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Virtual Enterprise Model for the Electronic Components Business in the Nuclear Weapons Complex

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Abstract

The electronic components business within the Nuclear Weapons Complex spans organizational and Department of Energy contractor boundaries. An assessment of the current processes indicates a need for fundamentally changing the way electronic components are developed, procured, and manufactured. A model is provided based on a virtual enterprise that recognizes distinctive competencies within the Nuclear Weapons Complex and at the vendors. The model incorporates changes that reduce component delivery cycle time and improve cost effectiveness while delivering components of the appropriate quality.

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Executive Summary

The Enterprise Integration Team was commissioned by directors from Sandia National Laboratories and AlliedSignal/Kansas City Plant to develop a virtual enterprise model for the electronic components business in the Nuclear Weapons Complex. This model was developed with a primary focus on the electronics components business; however, most of the infrastructure and many of the concepts are directly applicable to any portion of the Nuclear Weapons Complex business. By re-designing the electronic component business the team identified efficiencies that will reduce the product realization cycle time to approximately one half the current cycle time with commensurate savings projected in cost.

It is critical for the Nuclear Weapons Complex to adopt and implement these enterprise characteristics. If they are not adopted, it will be impossible to support customer requirements for faster product realization cycles and reduced costs. Future customer requirements will have smaller production quantities and will expect fewer development cycles and lower costs. These benefits can only be achieved by partnering in a virtual enterprise arrangement.

The model proposed suggests significant changes in business practices and organizational structures within the Nuclear Weapons Complex. The team developed the following recommendations to realize the model proposed in this report:

- Form a Virtual Enterprise Process Management Team comprised of technical, business, and legal participants from DOE, AS/KCP, and SNL.
- Develop an implementation road map
- Benchmark against other virtual enterprise corporations
- Integrate with existing re-engineering activities
- Begin implementation in key areas such as creating business and legal agreements, developing information infrastructure, developing business practices to enable heavyweight project management, and developing preferred suppliers
- Develop and implement a pilot project

Five key objectives were derived from the mission statement and stakeholder interviews. These objectives are: improving cost effectiveness, reducing cycle time, providing components of appropriate quality, minimizing the number of people involved, and broadening the electronic component base for the enterprise partners. All the characteristics of the enterprise had to support one or more of these objectives and all objectives were supported by the resultant model.

While there are local areas of strengths in the present business structure, the overall analysis suggested that a major paradigm shift in the organizational, business, and engineering practices needs to occur to achieve the desired objectives of the electronic components business. The intent of the as-is analysis was to uncover strengths and weaknesses to determine which existing practices need to be nurtured and where improvements could be made. The analysis included development of work and information flow diagrams for representative electronic component lines. The work flow diagrams show that there are many steps considered to be non-value added activities such as walking purchase orders through, negotiating ICOs, TMS of suppliers and transferring design drawings into manufacturing drawings. These non-value added activities significantly impact cycle times, product cost, and the frustration level of the people involved. Information flow diagrams show that there is redundant data entry from one system to another

and a general lack of system integration. In addition, the organization structures and current technology systems were examined. It was determined that the current organization structure hinders effective cross-organizational teaming. The limited synergy between organizations tends to result in narrowed approaches taken in developing solutions. The technology systems assessment indicated that our present systems are not integrated and primarily focus on point solutions to identified problem areas.

Key areas having the highest impact on the objectives were identified as: information technologies, supplier partnerships, procurement system, integrated definition configuration management system, and approval cycle times.

Enterprise characteristics developed for work, information flow, technology and organization areas were the basis for the model. Key characteristics of the proposed virtual enterprise include the following:

- Enterprise legal/business agreements and strategic plan
- Dynamic Integrated Product Teams working with customers, suppliers, designers, and manufacturers in a concurrent engineering environment to capture evolving component definitions in product realization scripts. Teams are led by customer-focused heavyweight project managers.
- Use of pre-qualified suppliers and subscription to a supplier management system
- Manufacturable designs based on capable processes
- Integrated information technology systems providing:
  - excellent communications via email, file exchange and interactive video
  - guidance to resources, experts, process history, design history, and design guides through an expert knowledge based system
  - desktop accounting and common cost identifiers for the enterprise
  - instantaneous initiation of procurement activity and funds transfer

By applying the model to specific business cases, the team demonstrated that cycle time reductions up to 60 percent with corresponding reductions in development costs could be realized by the enterprise. Other key customer benefits include the delivery of appropriate quality components, the enterprise staying ahead of customer needs, the expansion of technology transfer, a unification of the nation's two industrial bases (defense and general commerce), and the contractors' ability to focus on strengths.

