unclear how successful these internal projects have been. Several large OEMs have announced that they have abandoned or restructured their projects. The outsourcing that has occurred in parallel within many of these companies has clearly aggravated the situation.

One of the larger challenges in implementation within a company is the "change management" aspect of getting an entire company to define and adopt a new set of processes. By outsourcing a key part of the overall operation, this issue becomes much larger in scope. Interfaces to different systems can be developed, but each one adds a new layer of complexity to an already complex system. There must be a core set of interoperability standards across the supply chain, and organizations such as NEMI, IPC, RosettaNet, and others are working to put them in place. Given the difficulties that OEMs have had within their own companies in developing and implementing standards of this type, the challenge in implementing them across an entire industry is enormous. However, these standards are absolutely essential to having the right type of information systems.

5.4.2 Time-to-Market

As noted earlier, time-to-market is especially critical in the PC industry. Product life cycles have shortened to a few months, with at least one example of a product that had a life cycle of 2 weeks. Given weekly price erosion in the range of 1 to 2 percent, a large percentage of the life cycle profit is made within the first few weeks after product introduction. The manufacturer must get the new product to market as quickly as possible, and then ramp production volumes up rapidly to meet market demand.

OEMs have focused on time-to-market improvements for years. A primary area of focus has been to improve the participation of manufacturing in the design process to avoid issues that might delay or limit production at introduction. Over 10 years ago, the problem was frequently described within the industry as design "throwing the product over the wall" to manufacturing. Within the last 10 years, OEMs have made significant progress in removing the old barriers between design and manufacturing. These improvements have resulted in product designs that were much more likely to be ready for manufacturing, and vice-versa.

Unfortunately, the move to EMS outsourcing has created new barriers between manufacturing and design. These organizations are now parts of two different companies, the manufacturing standards are unknown, and the EMS selection decision is frequently not made until late in the design cycle. In addition, there are new problems regarding simple communications between the OEM's design organization and the EMS company. There are few standards for communication of design data between the companies, and different design organizations within an OEM frequently have different standards.

This inconsistency creates delays while the EMS provider translates the data for use in its systems, limits the amount of automated error-checking that it can do, and generally transforms what should be an automated process into a manual one. All of this means that manufacturing is less prepared to build the product, the product is not necessarily ready for production, and engineering changes take much longer to implement. NEMI is in the process of putting together an industry forum on the topic, titled "The Perfect BOM." This forum will be a good step in focusing industry attention on the issues, and hopefully it will lead to projects to define and adopt standards for communication of design data across the supply chain.

A related issue is the management of ECNs and AVLs. In the normal model of EMS outsourcing, the OEM design organizations maintain control of the design (i.e., they are the originators for all ECNs and supplier changes). This plan adds to delays in responding to issues that might arise during production and creates communication issues due to incompatible systems between the companies.

Interestingly, the ODM outsourcing model is much more likely to provide better performance in overall time-to-market and time-to-ramp. The key reasons are as follows:

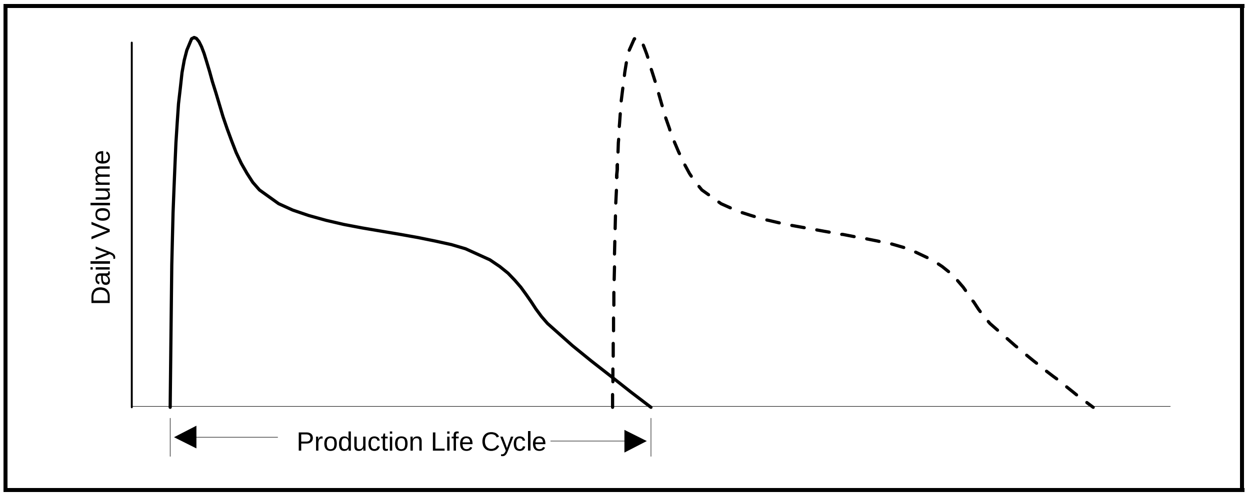
- The ODM company generally already has a base product design completed when it is selected by the OEM, and may already have some experience in building the product.
- The ODM fully owns the design and can quickly detect and correct any design errors that arise during manufacturing start-up.
- The critical information flows between design and manufacturing are all within ODM, eliminating the issue of incompatible systems.
- The ODM has the opportunity to have manufacturing involved with engineering from the beginning.

Given the lack of standards and partnering in the EMS outsourcing model, the ODM model has a structural advantage in the area of time-to-market and time-to-ramp.

5.4.3 Efficiency

One argument in support of EMS outsourcing is that the EMS company can bring more manufacturing assets to bear during peak demand periods, and can put those assets to use elsewhere during the periods of low demand. Within the PC industry, demand swings on individual products can be severe, as shown in Figure 5-8.

Figure 5-8. Sample Consumer PC Demand Profile



Immediately after a design's release to production, the desire is to quickly ramp production up to a peak level to capture the early market opportunity. Following this initial surge, the demand tends to be much more constant throughout the remainder of the product life cycle. Near the end of the product's production life cycle, production is quickly scaled down to clear out inventory in advance of the next product introduction (the dotted line in Figure 5-8). Production swings of this magnitude can be challenging for a manufacturer.

At the peak of production, a manufacturer might need 10 lines of production, going down to 3 lines for the ongoing production period, and less than 1 line at the tail-end prior to the next product's introduction. This effect seems to be the most pronounced on consumer retail PCs, but exists to some extent in the other products. Additionally, production is sometimes shut down due to parts shortages or product issues. In these cases, there is a production lull resulting in excess manufacturing capacity, followed by a volume spike requiring extra capacity to catch up after the problem has been resolved.

The EMS outsourcing model can theoretically provide more manufacturing flexibility than an OEM during such production swings. Unfortunately, this statement assumes that the production is standard enough that a line can smoothly switch from building products for one OEM to another. As noted earlier, these standards do not exist, and it is not uncommon for an EMS company to dedicate lines to production for one OEM. In this case, these potential flexibility advantages are limited by the amount of commonality across the production lines. It seems that there are only two acceptable end-states to this issue: either partnering between OEMs and EMS companies, or a comprehensive set of manufacturing standards that are used at least within an industry segment.

5.4.4 BTO/CTO Support

BTO, CTO, engineer-to-order, and similar terms all refer to strategies aimed at improving responsiveness and removing inventory from the supply chain. Dell's 5 days of inventory demonstrates how important these processes can be. Effective implementation of these systems requires real-time information on the availability of all subassemblies, including PCA boards that are being assembled by an EMS. This communication should ideally happen automatically to ensure timeliness and accuracy.

An effective BTO/CTO system as part of a direct sales operation will eliminate channel inventory (which is a liability given the industry's price erosion profiles), and can allow the OEM to more tightly match demand and supply. This need has been recognized in the industry for some time, but it is not clear how far companies have progressed in implementing solutions. Dell is probably the leader in this area, although it appears that the system connections with their suppliers are still more manual than automated. The need for BTO/CTO is likely to become more important during the current softening in the PC market.

5.4.5 Partnering vs. Standards

Electronic OEM manufacturing organizations have historically been slow to see the value of standards. In the early days of Surface Mount Technology (SMT) manufacturing, each manufacturer believed that it had a competitive advantage in this area. Manufacturers tended to be unwilling to share information, and they had little interest in industry standards. For example, at one time, most large OEMs had their own custom formulation for solder paste. They believed that it gave superior results, that it gave them an edge over their competition, and did not care that the custom formulation was expensive and had a long procurement lead-time. The product also had a relatively short shelf-life, and companies frequently faced the decision of either shutting down production to wait for the next batch to arrive, or to take a risk on one of the standard formulations of paste.

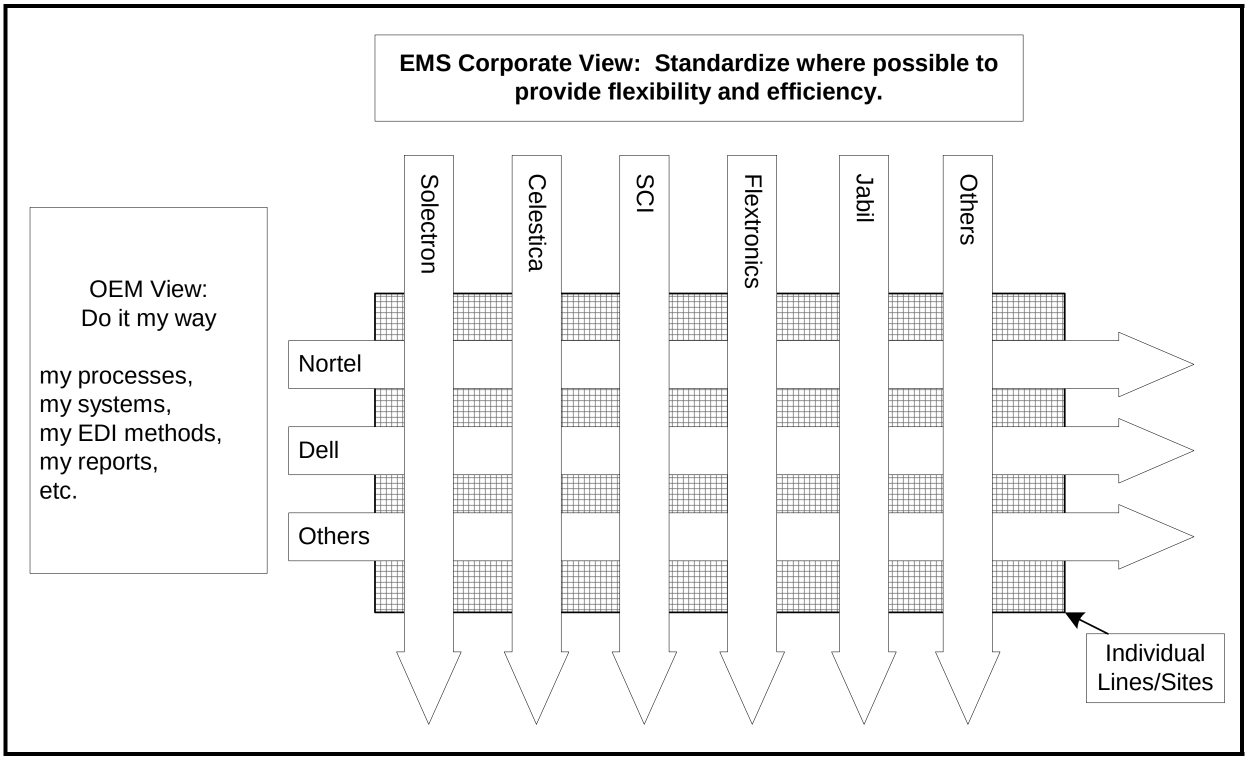
In the last 6 or 7 years, OEM manufacturers have become more interested in collaboration with their peers through organizations such as NEMI. This collaboration has been assisted by stabilization, in-process technology, and by OEMs challenging their manufacturing organizations to become more efficient.

In some ways, the outsourcing trend is threatening to slow down the rate of collaboration. Whereas many of the OEMs eventually decided that manufacturing technology was no longer a competitive advantage and became more willing to collaborate, some companies became more protective.

However, significant pressures within the industry are likely to result eventually in either OEM/EMS partnerships or widespread industry standards. The intersection points in Figure 5-9 are individual EMS sites and lines. As noted earlier, OEM customers generally require these individual sites and lines to meet their specific requirements in processes, systems, reporting, and so forth. At the same time, the EMS corporate group usually likes to have each site operate in the same way as other lines and sites within the company to gain flexibility and efficiency. (As noted earlier, it is common today for EMS companies to dedicate specific lines to individual OEMs in order to provide the "common look" desired by the OEM. This solves the problem from the OEM's view, but it severely restricts the flexibility that the EMS provider has in shifting products across lines to match peaks and valleys in a product's demand.) The current slowdown in the industry is likely to increase the pressure for standardization within the EMS. The squeeze point between the OEM customer and the EMS corporate requirement is the individual line, and it seems likely to result eventually in either partnering or some amount of industry standardization.