Fundamental barriers to creation of the Enterprise are the current organizational structure and the traditional business practices within the Nuclear Weapons Complex. Each site has specific missions, and funds are allocated from DOE according to those missions. Funding mechanisms are defined by project rather than technology capability. In addition, the Enterprise can only thrive with cross-functional product teams. Personnel and business practices enabling heavyweight project management are necessary for this environment. Finally, government procurement regulations impede creation of the necessary working relationships with industry for supplying components and/or the materials needed for manufacturing.

1. Scope

1.1 Objective

The purpose of this project was to develop a model that fundamentally changes the way electronic components are developed, procured and manufactured. These changes will reduce component delivery cycle time, provide components of appropriate quality, and improve the cost effectiveness of the electronic component business.

1.2 Background

In order to provide the highest value to the Department of Energy (DOE) Defense Programs customers as well as the non-traditional customers, Ray Bair and Jim Searcy, Directors of Sandia's Electronics Components and Manufacturing Technologies Centers respectively, and Dennis Cummings, Director of Engineering and Information Services at AlliedSignal's Kansas City Plant, made a commitment to examine ways to enhance the electronic components business. As a result, they chartered a team in November 1993 entitled "Enterprise Integration" consisting of Sandia National Laboratories/New Mexico (SNL/NM), Sandia National Laboratories/California (SNL/CA), and AlliedSignal/Kansas City Plant (AS/KCP) personnel to create a seamless business model which allows SNL and AS/KCP, together with key vendors, to operate as a virtual enterprise offering maximum benefit to the electronic component customers. The team defines a virtual enterprise as:

> An enterprise comprised of multiple companies that work in cooperation so that they appear as a single entity to their customers. This includes creation of an agile environment where appropriate interfaces with suppliers are in place in anticipation of the customers' broad applications and needs.

Electronic components considered in the model include devices such as resistors, capacitors, application specific integrated circuits (ASICs), cables, hybrid microcircuits and printed wiring boards.

The electronic components business within the Nuclear Weapons Complex (NWC) is very diverse. Early on, the team discovered that a unique development process is used for virtually every device family. Because it was neither possible nor useful to investigate each component's development process, the team divided electronic components into four lines of business. This report provides generic models for each of these business lines and includes all processes beginning with establishing customer needs and ending with delivery of production devices. The four lines of business are defined as:

- **NWC Designed, NWC Manufactured** where SNL is the design agency and AS/KCP is the production agency. Examples include cables and hybrid microcircuit networks.
- **NWC Designed, Industry Manufactured, AS/KCP Procured** where SNL is the design agency, the component is manufactured by industry, and AS/KCP is responsible for procurement of production devices. Examples include some integrated circuits and specially designed capacitors.
- **NWC Designed, Industry Manufactured, Manufacturing Development Engineering (MDE) Procured** where SNL is the design agency, the component is manufactured by

industry and SNL procures the part through the MDE program. Examples include Application Specific Integrated Circuits (ASIC) and Surface Acoustic Wave (SAW) devices.

-- **NWC Specified, Commercially Available** where SNL specifies a commercially available component and AS/KCP procures the devices for production. Examples include standard capacitors, inductors, and logic families.

Note: These four lines of business are reduced to three in the "to-be" virtual enterprise environment. This is because the enterprise procurement process does not differentiate between whether SNL or AS/KCP does the procurement.

1.3 Mission Statement

The team composed and followed the mission statement below:

> The Enterprise Integration Team shall propose a model for how to partner in the selection, evaluation, development, procurement, and manufacture of electronic components. The model will be based on a virtual enterprise that recognizes distinctive competencies. The enterprise will be seamless and of maximum benefit to the customer. This model will define the elements and their functional relationships required to successfully implement a virtual enterprise.
>
> The team will identify business practices, communication methods, and processes that are required by the virtual enterprise. In addition, barriers to implementation and payoffs from adoption will be identified.

1.4 Overview of Cross-Organizational STEP Adoption Tool (COSAT) Process

Two consultants, Mitchell Fleischer and Michael Wood from the Industrial Technology Institute (ITI), trained and facilitated the EIT in the methodology for the virtual enterprise analysis and design. The process used is called the COSAT Process.[1] COSAT is a computer software tool designed to assist a company in making business changes that gain the maximum benefit from technologies and human resources.