Partnering can create an OEM with "virtual" manufacturing. This partnership between the OEM and the EMS company would allow the use of customer-specific processes and procedures with little penalty. So far, there seems to have been little willingness for OEM companies to

Figure 5-9. Pressure to Standardize



partner with their EMS providers. A significant exception to this rule was Motorola's decision in June 2000 to outsource manufacturing to Flextronics, while purchasing an equity position in Flextronics. However, most OEMs still appear to believe that it is beneficial to have multiple EMS suppliers and generally want them to follow the OEM's rules.

5.4.6 Opportunities Summary

The trend toward EMS outsourcing of PCAs has been accelerating over the last 6 or 7 years, and it is spreading to include other manufacturing-related services, such as procurement and engineering. However, today's structure implicitly assumes that the EMS operation would become a virtual part of the OEM's operation, whereas the OEMs appear to have little interest in forming long-term partnerships with EMS companies. Without the right set of standard definitions and processes to allow these operations to link seamlessly, the OEMs and/or the EMS companies are at a competitive disadvantage to companies with internal manufacturing—or to OEMs that use ODM outsourcing. Figure 5-9

Table 5-9. Specific Opportunities for Standardization

Opportunity	Benefit Area
Design data	Time-to-market
Manufacturing processes	Time-to-market/ramp, DFM, manufacturing cost, flexibility
ECN communication	Manufacturing cost, predictability, quality
AVL communication	Supplier cost, predictability, flexibility, quality
Process quality reporting	Manufacturing cost, time-to-ramp, predictability, quality

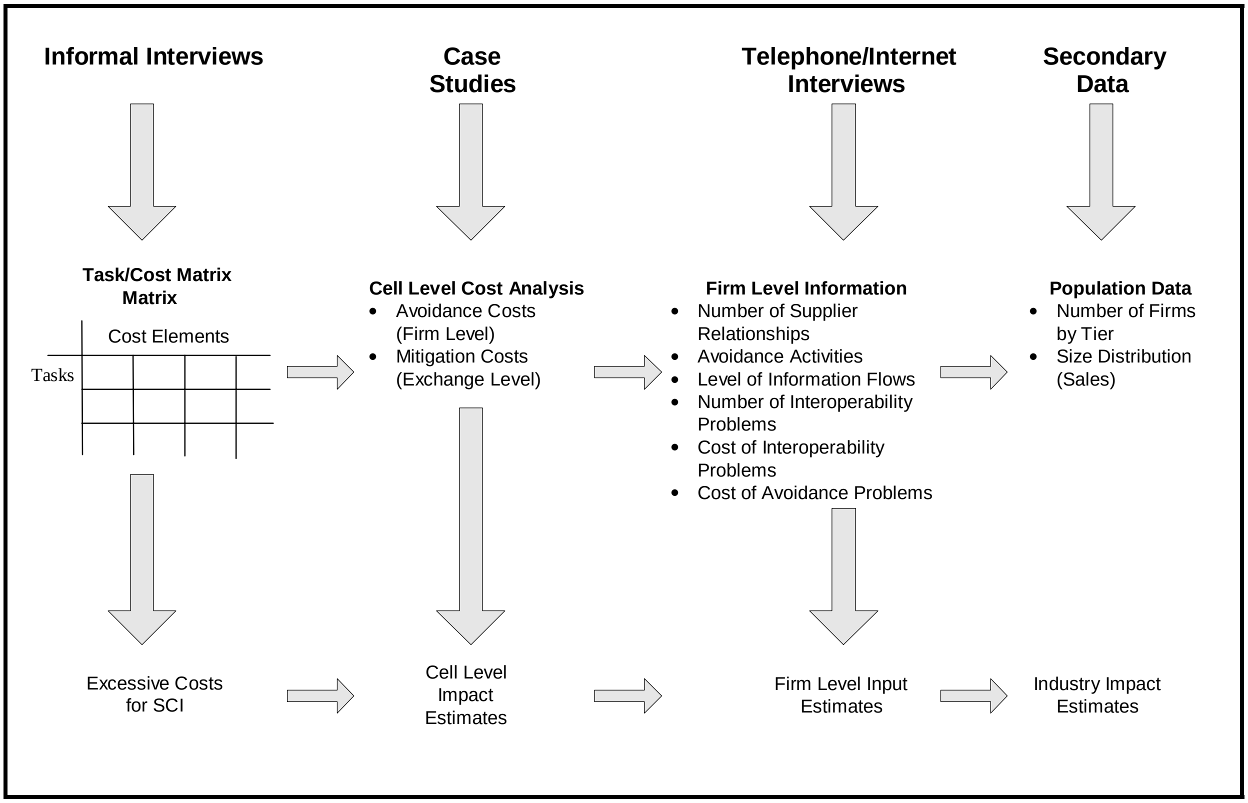
provides a good picture of the necessary standards. Any information flows that cross company boundaries should ideally be covered by a consistent set of standards. A few specific opportunities for standardization are listed in Table 5-9.

6 Conceptual Approach for Measuring Costs

In this section, we discuss RTI's methodology for measuring the costs of inadequate standards for supply chain integration. We modeled our approach on others used successfully by RTI in several previous economic studies for NIST, including an *Interoperability Cost Analysis of the U.S. Automotive Supply Chain*, an *Economic Impact Assessment of the International Standard for the Exchange of Product Model Data (STEP)*, and *The Economic Impact of Inadequate Infrastructure for Software Testing* (Brunnermeier and Martin, 1999; Gallaher and O'Connor, 2002; and RTI, 2002, respectively).

Figure 6-1 provides an overview of this methodology for estimating industry-level impacts using a bottom-up, cost component approach. We began by developing a task/cost matrix for the industry sectors being studied. These matrices identify the most important information flows for which excessive costs are likely being incurred. We then used representative case studies or in-depth interviews to estimate excessive costs for each cell of the task/cost matrix. We conducted a large-scale survey to provide data that allowed us to estimate the incidence of these costs across various elements of the industry sectors studied. Finally, secondary data on industry sales and employment and wage rates allowed aggregation to industry-level impacts.

Figure 6-1. SCI Estimation Methodology



For this SCI study, we first identified the scope of activities affected by the lack of an adequate standards infrastructure, striving to understand the basic sources of costs and benefits that may be affected. Following this step, we created an implicit counterfactual to compare the current state with one in which an ideal infrastructure is in use. In each of the cost categories identified, we developed technical and economic metrics that allowed quantitative estimation of costs and benefits for the firms involved, relative to the lower-cost ideal state. We used these metrics to develop the task/cost matrix for the methodology. Data were then collected to inform the metrics, first through a series of structured interviews with representatives from several firms in the industry, and then through wide-scale placement of a more structured survey. As the project was a prospective study, we looked at potential benefits from creation and adoption of an ideal standards infrastructure, but not at the public and private costs required to develop such a system.

Due to the scope and complexity of supply chain activities in our chosen sectors, we refined our proposed methodology before its execution. Details of the methodology, as originally developed and including subsequent revisions, are described in Sections 6.1 through 6.5. We executed the scoping and metrics development steps and created data collection instruments to gather the desired information.

When we began the actual data collection, however, it became evident that our methodology needed modification. Several of the motivating factors for revising our procedure are discussed in Section 6.6, along with a brief description of the revised methodology. A more detailed discussion of the industry data and interview feedback that informed our revisions is presented along with the data collection results in Section 7, which also contains the calculations and explanations for the cost estimates.

6.1 SCOPE OF SUPPLY-CHAIN ACTIVITIES

Based on input from the project team and preliminary discussions with knowledgeable industry experts, we identified the key characteristics of the information flows involved in supply-chain activities in the automotive and electronics sectors. Despite their obvious technological differences, the two sectors have a great deal in common from a supply-chain perspective. Automobiles, personal computers, and communications devices are all assembled products, each containing hundreds or thousands of component parts, supplied by a large number of independent firms. Information on inventory and production quantities, shipment dates, prices, and quality attributes must be passed from one partner to another; the speed and accuracy of the communication is critically important to the sales of the ultimate consumer products, and in turn, to the success of each firm.

As the earlier sections of this report detail, the electronics industry has progressed much faster than the automotive sector toward SCI using Internet-based, XML-enabled information systems. The NEMI initiative and RosettaNet consortium have achieved considerable progress in enumerating and understanding the basic information processes involved in complex, assembled-parts supply chains. The first column of Table 6-1, which was adapted from RosettaNet's directory of PIPs, details many of the important supply-chain activities that are relevant for this study. In the second and third columns of Table 6-1, we include our project team's subjective assessment of the frequency and complexity of these information flows, an important factor in their likely overall cost impact. As the length and detail of the table demonstrates, a

Table 6-1. Supply-Chain Information Processes and Relative Importance

Supply-Chain Tasks	Frequency	Complexity
1. Managing Partner Information		
Request Account Setup—New Partner	Low	Medium
Maintain Account—Existing Partner	Medium	Low
Manage Product Information Subscriptions	Low	Medium
2. Managing Product Information		
Distribute New Product Information	Medium	Medium
Distribute Design Engineering Information	Low	High
Query Product Information	High	Low
Query Marketing Information	Medium	Low
Query Technical Information	High	Medium
Query Product Discontinuation Information	Low	Low
Change Basic Product Information	Medium	Medium
Change Marketing Information	Low	Medium
Change Technical Information	Low	High
Change Product Lifecycle Information	Low	Medium
Notify of Product Change	Medium	Low
Distribute Engineering Change Status	Low	Low
Request Engineering Change	Low	Medium
Request Engineering Change Approval	Low	Medium
Notify of Engineering Change	Low	Low
Request Bill of Material	Medium	Low
Notify of Bill of Material	Low	High
Notify of Approved Manufacturer List	Medium	Medium
Request Approved Manufacturer List	Low	Low
3. Order Management		
Request Quotation	High	Medium
Request of Price and Availability	High	Medium
Request Purchase Order	Medium	Low
Notify of Authorization to Produce	Medium	Low
Query Order Status	High	Low
Distribute Order Status	High	Medium
Notify of Purchase Order Update	Low	Medium
Request Purchase Order Change	Medium	Medium
Request Purchase Order Cancellation	Low	Low
Notify of Shipping Order	Medium	Low

Source: Adapted from RosettaNete Partner Interface Processes PIP Directory. (continued)

Table 6-1. Supply-Chain Information Processes and Relative Importance (continued)

Supply-Chain Tasks	Frequency	Complexity
Request Shipping Order	Low	Low
Notify of Shipment Confirmation	Medium	Low
Notify of Authorization to Ship	Medium	Low
Notify of Shipment Documentation	Medium	High
Distribute Shipment Status	High	Medium
Query Shipment Status	High	Low
Request Shipment Change	Medium	Medium
Return Product	Low	High
Request Financing Approval	Medium	Medium
Notify of Invoice	High	Medium
Notify of Invoice Reject	Low	Medium
Notify of Remittance Advice	High	Low
4. Inventory Management		
Notify of Strategic Forecast	Low	High
Notify of Release Forecast	Medium	High
Notify of Forecast Reply	Medium	Medium
Notify of Shipment Receipt	High	Low
Distribute Inventory Report	High	High
5. Manufacturing Information Management		
Distribute Work In Process	Medium	Medium
Query Work In Process	Medium	Low
Notify of Manufacturing Work Order	High	Medium
Work Order Change Notification	Medium	High
Notify of Quality Goals	Low	Medium
Notify of Manufacturing Quality	Medium	High
Query Manufacturing Quality	Medium	Low
Distribute Product Quality Event Data	Low	High
6. Marketing Information Management		
Distribute Product List	High	High
Request Design Registration	Low	Low
Distribute Registration Status	Medium	Medium
Query Registration Status	Low	Low
7. Service and Support Management		
Query Service Entitlement	Low	Low
Request Warranty Claim	Medium	Medium

Source: Adapted from RosettaNet Partner Interface Processes (PIP) Directory.

large number of critical business functions fall under the purview of supply chain management. This complexity makes it very challenging to attempt to analyze the entire supply chain process.

Table 6-1 shows that the major categories important in integrating supply chains relate to information about partners, products, orders, inventories, manufacturing, marketing, and service and support. Of these, the product and orders categories have by far the most elements, although the order and inventory sections have the largest number of items with high frequency and/or complexity.

Our preliminary hypothesis was that a significant amount of the total cost of the inadequate infrastructure would be found in *order management* and *inventory information*. Our methodology and data collection instruments were designed to focus on these phases of supply chain information flows, especially in the automotive sector where most recent integration activity has been in *inventory visibility*, with secondary focus on order change management. In the electronics sector, the explosion in Internet-based business-to-business software products during the 1999-2001period led to a large amount of spending on product and marketing databases, but the past year has seen a dramatic reduction in this activity. As our data collection results show, most excess cost and improvement efforts in electronics are focused on order and inventory areas, just as in the automotive sector.

6.2 CATEGORIES OF EXCESSIVE COSTS

Tasks in a well-integrated supply-chain information system will place relatively low burden on suppliers and customers, along the lines of the ideal system described in Section 1.4 and illustrated with an invoice approval example. Most of the “notify” and “distribute” tasks listed in Table 6-2 can be generated automatically by physical activity at the supplier site (scanning a bar code, for instance); many customer “queries” and “requests” will also arise without manual intervention. The “maintain” and “change” activities, along with unusual events such as cancellations or quality event distributions, are manually driven at least at the initiating end, but standard formats and protocols should reduce the complexity in these cases as well.

If multiple systems are being used to manage different portions of the supply chain, however, several types of additional costs will be incurred, unless the systems have been designed to interoperate. Likewise, if systems are only partially integrated, translation or data reentry are required for flows to and from all supply-chain partners that do not share the improved information systems. Finally, if the lower tiers of the supply chain do not have the financial resources or technical capability to support integration, their internal work processes and communications are likely to be significantly less efficient than in an optimal system.

These situations give rise to excessive costs within the supply network, which serve to raise prices of intermediate goods and finally of the OEM's consumer products. These costs have been usefully categorized in previous RTI work as avoidance, mitigation, and delay costs (Brunnermeier and Martin, 1999). Manufacturers incur *avoidance costs* to prevent technical interoperability problems before they occur and *mitigating costs* to address interoperability problems after they have occurred.

Examples of avoidance costs in the present context include

- the cost of purchasing, maintenance, and training for duplicate systems required by one or more suppliers or customers;
- the cost of purchasing, maintenance, and training for translator programs that link noninteroperable systems;
- the cost of manually entering data generated by a production process or other system not interoperable with the SCI system; and
- costs associated with sending and receiving faxes, telephone calls, and letters to communicate supply chain–related information, such as production or ship dates, quantities, or product queries.

Mitigation costs that are experienced across the supply-chain tasks detailed above include those associated with

- routine reentry of data from one information system into another within the supply chain;
- correcting errors in manually generated, reentered, faxed, or telephoned data;
- correcting errors generated by translation software and from troubleshooting translation systems;
- tentative or delayed approvals of orders, schedules, shipment notifications, and invoices due to a lack of confidence in the systems in use;
- expediting orders or shipments to meet unanticipated or changed due dates;
- product losses stemming from inappropriate decisions made without the proper information;

- premium costs, such as overtime pay and higher freight charges, incurred as a result of communications errors and/or delays;
- fines or penalties imposed by customers because of information-related missed deadlines; and
- lost business from incompatibility-induced delays or delivery failures.

6.3 TECHNICAL AND ECONOMIC IMPACT METRICS

Quantifying the economic impacts of these cost-related factors requires appropriate metrics that capture the most important tangible costs. For each of the factors listed above, we developed two kinds of impact metrics:

- *Technical impacts* describe the impact of ineffective integration on the accuracy and usability of information flows and the resources required to avoid or mitigate interoperability problems.
- *Economic impacts* describe how technical impacts translate into changes in cost and economic activity. These measures can be either quantitative or qualitative.

We used the technical and economic metrics to inform planning activities for the in-depth interviews (case studies), the large-scale survey instruments, and other data collection activities. Table 6-2 shows the two sets of metrics developed for the cost factors from the previous section.

6.4 INFORMING THE METRICS THROUGH DATA COLLECTION—CASE STUDIES

Primary data collection is necessary to inform the impact metrics developed during the conceptual phase of the study. As it would be difficult or impossible to design a single instrument to collect information from a cross-section of the industry's firms, it was necessary to acquire much of the data needed from a small number of in-depth interviews. These structured conversations are similar to the case studies done in many qualitative analyses, although in this case the intent was to gather components of excessive costs borne by firms due to the lack of adequate information infrastructure. Then, by summing these components of cost, we developed an estimate of the cost of inadequate standards for SCI. The cost component approach has the advantage of building an impact estimate from information provided by industry and other sources. Interviewees provide only pieces of the total estimate.

This approach puts a smaller burden on industry sources to process the information and provide an overall estimate.

Table 6-2. Impact Metrics for Inefficient SCI

Source of Cost	Components	Technical Metric	Economic Metric
Avoidance Costs			
Multiple information systems	Purchase or license of SCI software	Number of SCI software products required within the organization	Investment in purchased SCI software or license fees
	System maintenance	Labor required to maintain all SCI software systems	Cost of labor required to maintain SCI systems
	System training	Labor hours devoted to training and certification on all SCI software systems	Cost of labor time required for training on all SCI systems
Multiple translators	Translation software licenses	Number of translation software licenses required by type	Investment in translation software licenses
	Software training	Labor hours devoted to training on the use of different translators	Cost of training labor to use different translators
Interfacing with noninteroperable systems	Manual data entry from order, production, shipping processes	Labor hours consumed by manual data entry in sales support, materials management, production	Cost of labor expended in manual data entry across functional areas
	Telephone, fax, communication of supply-chain information	Labor hours devoted to fax, and phone communication to suppliers and customers	Cost of labor expended in telephone, fax, communication
Investments in interoperability solutions	In-house interoperability research	Capital, labor, and materials devoted to in-house interoperability research	Cost of in-house interoperability research
	Activities in industry consortia	Time and materials devoted to participation in industry consortia	Cost of membership, labor effort, and materials devoted to consortia activities
Mitigation Costs			
Routine data re-entry	Manual re-entry of data from one system into another	Labor hours expended in routine re-entry	Cost of labor expended in re-entry of data
Preventing and correcting errors	Correcting errors from fax, telephone, manual data entry	Labor hours consumed by error correction of low-tech date entry	Cost of labor expended in error correction
	Correcting errors introduced by translation software	Labor hours devoted to troubleshooting translation software, correcting errors	Cost of labor expended in translation software troubleshooting

	Cautionary approvals due to lack of confidence in system	Supervisory hours required for additional oversight, manual approvals	Cost of supervisory effort for secondary approvals of orders, schedule, shipments

(continued)

Table 6-2. Impact Metrics for Inefficient SCI (continued)

Source of Cost	Components	Technical Metric	Economic Metric
Mitigation Costs (continued)			
Expediting to make up for late or inadequate information	Re-ordering production, shipment schedules to meet emergency needs	Labor hours devoted to expediting plus forced changes in schedules	Labor cost for expediters plus loss of efficiency in production, shipment
Product losses from unneeded or unshippable production	Operating without forecast or order data leading to unneeded production	Quantity of unshippable product made due to production ahead of orders, poor information flow	Total produced cost of unshippable product
Premium costs	Overtime pay and/or premium freight due to delays caused by poor information	Hours and materials used by overtime operation or use of airfreight or expedited truck delivery	Total plant cost of overtime operation or charges for air freight or expedited truck delivery
Fines or penalties	Penalties imposed by customer for failure to meet delivery dates	Number of penalties or fines imposed by customers	Cost of penalties or fines imposed by customer
Lost business	Sacrificed sales and profits as result of delays or missed shipments	Order cancellations or loss of parts contracts for future products	Value of lost profits from cancelled orders or lost future business

We developed interview guides for the electronic and automotive industries to provide a structure for the conversations. Copies of these guides are included with this report in Appendix A. Members of our project team shared these interview guides with prospective interviewees along with a brief description of the entire project to solicit their participation. Although we expressed a preference for on-site visits with the selected firms, past experience has shown us that we can achieve meaningful results in a telephone conversation with proper preparation. Our goal was to have conversations with up to nine firms, with representation from the automotive and electronics sectors. Early in the project, we believed that it might be useful to interview supplier/customer pairs from each of the supply chains. Upon discovering that firms in these two industry sectors were not actually cooperating in developing supply chain information processes (except through consortia like

RosettaNet and the Automotive Industry Action Group), we elected to convert our case study plan into profiles of individual firms.

The end product of the case study interviews was to be a task/cost matrix for each firm that could be aggregated with the other in-depth responses to create the primary cost metrics for the economic estimation. The one we designed for this study appears here as Table 6-3. In this table, we selected the information processes with the highest frequency and complexity scores from Table 6-1, combined with the major cost metrics outlined in Table 6-3. This matrix was intended to be somewhat fluid, with additional processes or cost elements to be added if the in-depth interviews made that necessary.

Table 6-3. Supply-Chain Task/Cost Metrics Matrix

	Avoidance Costs				Mitigation Costs		
Detailed Task Description	**Multiple Systems**	**Multiple X-lators**	**Manual Entry**	**Data Re-entry**	**Error Correction**	**Order Expediting**	**Product Losses**
Distribute New Product							
Query Product							
Query Technical Information							
Request Quotation							
Request Price and Delivery							
Distribute Order Status							
Request Purchase Order Change							
Distribute Shipment Status							
Notify of Invoice							
Notify of Remittance							
Distribute Inventory Report							
Distribute Work in Process							

6.5 EXTENDING THE COST DATA TO THE INDUSTRY LEVEL—LARGE-SCALE (INTERNET) SURVEYS

After the differential costs per transaction were estimated through the case studies, our methodology called for using telephone or Internet-enabled surveys to characterize the Tier 1 and Tier 3 supply-chain populations for the automotive and electronics industries. We designed a survey suitable for both industries and obtained OMB approval for the instrument. The instrument was designed to be fielded primarily over the Internet, although electronic and hard-copy documents were also prepared for potential telephone placement. The survey was closed-ended and not burdensome for the respondents; OMB estimated 30 minutes' preparation and 30 minutes' completion time for the instrument.

The survey instrument was designed to collect data on each company's supply-chain information activities and to determine the distribution of companies by size and by position in the supply chain (OEM, Tier 1, Tier 2, or lower Tiers, for example) in terms of their

- number of supplier relationships,
- type of information flows and level of complexity,
- frequency of information flows, and
- avoidance activities.

The survey also asked direct questions about interoperability problems and costs during the Internet surveys. However, experience from past projects led us to believe that it would be difficult to obtain usable cost details from companies through a standardized electronic survey instruments. Thus, our approach was designed to provide defensible estimates of industry-level impacts even if little or no quantitative cost data were obtained through the telephone/Internet survey. For companies that did provide usable cost data on their interoperability problems, we planned to integrate this information directly into the study. However, for companies not able to provide these data, we were to estimate costs using the matrix developed from the case studies and companies' data exchange characteristics obtained through the telephone/Internet surveys.

Once the task/cost matrix for each industry sector was complete and information was obtained through the large-scale survey, total interoperability costs for a surveyed company could be expressed as

$$C_i = \Sigma_j \text{ avoidance costs}_{ij} + \Sigma_j \text{ mitigation costs}_{ij} ,$$

where

i = company identifier

j = type of information flows.

For surveyed firms able to provide quantitative estimates of their actual costs, these estimates were entered directly into the costs database. For those that provided only activity, tier, and scale information, an appropriate set of activity-specific costs from the in-depth interviews were included. Once interoperability costs were calculated for all the companies included in the telephone/Internet interviews, secondary data were used to weight the survey population impact to obtain industry cost estimates.

Our background research and discussions with industry experts suggested that we might find significant differences between firms of different sizes or supply chain tiers. If our actual data supported such a possibility, the respondent firms would be stratified and results aggregated separately.

Two weighting procedures were planned for the estimation:

1. Mitigation costs were to be weighted by sales. The *value of annual sales* by the firms that were surveyed would be found from the most recent Economic Census (EC), or Annual Survey of Manufactures (ASM). We believe sales is the appropriate weighting metric because mitigation costs are a function of the level of production activity (quantity of information flows), and this is best represented by sales.
2. Avoidance costs were weighted by the number of U.S. establishments involved in the industry supply chain, also obtainable from EC or ASM data. The *number of entities* is the appropriate weighting metric because avoidance costs are mostly firm-level annual costs such as licensees and staff training and do not necessarily vary by intensity of use.

We used this hybrid weighting approach to scale up avoidance and mitigation costs for surveyed companies to obtain industry-level impact estimates:

Industry cost estimates = Mitigation costs x (Industry sales/surveyed sales) + Avoidance costs x (National entities/surveyed entities).

Table 6-4 provides an overview of the proposed weighting process, which was to be implemented separately for the two industry sectors being studied.

Table 6-4. Overview of Weighting Approach

	Industry Subsectors			
Cost and Weighting Categories	**OEMs**	**Tier 1 Suppliers and Integrators**	**Tier 2 Suppliers**	**Tier 3 and Lower Tier Suppliers**
(A) Avoidance costs	$	$	$	$
(B) Mitigation costs	$	$	$	$
(C) Number of entities in surveyed population	#	#	#	#
(D) Total number of entities	#	#	#	#
(E) Sales of entities in surveyed population	$	$	$	$
(F) Industry sales	$	$	$	$
Total end-user industry costs	= A x (C/D) +B x (F/E)	= A x (C/D) +B x (F/E)	= A x (C/D) +B x (F/E)	= A x (C/D) +B x (F/E)

6.6 REFINING THE METHODOLOGY

As we began to conduct the structured interviews, we found that respondents either did not understand our counterfactual approach or had access to only a fraction of the information needed for us to complete the data collection effort. The most important of the concerns are discussed below.

6.6.1 Difficulties with Understanding "Excessive Costs"

The complexity of supply chains and the multidisciplinary nature of SC activities make it very difficult to isolate costs related to inefficient or incomplete integration. Most firms have invested considerable effort in using information to manage inventories, for reasons that are discussed in the early sections of this report. As a result, managers in logistics or IT roles were often quite aware of their firm's savings from inventory reduction, and even cost/benefit ratios or rates of return from investments in integration.