In addition, Fleischer and Wood provided information about best practices in concurrent engineering based on various studies and cases from many companies. These best practices include the following basic elements:

- Strong interface with the customer
- Top down systems engineering design approach
- Multi-functional and multi-disciplinary teams, and continuity of teams
- Engineering optimization of product and process characteristics
- Design benchmarking and soft prototyping
- Simulation of product and downstream process
- Experiments to confirm/change high risk predictions
- Early involvement of subcontractors and suppliers and corporate focus on continuous improvement and lessons learned.

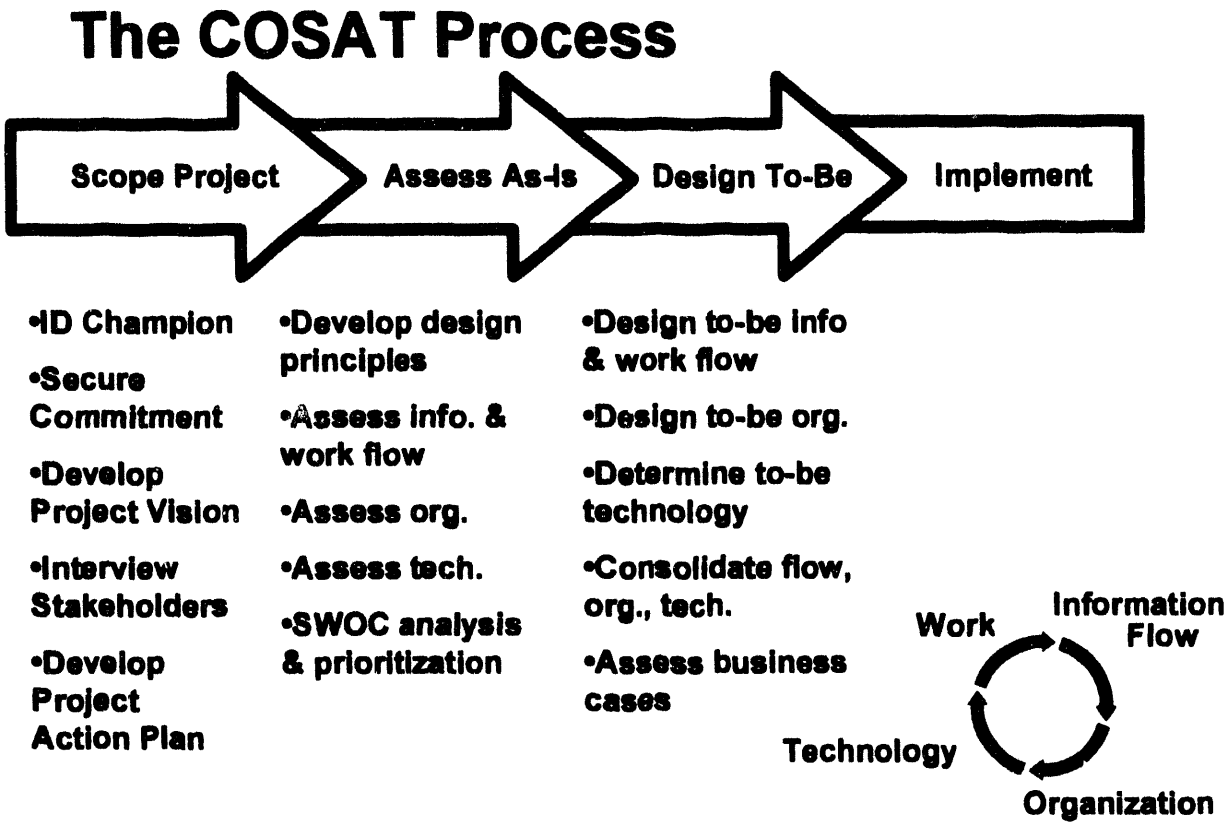


Figure 1: Overview of the COSAT Process

The business organization design process within COSAT is somewhat traditional; however, the planning provides a framework for designing organizations and systems which meet concurrent engineering objectives. There are four major phases of the COSAT Process: project scope, assess as-is, design to-be, and implementation as shown in Figure 1. Throughout the process, the relationship between work, information flow, technology, and organization are evaluated and considered in the design.