However, managers had difficulty understanding the rationale for and potential benefits to their firms from shifting the focus to potential benefits from an *improved* information infrastructure, except in a few well-defined cases such as inventory visibility. Almost all of the managers we spoke with who understood the excessive costs their firms were experiencing in other supply chain areas reported that their management hierarchy was not prepared to take the steps needed to quantify such costs. Implicit in this rationale is an assumption on the part of management that other active corporate initiatives had far greater potential for reducing costs and/or raising profitability.

6.6.2 Lack of Unified Information

Information on materials, subassemblies, work-in-process, and finished product is increasingly spread across manufacturing organizations within a supply chain. As such, a large number of people are involved in operating and optimizing information flows. Only in a very few firms is there one person or functional group that has sufficient knowledge to estimate the costs we sought for our study. As an example, one large firm we contacted in the electronics industry has had more than 1,000 employees involved in optimization of supply chain information flows. By contrast, engineering product and process design, which was addressed in our recent STEP analysis (RTI, 2002), are well-defined and focused activities within a manufacturing organization. It is a fairly straightforward task to identify the organization and individuals who are knowledgeable about costs and systems used for engineering design.

6.6.3 Sensitivity of Information

Much of the information we requested from firms in the automotive and electronics industries is closely guarded, as it is critically important for their financial success. Not only are these firms intensely competitive, but the financial strength and negotiating leverage of many of their key OEM customers makes data on staffing levels, software development and licensing costs, and accounting practices very sensitive. This is especially true in the automotive sector, where OEMs and the largest Tier 1 firms demand and analyze detailed cost and profit data from their suppliers as a part of the negotiations for new sourcing decisions.

6.6.4 Many Metrics with Low or Unobtainable Costs

Finally, it became apparent from our discussions that inefficiencies in many of the supply chain information processes listed in Tables 7-1 and 7-4 do not contribute significantly to bottom-line product costs (inventory communications and order management being clear exceptions). In all of the in-depth interviews, the contacts we spoke with stated that little attention was being paid to optimizing processes such as sharing product information, marketing communications, and after-sale warranty work. This is not to say that these activities are not costly, just that inefficiencies in communicating information do not add significantly to costs.

During the height of the dot-com boom of 2000-2002, hundreds of start-up firms were selling B-to-B software products that claimed to solve costly information and communications problems for industrial firms. Among the offerings relevant to the present study were proprietary portals (often called marketplaces) where buyers and sellers could be matched electronically, Web-based product catalogs, enterprise resource planning systems, and both open source and proprietary supply chain integration software. On-line catalogs were especially popular in the electronics industry, while many firms in the automotive industry chose to or were forced to support Web portals such as Covisint, a start-up funded by most of the major U.S. OEMs.

The bursting of the dot-com bubble carried away many of the small B-to-B firms, and left the electronics and automotive supply chain participants in a quandary as to how to proceed. More sober reflection on the potential of these solution providers to reduce costs led to a sharp reduction in software usage and incremental investments. In electronics, most of the XML-based online product catalogs were retained, although competition drastically reduced the prices of the software required to operate them. Most of the electronic marketplaces were abandoned as firms realized that the reverse-auction mechanism did not necessarily produce savings sufficient to replace the supplier-customer cooperation that was lost in the process. As a result of these changes in electronics, we did not find that firms are experiencing costly inefficiencies in their communications of product marketing information.

In the automotive sector, we learned through our in-depth interviews that the historical nature of contracting is strongly at odds with the reverse-auction marketplace approach, despite the presence of the OEM-sponsored B2B electronic marketplace, Covisint. When a new car or truck model is being developed, suppliers compete aggressively for their parts or subsystems to be specified. A great deal of technical information is exchanged, face-to-face marketing and sales communications are common, and price and delivery terms are negotiated. Once the supplier has been chosen for a particular part, however, the competition ceases; most parts are sole-sourced for the 3- to 5-year duration of the model's production run, as long as the supplier meets cost, quality, and delivery expectations. Repeated contracting is not experienced for most of the expensive and critical parts of an automobile, and thus, product feature and marketing information is rarely exchanged and costs of these information flows are low. The belated realization of these common industry norms appears to be one of the elements behind Covisint's recent abandonment of reverse auctions, and its reshaping into a SCI firm focusing on inventory visibility solutions.

6.6.5 Resulting Changes to Execution of Data Collection Activities

As a result of the feedback we received from our initial in-depth interviews, we elected to significantly simplify the analysis and estimation procedures in both the remaining case studies and in the survey execution. First, we placed a greater degree of emphasis on those activities we knew were leading to large costs for electronics and automotive firms, especially sharing of inventory levels and communication of order and shipment information. In our onsite and telephone interviews, we restricted the quantitative discussions to metrics related to these activities: inbound logistics staffing; outbound logistics staffing; in-house or contract costs for EDI systems; license fees for customer-required proprietary information systems; handling of payment to suppliers through an accounts-payables function; and billing and recording of payments from customers through an accounts-receivables organization. Although the already-approved survey was not modified, we altered our instructions for its completion.

Resolving the issues around respondents' breadth of knowledge and sensitivity of information required a more creative approach to recruiting and enrolling survey respondents. With supply chain information affecting purchasing, production operations, materials management, logistics, accounting, and information systems functions, managers in any of those organizations might have some or all of the information we required. Organizations that had chosen information integration as a key priority might have cross-functional teams leading their efforts. On the other hand, highly focused firms might have outsourced optimization efforts to a consultant or logistics supplier. Smaller companies might not have even one person who could estimate these costs. We could not envision a way to decide a priori who was most likely to be able to respond in each sector and for each target firm.

Rather than engaging in an expensive and uncertain search process across the universe of automotive and electronics firms, we elected to sacrifice some randomness in the selection of survey firms by working through an industry association that we knew was already involved in supply chain integration. For the auto sector, we contacted a technical group within AIAG that was involved in an inventory visibility test using a set of XML-based transaction messages. Other partners in the venture include the Original Equipment Suppliers Association (OESA) and ODETTE, a European consortium of automotive suppliers. They offered to introduce our survey through an email listserve and to encourage their members to participate, in the hopes that our data and analysis would prove interesting and valuable to their membership.

In the electronics industry, the logical choice for a similar effort was RosettaNet, the consortium that has been working on interoperability in supply chain communications for a number of years. Upon reviewing a copy of our survey, the person we contacted let us know that our questions were very similar to a survey that had been placed in September 2003 with members of several of their working groups, including Semiconductors and Information Technology. Although RosettaNet was not interested in supporting a second survey of very similar nature to their internal effort, they agreed to share the results of that survey with us for our use in this study. In taking this approach to the large-scale data collection, we were confident that we would receive responses from a broad spectrum of industry participants, that the respondents would understand the details of the information we needed, and that RosettaNet would have already forged contacts within these firms necessary to gather information across the spectrum of functional areas.

7 Analysis of Data and Development of Cost Estimates

In this section, we describe how the methodology developed in the previous section was applied to the challenge of estimating costs related to inefficient and incomplete integration within automotive and electronics supply chains. We first describe the in-depth interviews we conducted to gather detailed cost data for a few large firms. A couple of these firms are profiled in greater depth, to highlight the complexity of the problems and various approaches taken to create truly interoperable structures. We then move to the industry-wide surveys conducted to gather data that allow aggregation of costs across the entire industrial sectors that formed the heart of this study. The actual calculations and resulting estimates are presented next, along with a qualitative assessment of those cost elements we were unable to quantify. The section concludes with an extended discussion of the difficulties encountered in data collection and interpretation, along with several cautions and limitations of the results. Broad conclusions and recommendations are left for the concluding section of this report.

7.1 IN-DEPTH INTERVIEWS

The heart of our data collection for this study is in the series of nine in-depth interviews we conducted during the summer and fall of 2003. Five of the discussions were held onsite at the firm’s corporate or divisional offices, and four were conducted over the telephone. In each case, we sent an interview guide to our contact several days before the visit or telephone call and asked the recipients to gather as much information as possible prior to the contact. The conversations averaged about 60 minutes and relied extensively on the interview guides to structure the questions asked. In most cases, we spoke with only one person, although for two of the interviews a small group was assembled to provide information.

All of the corporations we contacted reported more than $1 billion in sales for the most recent fiscal year, making these firms larger than average in both industry sectors. The majority of the respondents were from firms that operate primarily as Tier 1s, although we did speak with two companies that have product lines in which they are OEMs. Especially in the automotive industry, it is common for the large, multidivisional firms to have products in several tiers of the overall supply chain—one of the firms we interviewed has operations at Tiers 1, 2, and 3. This focus of in-depth contacts on Tier 1, although not representative, makes a great deal of sense given the realities of both automotive and electronics industries. In background research and the in-depth interviews, we found that Tier 1-OEM interfaces are mostly automated (either via XML or EDI transactions processes), while the Tier 2-Tier 1 and lower tier linkages tend to be less integrated. As a result, the Tier 1 firms end up incurring most of the inefficiency costs, including management of multiple systems, manual reentry of data, and duplication of effort.

Two of the interviews were especially illuminating, as one of the firms is very close to the “ideally integrated firm” described in this report, while the other has only begun the process of information integration. They provided useful reference cases for effort levels and costs. These firms are profiled in greater detail below, along with the specific costs and activities reported by their representatives. Although the data shared during the interviews were not obtained as Confidential Business Information (CBI), we did assure the firms that we would not disclose their identities in our final report. For this reason, the profiles and ensuing discussion have been somewhat generalized to avoid accidental disclosure.

7.1.1 Profile—An Ideally Integrated Firm

Our interview with the architect of the “ideally integrated firm” provided us with much of the quantitative information we used to anchor the baseline of our industry estimates. In the following paragraphs, we discuss some of the salient features of this firm’s supply chain information systems.

As background, this corporation is a multibillion dollar, global Tier 1 firm with more than 30 plants in North America. These facilities are located in close proximity to their major customers to insure on-time delivery. An average plant for this firm has about $30 million in sales. Most of their products are shipped directly to OEMs or systems integrators, although some parts are produced for aftermarket sales. New acquisitions are being integrated into this firm’s information systems as a part of the initial assimilation process.

Outbound Logistics

Approximately 30 million transactions come into this firm's information systems from its customers, almost all via EDI. Currently, these are structured as ANSI X.12 data streams. Although our contact believes that EDI will continue to be used into the indefinite future, the format of these messages is in the process of being converted over to XML, which will lower the cost and make them more flexible. Messages automatically pass into the firm's planning systems, where they are used to generate production and shipping schedules for the facility in question. Each new customer publishes its EDI standards to the firm, which are sent along to a third-party software house for development of new program code to link the new customer to the firm's information systems. Currently, the cost of adding a new customer is around $5000.

It is the responsibility of the firm to plan production and shipments so that its products land on its customers' docks at the specified time window. In addition, each plant is required to manage its customers' in-plant inventory levels of the parts it supplies, and is authorized to self-generate releases to correct any shortages. Penalties for shutting down a customer are prohibitively high, but this firm has never shut down a customer's facility due to logistics or information systems-related failures. (Some shutdowns have occurred due to quality or part performance problems, but this is extremely rare.) Each plant has one or more full-time-equivalent workers (FTEs) to handle exceptions to the automated processes and to manage emergency situations.

Inbound Logistics

Once the production schedule has been set, the planning system automatically generates production and shipment authorizations for materials and other parts provided by outside suppliers. These authorizations are 'published' on a secure Web site accessible to all suppliers, using XML-based data elements. Supplier firms also have restricted access to downstream schedules and inventory levels that affect their products. As shipments are received at the facility or as inventory is pulled into production, parts are scanned into the data system. This receipt and usage data is also published on the supplier Web site.

All suppliers are required to use the Web-based system, to take information from it, and to plan their production and shipments accordingly. Depending on their capabilities and information systems, suppliers can download information in structured electronic format, dump it into a planning system or Excel spreadsheets, or make hard copies. They are required to acknowledge the information published and to enter planned production and ship dates into the Web site. Reports of actual shipments are also required to be entered. Although the firm has a couple of suppliers that cannot yet meet these requirements, in the long run, suppliers that refuse to support the Web site will be disqualified.

Accounts Payable and Receivable

All inbound and outbound accounting transactions are handled automatically by the firm's information systems. Payments for all shipments come into the accounting system via EDI transaction streams, and there is little or no need for manual intervention. On the outbound side, this company has achieved 98 percent automatic application of cash from customers for product shipments. On the inbound side, remittance advices are generated automatically and sent to the Web site, where the supplier can download them to their systems or record the payment manually. Actual payment is made electronically through automated financial networks. As a result of this integration, two people oversee accounting information flows for all of North America, one for receivables and one for payables.

7.1.2 Profile—A Firm in the Early Stages of Integration

The second firm to be profiled operates more than 100 plants worldwide, has annual sales of several billion dollars per year, and deals with about 75 major customers. This firm makes products in several distinct lines, each of which has its own production locations, supply networks, and distribution systems. The firm's involvement in several recent acquisitions, along with a history of independence at the plant level, has produced a highly decentralized supply chain system. Across the domestic manufacturing operation, more than 25 unique, non-interoperable planning and logistics information systems are in use.

Although the firm is committed to supply chain integration as one of its key strategic priorities, management recognizes that this effort will be costly and time consuming.

The individual we interviewed has responsibility for a great deal of the integration tasks for the worldwide organization. His efforts have been focused on standardization and simplification, and he is actively supporting industry-wide efforts to create true interoperability. As resources and time allow, he plans to bring the plants toward a single planning system, and to incorporate XML-based solutions wherever financially feasible.

Outbound Logistics

As a result of our in-depth interview, we were able to quantify information about costs, both at the plant level and across the corporation. An average plant for this firm has about $45 million in sales revenue each year, approximately 300 suppliers, and 25 to 30 customers (as defined by unique ship-to points). Throughout the firm’s network, most scheduling and shipping functions are handled through EDI transactions with customers, whereas purchase order releases and other in-bound logistics are handled more traditionally, i.e., through fax, phone, or paper communications.

A staff of 5 to 8 people in corporate headquarters manages the EDI systems, which are well established and reasonably efficient. Most software development costs are sunk at this point, but about $100,000 per year is spent for license fees for translator programs. Because several of this company’s most important customers insist on using custom or proprietary logistics systems, each facility has two full-time people who handle routine reporting and tracking functions for these systems. Additional people at the plant level are needed to handle exceptions and emergencies.

Inbound Logistics

On the inbound side, the corporation is beginning to institute common practices across plants, including a requirement that suppliers be capable of supporting electronic transmission of data. Currently, the planning systems at most of this firm's plants generate advanced shipment notices (ASNs) that are faxed to suppliers. This manual data process not only requires significant effort, it also introduces errors into the process that must be corrected after the fact. More importantly, there is currently no standard format for the ASNs, making electronic (software-based) processing of these notices impossible.

Accounts Payable and Receivable

For all plants in the country, shipping notices for outbound transfers and receiving reports for purchases are handled by a staff of 30 accounting personnel at a central location. Approximately 40,000 invoices per month are processed manually by this staff. Although billing to most customers is handled automatically via the EDI system, payments to suppliers are still initiated by the accounting organization. Our contact estimated that if systems were well integrated, even without a change in supplier or customer capability, as few as 5 to 10 people would be needed for these tasks.

As the result of significant assistance from the executive we spoke with, we were able to get a fairly complete estimate of the costs this firm is incurring due to its incomplete supply chain integration. Once again, it is interesting how closely this firm resembles the hypothetical situation we outlined in our methodology. As will become clear in the next section, a large number of firms in the electronic and automotive industries find themselves at this point in their evolution toward supply chain integration.

7.1.3 Cost Estimation for Different Degrees of Integration

In addition to the two profiles included above, representatives we interviewed in depth from other firms provided useful quantitative estimates of their size and complexity (annual sales, number of plants, customer and supplier networks), staffing levels, and one-time and annual software charges. We were also able to get substantive information concerning their degree of integration, current efficiency of information flows, and integration-related activities. From the quantitative information shared, we were able to construct a matrix of effort requirements and costs representative of three distinct degrees of integration: traditional, incompletely integrated, and ideally integrated operations.

Several firms we interviewed had *traditional relationships* with their suppliers, similar in nature to that described in the second case study profile. Based on two of the interviews for which we received detailed information on staffing and effort, we estimate that managing purchase order releases and coordinating inbound logistics would require 4 full-time equivalent (FTE) employees for an average-sized plant of $30 to 35 million in annual sales. Outbound logistics coordination includes customer management, coordination of routine scheduling and shipping information, and handling exceptions and emergencies. Traditional handling of accounts receivables and payables involves effort at the facility to generate and distribute receiving reports, shipment notifications, and freight bills. The accounting for these transactions is most often done at the corporate level, along with distribution of invoices and processing of payments. Firms may maintain in-house accounting organizations or may outsource accounts payable and accounts receivable activities. Estimated FTEs for logistics and accounting efforts, standardized to $100 million in annual sales, are as follows:

- Inbound (supplier) logistics coordination
  12 FTEs per $100 million in sales
- Outbound (customer) logistics coordination
  7.5 FTEs per $100 million
- Inbound financial (payables) accounting
  1 FTE per $100 million
- Outbound financial (receivables) accounting
  1 FTE per $100 million

Firms with *incomplete integration* most often used EDI for their customer communications, and several reported using EDI with their larger, more sophisticated suppliers. In addition, the Tier 1 firms were almost all obligated to support one or more proprietary logistics systems by their customers. As a result, their costs were a combination of planning and coordination effort and information systems charges (license fees, in-house software development, contract software costs, and charges for EDI translators). Based again on our in-depth interviews, we estimated the following FTEs for logistics and accounting:

- Inbound (supplier) logistics coordination
  10 FTEs per $100 million in sales
- Outbound (customer) logistics coordination
  6 FTEs per $100 million
- Inbound financial (payables) accounting
  0.6 FTE per $100 million
- Outbound financial (receivables) accounting
  0.6 FTE per $100 million

In addition, these firms spent, on average, a little more than $10,000 for an average sized ($30 million annual sales) plant to support third-party development of in-house information systems. This equates to approximately $32,000 per $100 million in sales.

We spoke with one firm that we would characterize as having an *ideally integrated supply chain information system*, the company that is profiled at the beginning of this section. Despite their high degree of automation, they still experienced some costs of inefficient integration, mostly in dealing with suppliers with a low degree of e-capability and customers that required use of proprietary systems. We estimated the following costs for logistics and accounting for nearly ideally integrated firms:

- Inbound (supplier) logistics coordination
  4 FTEs per $100 million in sales
- Outbound (customer) logistics coordination
  2.4 FTEs per $100 million
- Inbound financial (payables) accounting
  0.1 FTE per $100 million
- Outbound financial (receivables) accounting
  0.1 FTE per $100 million

Although some of the staffing and logistical effort expended by these firms is employed to support 'non-ideal' transactions required by their customers or suppliers, it was not possible to estimate the costs for a truly interoperable system, i.e., one in which every supply chain partner is operating with open-source, interoperable information processes. Nonetheless, the staffing levels described here are likely a practical minimum for automotive and electronics firms, even as the overall level of integration increases. Finally, in the ideal type of system that we describe, ongoing software development costs would be very low, and license fees and charges for EDI translators would not exist.

The information on facility and firm-specific costs that we were able to quantify are summarized in Table 7-1.

Costs from inefficient integration for a number of process areas could not be quantified, either because these costs were low or because information was not available. None of the respondents in the in-depth interviews reported significant staffing or out-of-pocket costs associated with distributing or querying product information, nor were any other types of routine queries noted. There was actually significant interest in

Table 7-1. Plant-Level Effort Requirements and Identified Costs (per $100 million in annual sales)

	Traditional	Incompletely Integrated	Ideally Integrated
Inbound Logistics	12 FTE	10 FTE	4.0 FTE
Outbound Logistics	7.5 FTE	6.0 FTE	2.4 FTE
Inbound Accounting	1.0 FTE	0.6 FTE	0.1 FTE
Outbound Accounting	1.0 FTE	0.6 FTE	0.2 FTE
Information Systems Costs	$0	$32,000	$0

Source: In-depth interviews with automotive and electronics firms.

visibility of work-in-process to next-in-line customers, but our contacts were unable to estimate costs from the lack of this information in current operations. Sharing product quality data and communications regarding warranty claims are other areas where significant expenditures are being incurred, but it proved impossible to estimate the portion of those costs related to incomplete or inefficient supply chain integration.

During our in-depth interviews, we were unsuccessful in obtaining quantitative estimates for several of the mitigation cost metrics. These also proved elusive in the large-scale survey, as is detailed below. Aside from the data we obtained about staff for handling exceptions and emergencies (commonly called expediting), we did not obtain data on information-related costs for error correction, product losses, premium freight, or shutdown penalties. The last of these items was interesting in that most of our contacts reported huge *potential* costs from shutting down key customers, on the order of $100,000 to $500,000 per hour. However, none of these people recalled a situation in which information systems problems had led to this type of failure.

7.2 QUANTITATIVE AND QUALITATIVE SURVEY RESULTS

With the results of the in-depth interviews in hand, we proceeded with large-scale surveys of the two industry sectors. The automotive portion of the survey was fielded with an AIAG working group through an email listserve announcement, and was completed by logistics or information systems professionals actively working on supply chain integration issues. The survey posed questions about the degree of integration and labor effort required in each of the major supply chain processes, the number of software systems supported and their annual costs, and effort expended in several avoidance and mitigation areas. In electronics, we were fortunate to be granted access to results from a RosettaNet survey conducted in the fall of 2003 by academics from San Jose State University. Although we did not have influence on the questions posed in the survey, they were quite similar to the core questions in our survey, and yielded us a reasonable profile of the degree of integration of electronics firms in the process areas we had identified in the in-depth interviews.

7.2.1 Results from Internet Survey of Automotive Firms

We placed our OMB-approved survey on an RTI internal web site during late fall of 2003 and collected responses from participants over a 5- week period. In the survey, we requested contact information (e.g., name, address, telephone number, and e-mail address) and asked for permission to follow up in case their responses were unclear or incomplete. We contacted several participants to obtain additional data during the survey period, although many of the respondents asked not to be contacted.

In all, we received completed surveys from 55 individuals representing 46 separate firms. Approximately half of the responses were for a single division of a larger entity, while the other half were for an entire company. We were pleased with the coverage achieved by this data collection effort, especially in light of the placement of the survey and the difficulties we anticipated in reaching knowledgeable managers in this industry. The firms represented in the survey account for about $220 billion in annual sales in North America, which is over half of the $400 billion reported for the automotive industry in 2001.

Almost two-thirds of the responses came from Tier 1 companies, with the remainder from OEMs and lower tier firms. This was an expected result, as AIAG membership is weighted toward Tier 1 firms. Although this weighting will force some caution in the use of cost estimates derived from this study, our background research suggested that Tier 1 firms have been bearing a large share of supply chain inefficiency costs.

Our overriding finding from the automotive firm survey was the tremendous diversity of process involvement, degree of integration, reported effort levels, and usage and costs of software systems. The range and calculated standard deviations of quantitative responses were so large that systematic analysis of means or medians would not be meaningful. As a result of this diversity, we used a relatively limited number of survey responses in quantifying costs for the study. Nonetheless, we found a great deal of useful qualitative information in the responses; the most notable of these are detailed here:

- As we suspected from the in-depth interviews, order and inventory management were the business processes with the greatest degree of automation, with more than 70 percent of respondents reporting use of automated systems. No difference was found between OEMs, Tier 1, and lower tier firms in the degree of integration for these key business processes.
- In contrast, only about one-third of the firms reported use of automated information systems in managing partner information, product and marketing communications, and service and support functions. Once again, this finding was robust across tiers of the supply chain. About half of the firms across the supply chain had automated their internal manufacturing management information flows.
- Respondent firms in the automotive industry were linked to almost 10 times as many suppliers as customers, although there was a great deal of spread in these data. The median firm had 300 suppliers in our database, with responses ranging from 10 to 7000. On the customer side, the median firm supported 40 customers, with a range of 1 to 2,000. This suggests that firms in the automotive supply chain, especially Tier 1 firms, may be able to achieve more benefits from working to establish integration with their suppliers than with customers.
- About 70 percent of the firms responding to the survey used EDI in their supply chain communications, and about one-fourth reported at least some use of XML-based information exchange. No companies were using XML systems for all of their customer/supplier interactions. At the other extreme, several lower tier firms reported only manual (paper/fax) communications with their customers. All of the remaining companies used more than one method of interacting with customers. Half of the firms in the overall survey used multiple approaches with suppliers. Table 7-2 summarizes the percentage of firms using various communications methods with suppliers and customers.
- Although not all of the participants shared information about the software packages used by their company or division, we did receive responses from 12 individuals. On average, their firms supported two to three separate packages, most of which were installed within the past 3 to 4 years. Some of the largest firms did not report a number of separate software systems, but commented that the number was almost too large to count. Installation costs were highly variable, ranging from $20,000 to $300,000, with license fees from $0 to $15,000 per user. The spread of these data was too broad to provide a meaningful estimate of average or median annual software costs.

Table 7-2. Percentage of Automotive Firms Using Each Communication Method for SCI Interactions

	With Suppliers (%)	With Customers (%)
XML/Internet	22.6	22.5
EDI	45.2	45.1
Paper/Fax	32.2	32.4

Source: RTI calculations based on automotive industry survey.

- Several comments about use of redundant systems were added to the section on software costs. By and large, these managers accepted the excessive costs and inefficiencies created by this duplication as a necessary cost of doing business.
- The final questions related to premium freight, material losses, penalties, and lost product sales were not answered by enough respondents to support qualitative or quantitative analysis. This does not indicate that the costs were low, just that the people responding to the survey did not have the data or chose not to share it.