Summary of Stakeholder Interviews

As a part of the baseline assessment process, stakeholder interviews were conducted. The stakeholders indicated that business changes are needed to foster the following characteristics:

- Teaming
  - Cooperation versus competition
  - Joint strategic planning
  - Practice concurrent engineering
- Business Practices
  - Use only value added processes
  - Get paper out of procurement process

- Weapons complex needs to operate like a private business

- Flexibility
  - Adapt to change rapidly
  - Do not force one process for all situations
- Communication
  - More openness and trust
  - Minimize location barrier by using electronic communication system

1.6 Design Principles and Enterprise Objectives

The first step in assessing the current environment and in preparing for design of a new environment is to establish a common set of principles to guide the process. Principles are the essential beliefs we hold about the way things ought to be and on which we base our actions.[1] The following design principles, the project team believes to be the key ingredients to a successful enterprise, were established.

1. The voice of the customer is the focus throughout the process.
2. Points of contact are established that facilitate satisfying the customer.
3. There is distributed general knowledge on the process of adding value to the customer.
4. Product-focused leaders are appointed for all important development projects.
5. Single points of primary responsibility and authority are required for each major task.
6. Decision making occurs at the lowest level and is traceable.
7. All stakeholders affected by a decision is represented by the decision.
8. Appropriate coordinating mechanisms to manage interfaces are developed.
9. Process driven, concurrent legal and business practices are in place.
10. Design history is captured and used.

Being guided by the mission statement, and following these design principles, the team derived the following five major objectives for the enterprise:

1. Improve cost effectiveness of the electronic component business
2. Reduce component delivery cycle (concept to delivery)
3. Provide components of appropriate quality (meets customer's electrical, mechanical, and environmental requirements)
4. Involve a minimum number of people
   - enable maximum two-stop contact to identification of project leader
   - use dynamic integrated product teams
5. Broaden the electronic component customer base

Each of these objectives is addressed in more detail throughout the report.

2. Assess As-Is

2.1 Overview - Top View Diagram and Description

Currently, the responsibilities for selection, evaluation, development, procurement and manufacture of electronic components for the NWC is divided between the design agency

(Sandia National Labs), the production agency (AlliedSignal/KCP), and selected vendors. Figure 2 shows a top level view for the as-is environment. While the missions of the companies overlap considerably, each company creates its own strategic plan and independently manages its roles in the component business.

Traditionally, Sandia's role is as the design agency. The electronic component customers are internal Sandia sub-system design departments or external customers interfacing with Sandia component engineers. Development of components is completed through various Sandia and AlliedSignal organizations. Each organization at Sandia is managed independently of the others and of similar counterparts at AlliedSignal. The purchasing, accounting and legal systems are designed to meet Sandia's needs, the requirements of our Managing and Operating contractor (Martin Marietta Corporation), and DOE.

Similarly, AlliedSignal/KCP's role is as the production agency. As next assembly engineers select components, the requirements are given to AlliedSignal for production support. AlliedSignal has various organizations dedicated to the production or procurement of these components. The Kansas City Plant's purchasing, accounting and legal systems are designed to meet their objectives in congruence with the parent company (AlliedSignal), and DOE.