In summary, the automotive survey was useful in supporting some of the conclusions we reached during the in-depth interviews, especially the rather narrow focus of integration investments on order and inventory management. Although this may have resulted partly from the process by which these respondents were identified, i.e., through an AIAG group working on inventory visibility, there was little information in the survey to indicate that other costs or concerns were of critical importance. Most importantly, we were able to obtain quantitative information on the fraction of firms at each stage of supply chain integration, data that feeds into the primary cost calculations detailed below.

7.2.2 Results from RosettaNet Survey of Electronics Firms

The electronics industry has moved much further along the path toward efficient supply chain integration than the automotive sector, most notably through the efforts of industry-wide consortia like NEMI and RosettaNet (RN). Since its founding, RN in particular, has been committed to interoperable e-business process standards, which align very closely with NIST's expectations for interoperability. In view of the complexities of our data collection task, made especially difficult in the case of a truly global electronics sector, we had hoped to link up with RN for execution of our survey. When our project team found out that RN had recently sponsored a survey of its members that asked questions similar to the ones we had posed, we requested access to their results and publications.

Thus, the primary source of our electronics industry supply chain data was a preliminary report entitled "Pilot Survey Project—RosettaNet Implementation Penetration Road Map" (Ongoiba and Saini, 2003), prepared by two researchers at San Jose State University (SJSU). Because data were collected under promise of confidentiality, we did not have access to the primary data, but we did obtain a list of the firms who responded. This did not provide us with the same amount of information we would have obtained from our own survey, but served to protect the identity of the respondents, as desired by SJSU and RN.

The survey form, the text of which is included in Appendix B, requested information about firms' use of several different methods of information exchange in the business process areas of interest to RN. The survey asked respondents to estimate the percentage of their transactions, currently and 2 years in the future, using traditional methods (fax/phone/e-mail), a Web site browser interface, EDI, RN, or a custom server-to-server connection. For our purposes, both RN and a Web site interface would be classified as ideal integration, while EDI or custom connection would be considered inefficient integration.

In the preliminary report, information was shared about the coverage of the survey, stratified both by sector and tier. Data were collected from September 22 through October 13, 2003, which corresponds closely to the timing of our automotive survey. A total of 29 responses were obtained, representing 22 separate companies. All were members of the RN Board, which consisted of 78 leading electronics firms at the time of the survey. After obtaining the names of the firms who responded to the survey, we determined that they accounted for $260 billion in U.S. sales annually, accounting for about 75 percent of the industry's domestic revenues.

The cross-sectional data revealed that four responses were received from companies in RN's IT grouping, 12 from electronics components firms, 12 from semiconductor manufacturers, and one from a telecommunications equipment maker. When divided out by tier, three responses were from component materials suppliers (equivalent to Tier 2 in the automotive industry), 15 from components manufacturers (like Tier 1 suppliers), four from OEMs, and 2 from contract manufacturers (similar to systems integrators or 'Tier 0.5's). The remaining participants were from other supply chain participants, including distributors and logistics services providers.

In the survey design, the participants' responses allowed percentages of firms using each technology to be stratified by electronics sector and tier. Unfortunately, we were limited to the information presented in the report, which did not contain all of the possible permutations. Nonetheless, we were able to extract sufficient data to inform not only our quantitative estimation, but to provide useful qualitative results as well. The only significant assumptions that the aggregate data forced us to make were that there were no significant size or tier effects (i.e., that large firms in the survey behaved like small firms), and that the firms surveyed were representative of the electronics industry as a whole.

Table 7-3 contains the quantitative information for the business processes of interest for our overall estimation, and provides some surprising results. In contrast with the automotive results in Table 7-2, many more of the electronic firms were still using manual processes for both planning/logistics and for accounting. On the other hand, far fewer were using EDI or other custom systems, which we have defined as incomplete integration. Perhaps due to the influence of RosettaNet on the respondents, compared to the automotive industry, a larger fraction of firms had implemented ideal integration, especially in the case of inbound (supplier) logistics.

Table 7-3. Business Processes and Degree of Integration of Electronics Firms

	Traditional (%)	**Incompletely Integrated (%)**	**Ideally Integrated (%)**
Outbound Logistics	46	32	22
Outbound Accounting	43	34	23
Inbound Logistics	51	14	35
Inbound Accounting	52	20	28

Note: Table entries are the percent of firms whose business processes are traditional, incompletely integrated, or completely integrated.
Source: RosettaNet survey and RTI calculations.

The most significant finding from the sector and tier information presented was the relative unimportance of product information among those firms that had implemented RN processes. Firms in the components sector reported that only 1 percent of their RN transactions related to design, and 6 percent to product marketing, the latter of which includes the formerly trendy area of online product catalogs. This pales in comparison to the forecast, order management, and manufacturing processes, each of which account for about 30 percent of the transactions volume. Semiconductor firms reported even smaller numbers, with 2 percent of their RN volume related to product marketing and none to design. We conclude from this information that electronics companies, like their peers in the automotive industry, are focusing their efforts on order and inventory management.

7.3 AGGREGATING COSTS UP TO INDUSTRY LEVEL

The data collected through the in-depth interviews and two survey efforts, which have been presented in Tables 7-1, 7-2, and 7-3, are nearly sufficient to calculate industry-level costs resulting from an inadequate infrastructure for supply chain integration. Two secondary data elements were needed to complete the picture: a total value of industry sales and estimates of labor rates to convert full-time equivalents into dollars. As with RTI's standard practice, we relied on the Census Bureau's latest Annual Survey of Manufactures (ASM) for the former and the Bureau of Labor Statistics' (BLS) Occupational Employment Statistics (OES) for the latter.

7.3.1 Industry Sales Revenues

Table 7-4 lists relevant information on both of the industries included in this study, taken from the 2001 ASM. To be consistent with the scope of the study as outlined in other sections of this report, we included only those portions of the industry connected in supply chain customer-supplier relationships. For this reason, we excluded navigational equipment, audio and video equipment, and magnetic and optical media (from electronics firms) and motor vehicle bodies and trailers (from the automotive industry). Therefore, the bottom-line sales revenue numbers used for quantitative estimates were $316 billion in electronics and $403 billion in autos.

Table 7-4. Value of Shipments and Employment Data for Electronics and Automotive Sectors

NAICS Code	Industry Group	Value of Shipments (millions of dollars)	Total Employees (thousands)
3341	Computer & Peripheral Equipment	89,528	193
3342	Communications Equipment	102,004	302
3344	Semiconductor & Other Components	124,215	567
	Total Electronics Industry	315,747	1,062
3361	Motor Vehicle Manufacturing	216,128	214
3363	Motor Vehicle Parts Manufacturing	186,839	736
	Total Automotive Industry	402,967	950

Source: "Statistics for Industry Groups and Industries: 2001." U.S. Census Bureau Annual Survey of Manufacturers. M01(AS)-1. January, 2003.

7.3.2 Industry Wage Estimates

Table 7-5 lists a variety of employment classifications and annual wage estimates from the OES data for 2002. Although all of the occupations listed here are relevant to our study, a review of the detailed role descriptions compared with the activities discussed in our in-depth interviews suggests that the category "Production Planning Clerks" is most appropriate for the logistics functions and "Accounting & Auditing Clerks" for the payables and receivables operations. To convert these direct wages into employer costs, including benefits and social security taxes, we multiply the wage numbers listed in Table 7-5 by 2.0 in our estimates.

Table 7-5. Industry-Specific Wage Estimates for Electronics and Automotive Sectors

SOC Code	Occupational Description	Annual Wages in Electronics	Annual Wages in Auto Industry
13-1023	Purchasing Agents	$58,560	$53,230
13-2011	Accountants & Auditors	$55,120	$54,610
43-3031	Accounting & Auditing Clerks	$32,510	$30,080
43-5061	Production & Planning Clerks	$38,160	$38,890
43-5071	Shipping & Receiving Clerks	$26,840	$28,720

Note: Loaded wage rates are estimated at 2.0 time wages listed in this table.

Source: "2002 National Industry-Specific Occupational Employment and Wage Estimates." U.S. Department of Labor, Bureau of Labor Statistics. January, 2004.

7.3.3 Costs of Inadequate SCI Infrastructure

With complete information on estimated effort levels, degree of integration by process, and industry data on sales and wage rates, it is possible to estimate the total annual costs to U.S. firms of inadequacies in their supply chain infrastructures. We performed the calculations as specified in the methodology and generated the results listed in Tables 7-6 and 7-7. Total estimated costs for the automotive industry were slightly in excess of $5 billion per year, which equals about 1.25 percent of the total value of shipments. In electronics, the figures were almost $3.9 billion per year, or an almost identical 1.22 percent of the value of shipments. In both industries, roughly 50 percent of the total costs were in dealings with suppliers, while nearly 40 percent arose from interactions with customers. Less than 1 percent of the total inefficiency resulted from purchase costs and annual expenses from software programs.

In order to put these figures into perspective, it may be helpful to consider the costs of operating under each of the integration scenarios to a typical firm in the automotive and electronics industries. Using data from the most recent Economic Census reports, we calculate that the value of shipments for the average automotive parts establishment was $30 million in 1997. Had such a facility operated with traditional supply chain systems, its managers could expect to incur almost $500,000 in annual costs for the logistics and accounting functions described above. Investing in incomplete integration would lower that figure to about $400,000 per year, while implementing an ideal integration strategy would result in a total of $150,000 in annual costs.

In the electronics industry, the average value of shipments for a semiconductor facility is $71 million per year, while a typical computer maker produces about $55 million in annual shipment value. Using the summary data from Table 7-7, we can estimate that a semiconductor facility operating traditionally would incur annual expenses of $1.15 million, while a computer maker would see logistics and accounting costs of about $900,000. Once again, incomplete supply chain integration would lower costs only slightly. Implementation of an ideal system, however, would reduce these expenses substantially – to slightly more than $350,000 for a semiconductor establishment, and to $280,000 for the slightly smaller computer facility.

Table 7-6. Estimated Costs of Inadequate Supply Chain Infrastructure: Automotive Industry

Process Operation	FTEs	Loaded Wage Rates ($/year)	Cost per $100M in Sales ($thousands)	Fraction of Firms	Total Industry Cost ($millions)
Traditional Processes:					
Inbound Logistics	12	$77,780	$933	0.322	$1,211
Inbound Accounting	1.0	$60,160	$60	0.322	$78
Outbound Logistics	7.5	$77,780	$583	0.324	$782
Outbound Accounting	1.0	$60,160	$60	0.324	$79
Incomplete Integration:					
Inbound Logistics	10	$77,780	$778	0.452	$1,417
Inbound Accounting	0.6	$60,160	$36	0.452	$66
Outbound Logistics	6.0	$77,780	$467	0.451	$848
Outbound Accounting	0.6	$60,160	$36	0.451	$66
Ideal Integration:					
Inbound Logistics	4.0	$77,780	$311	0.226	$283
Inbound Accounting	0.1	$60,160	$6	0.226	$5
Outbound Logistics	2.4	$77,780	$187	0.225	$169
Outbound Accounting	0.1	$60,160	$6	0.225	$5
Subtotal–Labor Effort					$4,989
Subtotal–Software				0.452	$58
Total					$5,047

Source: RTI calculations. For details, see text.

Table 7-7. Estimated Costs of Inadequate Supply Chain Infrastructure: Electronics Industry

Process Operation	FTEs	Loaded Wage Rates ($/year)	Cost per $100M in sales ($thousands)	Fraction of Firms	Total Industry Cost ($millions)
Traditional Processes:					
Inbound Logistics	12	$76,320	$916	0.51	$1,475
Inbound Accounting	1.0	$65,020	$65	0.52	$107
Outbound Logistics	7.5	$76,320	$572	0.46	$831
Outbound Accounting	1.0	$65,020	$65	0.43	$88
Incomplete Integration:					
Inbound Logistics	10	$76,320	$763	0.14	$337
Inbound Accounting	0.6	$65,020	$39	0.20	$25
Outbound Logistics	6.0	$76,320	$458	0.32	$463
Outbound Accounting	0.6	$65,020	$39	0.34	$42
Ideal Integration:					
Inbound Logistics	4.0	$76,320	$305	0.35	$337
Inbound Accounting	0.1	$65,020	$7	0.28	$6
Outbound Logistics	2.4	$76,320	$183	0.22	$127
Outbound Accounting	0.1	$65,020	$7	0.23	$5
Subtotal–Labor Effort					$3,843
Subtotal–Software				0.32	$14
Total					$3,857

Source: RTI calculations. For details, see text.

7.3.4 Cautions in Interpretation

As with any study of this type, potential biases are inherent in the data collection effort and the assumptions used to generate a national-scale estimate. Because of the selective nature of the in-depth interviews and the two survey efforts, the aggregate numbers calculated should be used with some caution. The following items deserve mention (for a more comprehensive study they would be part of a sensitivity analysis):

- ***The costs calculated arose from a fraction of total supply chain activities, i.e., the order and inventory management processes.*** Although we believe that these two areas contain much of the inefficiency-related costs now being borne by electronics and automotive industry firms, it is possible that other parts of the supply chain also make significant contributions. This factor in isolation would tend to suggest that our estimates may be conservative.