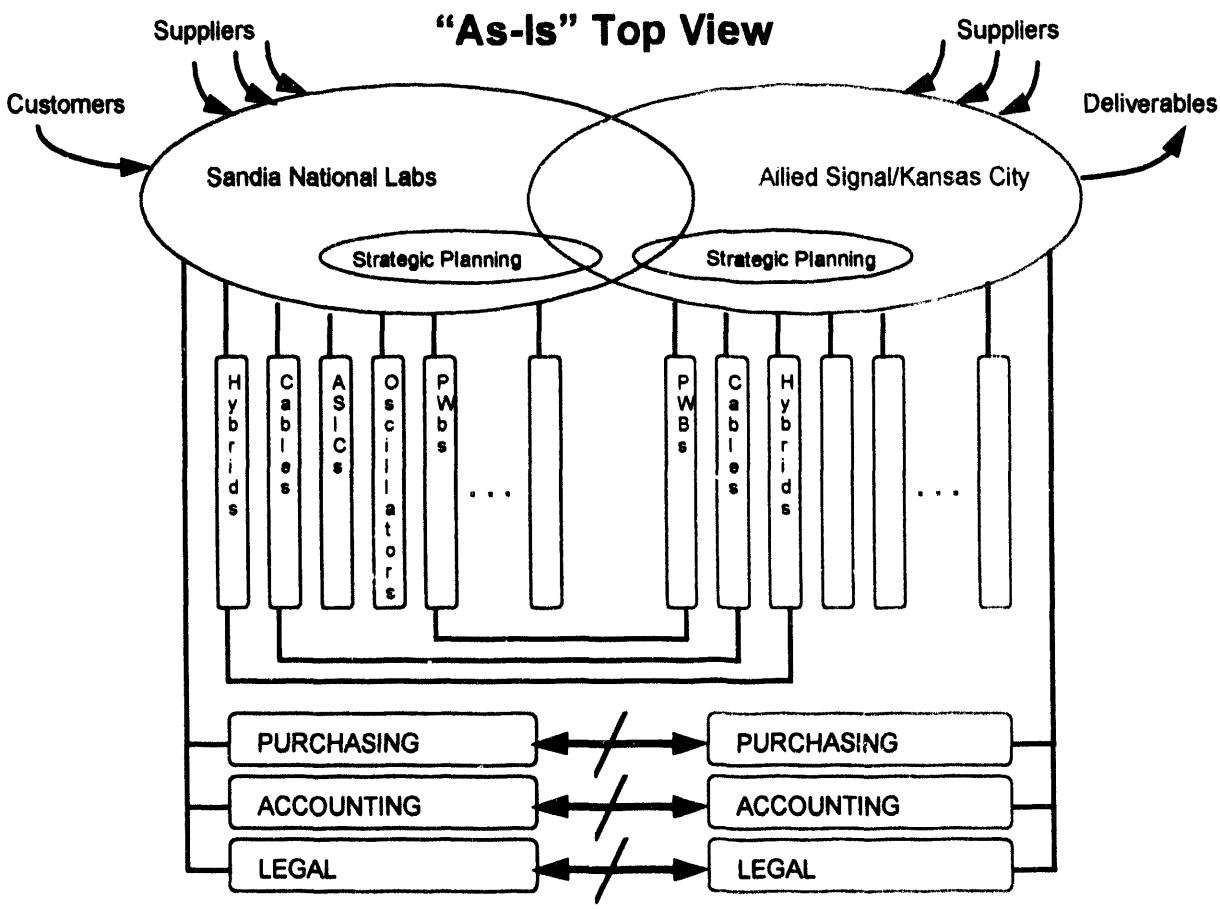


Figure 2: As-Is Top Level View

In this environment, work tends to be done serially and significant resources are dedicated to technology systems that support each company independently. A great deal of time is spent transferring information between non-compatible systems. Frequently the customer is the common party insuring that the final product meets requirements.

In addition, activities at sites overlap due to different business practices. Suppliers who work with Sandia in early development efforts and then with AlliedSignal for production activities must completely re-negotiate the terms and conditions of contracts as the responsibility for the product transitions from one company to the other.

2.2 As-is Work and Information Flows

To better understand the relationships between how AS/KCP and SNL work with each other and with their vendors, high level work and information flow diagrams were constructed to model the four lines of business. These generic models represent the majority of work that we do. The flows were generated from the perspective of the Project Leader, and were primarily based on the experiences of the team members. Work flow describes how tasks move through Sandia and AlliedSignal and to the vendors for items that are purchased from outside the NWC. The information flows model the movement of information, usually by paper, in the current system. The team generally felt that the biggest gains to be realized are in the area of information flow. The intent of the modeling is to uncover strengths and weaknesses to help the team determine where improvements can be made and what we would recommend keeping from the current processes. The modeling technique used is a modified version of the method presented in the COSAT software.[1] The as-is work and information flow diagrams for SNL and AS/KCP are given in Appendix A along with a detailed description of the modeling technique used.

2.2.1 NWC Designed, NWC Manufactured

The as-is information flow for the NWC designed and manufactured case for SNL and AS/KCP is characterized by little information flow between the sites, but significant information being generated at each site. Each site creates information both in paper and electronic form for their particular design and manufacturing responsibilities. The information is shared on an as needed basis, typically in paper form. Recently the sharing of electronic data has increased, especially in the form of drawings, design files, quality variables, and attributes data. A good example of electronic information sharing is the electronic transfer of Intergraph design files used for electrical definitions of products such as printed wiring boards.

Each site has created a unique set of business practices and information systems both paper and electronic to support their business needs. In most cases there is some integration of systems within sites, but very little integration between the two sites. There is a heavy use of paper forms and multiple approval levels are required to conduct business. Cycle times for the entire design and manufacturing process are typically 6 months or longer, with some electronic product requiring as long as 2 years for design and manufacturing. The long cycle times are the result of many work and information process steps, the involvement of many people, a large number of government and DOE rules and regulations, the large use of paper and little integration of existing systems. Many of these steps were found to be non-valued added.