- ***The subsets of each industry from which we gathered data may experience different levels of supply chain information inefficiencies compared with other, un-surveyed segments of our two selected industries*.** In particular, we did not have strong representation from the lower tiers of either manufacturing sector, which tends to house smaller, less e-capable firms. Large firms that supply basic materials to autos and electronics, including primary metals producers and chemical firms, also likely experience costs of supporting multiple systems and standards; they were also excluded from our study. It is not clear whether a more representative mix would have raised or lowered the resulting estimates, but the possibility exists that future work could explore this potential further.
- ***The geographic limitations of the study were somewhat difficult to nail down, as many of the firms operate globally and their basis for reporting was not always clear.*** We attempted to obtain quantitative data from our in-depth interviews from a consistent geographic region—North America for the automotive industry and the United States for electronics. Although facility-specific labor effort and software cost data should not have been affected by any such uncertainty, some of the sales data used to create the aggregate estimates could have been from a wider geographic area. To the extent that the Census value of shipments data may under-represent the production output of firms in our interviews and surveys, the aggregate costs of an inadequate U.S. infrastructure could be much larger than we estimated (although the value as a percentage of sales would remain unchanged).

8 Implications and Potential Applications of Results

In this study, we have described how the emergence of low cost communications and information processing has made it possible for manufacturing firms to fundamentally change the way they manage their supply chains. The use of XML-based specifications over the internet or proprietary networks can replace costly EDI implementations as well as paper and fax-based communications systems, resulting in considerable savings for the firms involved. The analysis in the previous section suggests that the total cost of managing supplier-customer inventory and schedule information exceeds $5 billion per year in the automotive industry, and almost $4 billion in the electronics sector. Almost all of this cost could be eliminated if firms implemented true interoperability, which we have termed 'ideal supply chain integration'.

In such an ideal integration, each piece of information needed by a supply chain participant is entered only once, preferably through an automated process such as bar code scanning. Subsequent use and dissemination of that information is managed through software programs, without the need of manual intervention or translation. Communication of this information across geography, among facilities within a firm, and between firms is accomplished seamlessly.

This type of interoperability does not yet exist, but firms in both automotive and electronics industries have come close to achieving this ideal state with some or most of their supply chain partners. Full implementation and widespread adoption of interoperability will require significant investments in standards and other critical infrastructures that are not in place today. The evidence from our study strongly suggests that businesses in these two key sectors have not made sufficient infrastructure investments to capture the benefits from interoperability. As we have discussed earlier in this report, the public goods nature of these infrastructures, along with possible coordination failures, suggests that government involvement is needed to support the optimal level of investment.

NIST's expressed purpose in commissioning this study was to determine if there was evidence of market failures in the creation of the critical infrastructures required to create effective integration. A secondary objective was to gather data that would enlighten potential roles taken by NIST's Manufacturing Engineering Laboratory (MEL) and Electronics and Electrical Engineering Laboratory (EEEL) in industry-wide consortia working on improving supply chain information systems. In the judgment of the present authors, the study's results provide support for both of these aims.

8.1 IMPLICATIONS FOR INDUSTRY

The automotive and electronics industries are the two largest manufacturing sectors in the U.S. economy, both in terms of the value of production and number of employees. They contribute significantly to our nation's GDP and have seen substantial growth over the past ten years. In addition, they exert a strong influence on other manufacturing sectors. Strategic directions set by automotive and electronics firms are frequently adopted across other manufacturing sectors; trends in these industries often mirror those in the U.S. economy as a whole.

As estimated in this study, the total costs of inadequate integration are significant—in excess of 1 percent of sales in both sectors. This represents a loss to the owners of manufacturing firms in these industries, including large numbers of shareholders and proprietors, as well as welfare losses to final consumers of products produced by these companies. Moreover, the lower profits resulting from these infrastructure inadequacies reduce investment incentives at the affected levels in the supply chain and thereby indirectly reduce domestic employment growth.

Although no evidence was collected on the level of expenditures that would be required to create the infrastructures needed to eliminate these excessive costs, it seems unlikely that they would compare with the $3 to $5 billion dollars per year being lost. Current initiatives in supply chain working groups at AIAG, OESA, and ODETTE in the automotive industry, as well as the more well-established electronics efforts at NEMI and RosettaNet, provide evidence that firms in these sectors believe that investments in integration infrastructures are justified. Nonetheless, the relatively slow pace of progress and the magnitude of unrealized benefits give evidence that private efforts are unlikely to produce the desired results without assistance from the public sector.

Second, the mismatch between those who would benefit greatly from an improved infrastructure, namely the first-tier firms, and those who would need to make additional investments, the lower-tier companies and many of the OEMs, supports the contention made in this study that a *coordination failure* may be preventing optimal levels of investment. This is especially relevant for historical and current behaviors in the automotive industry. The OEMs' continued efforts to drive down prices through automatic cuts and threats of loss of business have made coordination of infrastructure investments even more difficult.

As evidence of this difficulty, our contact at one of the firms we profiled in the last section observed that Tier 1 firms have been very reluctant to share information on logistics issues and systems efficiencies with their OEM customers. Many in top management positions in these companies are convinced that if they turn over proprietary information on product specifications, details of production operations, line configurations, and information flows, this will provide more opportunities for OEMs to extract price concessions.

Recent announcements that OEMs and first-tier firms may move production overseas provide more evidence of a lack of coordination. Aside from the strategic threat contained in these announcements, it is difficult to believe that moving a portion of the supply chain to East Asia would be a profitable option. In the first place, it is still the case that automobile parts have low value-to-weight ratios; as a result, they are difficult to ship long distances without losing money. Second, the entire automotive supply chain is built around just-in-time deliveries, with most factories located within 30 minutes' to 2 hours' transport time from their next-in-line customers. It certainly does not seem logical to move one or more operations 4,000 miles away, adding several days' or weeks' transit time to the inventory pipeline. Although complete manufacture of automobiles in China certainly is possible (or shipment of castings or chassis units from China to Korea or Japan for final assembly), it is very unlikely that substantial components business can profitably move overseas in the lower tiers. The Far East, North America, and Europe will very likely remain as distinct manufacturing centers for a long time to come.

However, this does not mean that suppliers are not threatened. All of the major OEMs have announced intentions to reduce their supplier base by a factor of at least 2 or 3 over the next major product cycle. This relentless pressure, along with the OEM's active oversight of profits from their suppliers, makes it likely that the recent spate of bankruptcies and mergers will continue. Only by making themselves more efficient, perhaps through more efficient supply chain integration, can first-tier and lower-tier suppliers hope to assure their future.

In electronics, the movement toward contract manufacturing, use of EMS providers, and wholesale relocation of the manufacturing supply chain will continue. The information improvements over the past 2 decades have made it possible, albeit risky, to supply the entire U.S. market from East Asia. Unlike automobiles, computers and their major components have a high value-to-weight ratio, so they can be shipped long distances at low unit cost. The largest risk within the supply chain is that the 1- to 2-month pipeline includes a lot of expensive inventory that may become obsolete prior to final sale. The next section focuses more on trends concerning globalization and associated risks.

8.2 IMPLICATION FOR THE GROWTH OF GLOBAL SUPPLY CHAINS

For many firms, the motivations to globalize trade are substantial, particularly in industries such as electronics, where efficiency and just-in-time delivery are necessary to keep up with market demand and new technology turnover. However, greatly increased complexity will accompany the transition to more global supply chains, and often the risks will be very uncertain. As an example, Li & Fung (previously discussed in Section 3.4.2) has succeeded because they are experts at understanding supply chain intricacies and potential problems, and they are able to react quickly and ensure timely and cheap manufacturing and shipping operations. However, when SARS became widespread in China and Hong Kong, Li & Fung, like many other companies, was caught unprepared. According to Dr. William Fung of Li & Fung Trading, “It shows you can’t have all your eggs in one basket as far as sourcing product is concerned. So the idea of having a diversified base of production and sourcing is very important” (Louie, 2003).

As the time between transactions decreases, the need for a more complete understanding of the inhibitors to more global trade (see Section 3.3.2) increases. Unfortunately, as supply chains become more global, the players in a supply chain lose more and more control over these potential problems. As such, investments by companies and government agencies, such as NIST, could reduce risk as well as leverage efficiency.

In comparison with other companies around the world, U.S. firms have not been consistent leaders of global supply chain efforts. U.S. automobile manufacturers have only recently reorganized on a North American basis to take advantage of post-NAFTA strategic realities, and are just now beginning to consider possible cost benefits from the use of truly global supply chains. In fact, the importance of transportation costs and need for just-in-time deliveries have induced many first-and second-tier automotive suppliers to move even closer to OEM facilities. This is certainly true of suppliers to the 'New American' automotive firms like Toyota and Honda; many of these suppliers have opened up facilities in the U.S. in place of their far-away East Asian operations. It remains to be seen if the extremely low labor costs in China will reverse this trend.

8.2.1 More Small Firm Players

As globalization continues to become more pervasive, firms that have never attempted to export any products and/or have relatively small customer bases are considering developing more global supply and distribution networks, and those that are not, should be. To compete in today’s marketplace, companies large and small are being forced to outsource operations in which they do not have expertise, or face the possibility of going out of business. Small businesses often take the brunt of this trend, as large companies such as Wal-Mart, which operate fully global, efficient supply chains, use global resources and their expansive buying power to undersell their competition in most cases.

However, the Department of Commerce has said that the number of companies with fewer than 100 employees that export merchandise increased from 96,000 in 1992 to almost 213,000 in 2001, accounting for almost $130 billion in exported goods. Donna Sharp, executive director of the World Trade Institute of Pace University in New York, was quoted as saying, “There is a new culture and openness in international business today. With a little know-how, creativity and confidence, even the smallest business can find opportunities around the globe” (Levere, 2004). As an example, in a matter of 5 or 6 years, Gayle Warwick started a global business that makes handmade bed and table linens; today, she uses labor in both Europe and Vietnam and sells to the United States and Britain, and she only just recently decided to hire a second employee (Levere, 2004).

As the availability of information has increased, smaller businesses are easily able to access global contacts and resources. In a *BusinessWorld* article, Hannah Ira V. Alcoseba writes that smaller businesses actually have an advantage because they have more flexibility. She encourages small organizations to focus on a small number of products that they can produce efficiently and outsource other activities. Similarly, she advises larger companies to rely more on smaller companies because of their flexibility, speed, and specialized nature (2003).

8.2.2 Increased Delays

The relentless movement toward global supply chains, based on a set of labor and market factors, will raise the importance and hence the cost of failures dramatically, whether these failures are caused by poor information on physical flows, quality defects, multiple data format and other institutional-based infrastructure issues, or cultural/political factors such as overt acts of sabotage or terrorism. U.S. automotive suppliers face fines upwards of $500,000 per hour if they cause the shut down of an automobile assembly line, a figure that reflects the economic loss from idling people and equipment due to lack of parts. Extended, complex supply chains may raise the probability that a system failure occurs, as well as reduce options for ameliorating the situation.

As an example, last September, the 10-day shutdown of West Coast shipping ports prevented many retailers from ordering adequate holiday merchandise. According to Peter Gatti, vice president for international policy at the National Industrial Transportation League (a group of cargo shippers), such a problem mainly affected “retailers that source a lot of their materials through Southeast Asia and Central Asia. . . when the spigot closes, you’re going to get shortages and retailers have been particularly affected by that.” As a result, many retailers found themselves unable to replenish toy store shelves before the holiday season came to a close (Chartier, 2002).

The reality is that increased globalization in the past has led to less expensive goods and increased profits for many companies, U.S. and foreign. However, as globalization has increased, new political, economic, and cultural issues have complicated supply chains, and increased collaboration between governments and industries is necessary to protect the U.S. economy while continuing to enable more efficient business practices to reduce prices for consumers.

8.2.3 Necessary Infrastructure Investments

Investments in infrastructures to support global supply chains, including hardware and software standards, information languages and protocols, and financial accounting and clearing systems, must increasingly be made across national boundaries. In the past, the focus of NIST's efforts has broadened from the United States to North America (due to NAFTA) to industrialized nations generally (through ISO and other international efforts). Today, however, as the market becomes more global, there is growing need for leadership in both international trading and standardization arenas.

8.3 IMPLICATIONS FOR NIST

The aggregated estimates produced by the case studies and industry surveys should prove useful in identifying the rough magnitude of NIST's opportunity in supporting the creation of a better standards infrastructure. As with any prospective study, the estimates generated are most useful in helping government agencies such as NIST prioritize their available resources and justify why additional resources are needed in areas such as interoperability, where the costs of inadequate infrastructure are high. The results of this study support implementation of the Enterprise Integration Act passed by Congress in 2003 that *authorized* NIST to provide leadership in supply chain integration.

Eliminating all of the inefficiencies in supply-chain information systems will likely prove impossible because of their high level of complexity and rapid pace of change. New supply-chain partners will enter the system, some with a low level of capability, others with incompatible legacy systems that must be integrated or adapted. Business and technical conditions will change, and today's optimal infrastructure will likely become inefficient. Realities of business rivalry among competitors and customer–supplier pairs may prevent close cooperation, even with neutral party leadership and coordination. Thus, an effective infrastructure support program is required that is of sufficient size and also flexible enough to respond over time to the dynamics of complex supply chains.

Second, there will be a significant resource cost to government organizations and all involved supply-chain members in developing and implementing new standards regimes. Firms must invest in time, human capital, and information systems software and hardware and incur startup costs to make the improvements that will lower their costs. Any subsequent analysis of the benefits generated by such a program will need to consider these costs, as well as evaluate the participation of supply-chain software firms and solutions providers, a now struggling business sector that will undoubtedly be thriving once a (nearly) optimal standards structure has been established.

In summary, the analyses conducted in this study indicate that government laboratories such as NIST can help address the need for infrastructure investment, a public good that otherwise would fail to receive sufficient private investment.

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Appendix A:
Site-Visit Guide

A.1 INTRODUCTION

Firms across the country have invested heavily in Supply Chain Integration (SCI) over the past several years, in an attempt to improve operating efficiency, reduce inventory cost and risk, and increase their responsiveness to new business opportunities. RTI and Altarum have been asked by the National Institute of Standards and Technology (NIST) to conduct a study that will estimate costs from inadequate standards that support SCI, in both the Automotive and Electronics Industry supply chains. The size and complexity of these supply chains make this a daunting task for any researchers, and our organizations greatly appreciate any help you can give us in completing our study. If the potential savings are found to be significant, NIST may be able to invest in leading a process similar to the one that developed STEP for the interchange of product data. We believe that the introspection provided by your support of this research can bring added benefits to your firm, and that the completed study may raise the level of interest within the automotive industry about the need for additional standardization in SCI.

A.2 SCOPE

In order to make this project manageable, we need to carefully define the scope of analysis, and would value your guidance in this effort. The breadth of supply chain information exchange is too large for any single study of this type—more than 150 separate businesses processes make up the supply chain, each of which offers some opportunity for improvement. We can divide these information processes into several major areas: accounts, products, orders, inventories, manufacturing data, marketing data, and service and support. In which of these major areas:

- are you actively involved in supply chain integration activities;
- have you spent significant amounts of money in supporting;
- do you see the greatest potential for savings from integration?

Are there specific activities within each of the areas you indicated that have occupied most of your efforts, expenditures, and future plans? For instance, is providing inventory visibility the primary focus of your integration efforts? What about XML-based online product catalog information? For the remainder of this interview guide, we would like you to focus on providing information related to those areas you have identified in this scope section.

A.3 YOUR DEGREE OF INTEGRATION

Our background research and preliminary discussions with automotive industry experts has convinced us that there is a broad spectrum of integration activity and capability across the industry, including what Altarum has called 'e-readiness'. Could you identify for us where you believe your company or division would fit in to the following integration taxonomy? (If different parts of your firm are at different stages, we would be interested in exploring each one.)

- Total integration—most or all critical and costly activities are linked through interoperable systems, approaching the ideal – each piece of data is entered once, and becomes instantly available to all other users of the system, both human and electronic.
- Inefficient integration—most or all critical and costly activities are automated, but different, non-interoperable systems are used, requiring high levels of support, custom translators, manual data re-entry
- Incomplete integration—many or most critical activities are not automated, requiring a great deal of human intervention - manual data entry and re-entry, routine expediting of production and shipments, extensive use of telephone and fax

A.4 COSTS OF INEFFICIENT INTEGRATION

In evaluating STEP and several other NIST initiatives, RTI and Altarum have successfully used an engineering-cost approach to estimate costs related to inefficient and incomplete integration. We would be interested in obtaining quantitative estimates from you (in the areas outlined in the scope section) about activities and costs for the following measures related to inefficient integration:

1. Support of multiple information systems, including capital cost or annual license fees, upgrade and maintenance contracts, labor costs for operating and supporting systems, training costs including out-of-pocket fees and effort hours for trainees
2. Capital and operating costs for custom translation programs used to link incompatible information systems, whether developed in-house or purchased
3. Number of people whose primary function is manual re-entry of data, and estimated annual labor costs for these positions

A.5 COSTS OF INCOMPLETE INTEGRATION

If there are areas within your firm where integration is less-developed, and would be best described as incomplete, we would like to obtain information from you on the following activities and costs:

1. Number of people whose primary function is original entry of data, including product, price, marketing, order, production, schedule, shipment, and billing information, and estimated labor costs for these positions
2. Number of people whose primary function is expediting or managing exceptional supply-chain events, such as emergency orders, cancellations, quality problems, and estimated labor costs for each

A.6 ORGANIZATION-WIDE DELAY COSTS

A final aspect of the costs related to and inadequate standards infrastructure (and therefore a lack of widely-available interoperable software products) relate to delays caused by incomplete or inefficient integration. As an example, in the electronics industry, rapid demand changes lead to frequent delivery schedule modifications, yet a batch EDI order-update job is run only once per day. This delay leads to frequent missed expectations, as well as a high level of product scrapping. Have you studied or can you estimate, at the level of the entire organization (division, company), annual economic or financial losses from these types of delays caused by lack of integration:

- Costs of scrapping products made but not sold due to order/shipment changes not communicated in a timely manner
- Penalties paid or discounts lost due to late shipments caused by information delays
- Premium costs, including overtime labor and rush shipment charges, incurred in attempting to meet customer-imposed shipment schedules
- Lost business from failure to meet customer expectations on delivery or responsiveness

A.7 CONCLUSION AND THANKS

We appreciate your time and efforts in helping RTI and Altarum with this important study for NIST. We would like to be able to follow-up with you at a later date if we have additional questions. In addition, RTI would be happy to send you a copy of the final report once it has been approved by NIST. Thanks again for your assistance!

Appendix B: Automotive and Electronics Industries Survey

Questionnaire: Automotive and Electronics Industries

Introduction

On behalf of the National Institute of Standards and Technology (NIST), RTI International is evaluating the cost associated with an inadequate standards infrastructure for supply chain integration (SCI) in the automotive and electronics industry sectors. Costs can arise in the form of investments in purchasing and supporting multiple information systems, excess effort required to interface with incompletely integrated systems, labor hours consumed in resolving problems with supply chain software interoperability, and costs stemming from information-related production delays. These costs are determined through assessing current adoption of SCI software by members of a supply chain and gauging relative inefficiencies within uninvested companies.

As a member of an industry that is actively involved in supply chain interaction, you have unique insight into the nature of supply chain management issues. The information you provide will help NIST better assess the benefits of supply chain integration projects and the needs of your industry in particular. Consequently, NIST will be better prepared to channel future investments toward projects that best meet those needs.

Questionnaire

Please answer the questions in the attached questionnaire with reference to your work in supply chain management and feel free to collaborate with colleagues when answering these questions. The data you provide will be considered confidential and will *only* be used in aggregate with other companies; no third parties will have access to this information.

If you have any questions about the purpose of the survey or how to answer the any of the items therein, please feel free to contact Brent Rowe via email at browe@rti.org or by phone at (919) 485-2626.

Thank you for participating in this survey.

1. Company Background Identification

This section requests background information on your company and your role within your company. As indicated earlier, your individual response to this questionnaire is confidential and will not be shared with any third parties, including NIST. Any information you choose to provide will be aggregated with other responses for analysis and results-reporting purposes.

Company Name: ____________________

Mailing Address: ____________________

Contact Name: ____________________

Title: ____________________

Phone Number: ____________________

E-mail: ____________________

Are you providing responses to this questionnaire for your division or your entire company? (Hereafter, your company or division will be referred to as "organization.")

☐ Division ☐ Company

At what tier of the industry supply chain would you characterize your organization?

☐ OEM ☐ Tier One ☐ Tier Two ☐ Subtier

What is your organization's approximate annual sales revenue for which your response is relevant?

$________ Dollars per year

__________ percent of total company sales associated with your division, if applicable.

2. Methods for Coordinating Supply Chain Management Activities

This section asks you to reflect generally on how your organization manages the exchange of supply chain information, such as purchase orders, schedules, and inventory levels.

How do you accomplish the exchange of supply chain information with your suppliers?

____

____

____

How do you accomplish the exchange of this information with your customers?

____

____

____

How does your organization manage the following seven supply chain management processes? Please indicate whether you use an automated or manual process for these activities. Additionally, please estimate the labor effort required (in full-time equivalent workers, or FTEs) to support each process.

Process	**Automated**	**Manual**	**Effort (FTEs)**
Managing Partner Information (e.g., account maintenance, credit approval)	☐	☐	
Managing Product Information (e.g., distribution of new product data, notification of product change)	☐	☐	
Order Management (e.g., checking order status, requesting price and availability, sending shipment notification)	☐	☐	
Inventory Management (e.g., distributing inventory reports)	☐	☐	
Managing Manufacturing Information (e.g., work order change notification, checking status of work in progress)	☐	☐	
Managing Marketing Information (e.g., distributing product list)	☐	☐	
Service and Support Management (e.g., requesting a warranty claim)	☐	☐	

If you would like to comment on your organization's method of coordination for each activity, please use the space provided below.

____

____

____

Has your organization encountered technical complications in managing the exchange of these supply chain information processes?

____

____

____

Approximately how many suppliers did your organization work with in its manufacturing operations in 2002?

_________ Suppliers

Approximately how many customers did your organization supply in 2002?

_________ Customers

3. Supply Chain Information Technology Investment

This section asks you to reflect on your organization's information technology investment in the management of supply chain information. Where percentages are requested, please provide approximate values based on your working knowledge.

3.1 Electronic Exchange of Supply Chain Information

Does your organization use EDI? EDI (electronic data interchange) is defined as the electronic interchange of processable data between computers.

- ☐ No
- ☐ Yes, for approximately _____ percent of business transactions
  - ☐ With your customers
  - ☐ With your suppliers
  - ☐ Internally, i.e., between your firm's manufacturing locations

Does your organization use XML-based systems? XML (extensible markup language) based software systems are defined as programs that allow standardized, automated information flows within and between organizations via the Internet, enabling the definition, transmission, validation, and interpretation of data between applications and between organizations.

- ☐ No
- ☐ Yes, for approximately _____ percent of business transactions
  - ☐ With your customers
  - ☐ With your suppliers
  - ☐ Internally

If applicable, please list supply chain integration and EDI or XML-based software systems your organization uses, including ERP (enterprise resource planning), PDM (product data management), and translator systems that manage supply chain information. Examples of commonly used software include iSupply, Powerway, BRAIN, BPCS, , and EDIFACT EDI.

Please also include the year the software was installed, approximate installation and startup costs, and information on licensing.

Software	First Year Used	Installation/startup cost (one-time fee)	Approximate Licensing Fee (annual)	Number of Licenses

If you would like to comment further on your software systems, please use the space provided below.

____

____

____

3.2 Software Users and Information Technology Staffing

How many employees in your organization use one or more of your aforementioned software programs for supply chain activities?

__________ Employees

Of this number, what is the average number of systems supported by each employee?

__________ Systems

On the average, how many hours of software training per user does your organization sponsor in a typical year?

__________ training hours per employee

What is the total level of IT staffing and support your organization employs for operating and maintaining your supply chain information technology investment?

__________ number of network systems administrators

__________ number of software support specialists

3.3 Supply Chain Integration Activities

Has electronic supply chain integration increased productivity (reduced the number of working hours needed) to fulfill business interactions with customers and suppliers? Please provide a percentage estimate based on your working knowledge.

☐ Yes, supplier interactions productivity increased by _____ percent

customer interactions productivity increased by _____ percent

☐ No,

☐ productivity did not change

☐ productivity decreased by _____ percent

☐ Don't know

Did your organization contract with an outside consulting firm to facilitate supply chain integration?

☐ Yes; approximate fees paid: $_____

☐ No

4. Manual Labor Effort Required to Manage Supply Chain Information

Does your organization use any of the following manual processes for customer/supplier interactions? Please estimate the number of employees involved in these activities, and the approximate hours each employee may spend on those activities in a typical month. If you would like to comment on the software system, please use the space provided in the comments field.

Activity	Total Number Employees Engaged in Activity	Typical Number of Hours per Month, per Employee for This Activity
Manual data reentry		
Faxing or phoning supply chain information		
Expediting delayed or overdue inbound or		

outbound shipments		
Resending information electronically		
Other		

If you would like to comment further on these activities, please use the space provided below.

5. Added Costs from Incomplete or Inefficient Exchange of Supply Chain Information

Have supply chain data exchange problems caused delays that have led to incurrence of premium operating or freight costs, payment of late charges or penalties, the need to rework or scrap finished product, or lost product sales in the last two years?

Cost Incurrence Category	Check Box if Yes	Approximate Average Cost per Occurrence?	Number of Occurrences in Last Two Years
Premium operating or freight costs	☐	$	
Payment of late charges or penalties	☐	$	
Rework or scrap finished product	☐	$	
Lost product sales	☐	$	
Other	☐	$	

If you would like to comment further on these activities, please use the space provided below.

6. Thank You Very Much for Your Participation in this Survey.

Are you available for further comments about supply chain management?

☐ Yes ☐ No