The work and information flow diagrams for the NWC designed and manufactured components are shown in Figures A.1-A.3. Figure A.1 is the work flow diagram for SNL and AS/KCP. Figure A.2 shows the information flow for SNL and Figure A.3 shows the information flow at AlliedSignal. Typical information that flows from SNL to AS/KCP includes design and weapons related information. Information that flows from AS/KCP to SNL includes customer order status, quality data, and production information.

2.2.2 NWC Designed, Industry Manufactured, AS/KCP Procured

The product realization process is primarily serial both in information and work flow with little connection between the design and manufacturing processes. After initial contact with the customer, requirements are negotiated. If the customer is from outside the weapons business, issues revolving around contracts and intellectual property must be resolved. This typically involves looping of information from the customer to the Project Manager, a Program Office, legal, purchasing, and DOE until the issues are resolved. This step is generally made more frustrating for both the customer and the engineer negotiating the requirements because of the cost accumulation structures that are used at SNL and AS/KCP.

Starting the design requires the negotiation for resources with other Sandia organizations. This is a cumbersome process often requiring help from relevant Center Administrative Assistants and the Program Management Offices. If capital equipment is required for the project, the manager needs to enter the capital equipment procurement process which often delays projects substantially.

The design process is heavily influenced by the designers' previous experiences in designing parts, usually this experience is within the NWC. This is seen both as a strength and a weakness of the current process. The design community in the NWC is seen as placing a high value on performance and reliability. Issues such as manufacturability and schedule sometimes suffer in comparison. The design process usually involves several iterative negotiations with purchasing: buying the required design tools and models, consulting services to include the vendor in the product realization process, a purchase order to procure prototype quantities of parts for evaluation, and incidental purchases. Since the purchasing organizations cannot maintain expertise in all areas of technology, purchasing agents sometimes require the assistance of the engineers involved to identify potential suppliers, write specifications, and evaluate bids. The design also has to be evaluated for reliability, materials compatibility and approval has to be secured for the use of any hazardous materials that the designers has specified. All of these processes are serial and require multiple layers of management approvals. Throughout the design process the Project Leader is required to track costs through a system that is difficult to enter and post costs in a manner that is hard to understand.

If the parts perform according to the design intent, the design is transferred to AS/KCP. The AS/KCP product engineer's first step is to have the part drawings redone to meet their requirements. The AS/KCP Product engineer is also required to establish a vendor according to AS/KCP rules. The result is that sometimes the Sandia vendor is not selected to continue on this project. This then requires that the vendor be brought up to speed on the project. Because the DOE rules are so restrictive, vendors frequently make special runs or establish separate lines to deliver products to the DOE. The result is higher cost and in some instances lower quality. As designs move away from the designers, the path required for approval of changes gets increasingly more cumbersome.

Figures A.4-A.6 show the work and information flow diagrams for the NWC designed, industry manufactured, AS/KCP procured business. Figure A.4 shows the work flow, Figure A.5 is the information flow diagram for Sandia, and Figure A.6 shows the information flow at AlliedSignal.

2.2.3 NWC Designed, Industry Manufactured, MDE Procured

Since the design process is essentially the same for all the NWC designed components, the same problems described in the previous section are encountered with setting up the initial project, procurement, cost tracking, etc. Differences in how complete the design needs to be before it leaves Sandia and the level of detail in the product acceptance are the most notable changes. Because AS/KCP is not in the loop, the Sandia designs for MDE have to specify the design more completely. This includes a more manufacturable design and a complete set of instructions on how the parts will be accepted. Since this is frequently not in the Sandia designers' usual experience it is anticipated that the chance of first time success will be lower, requiring more iterations to reach a product that meets the design intent. Some economy is realized from the fact that when the parts are qualified in the initial development process the same vendor is used for the production hardware, obviating the need to re-qualify the parts. In the MDE process, parts are generally accepted at the vendor and shipped directly to the user, usually AS/KCP's next assembly. The process of vendor qualification to produce Mark quality parts remains the same regardless of whether the parts are procured by personnel from Sandia or AS/KCP.

Where possible, MDE procurement takes advantage of the stability that is provided by the manufacturer's capability studies and the significant volume run through the production line. This is most prevalent in the production of integrated circuits where propagation delays, etc. are incorporated into computer aided simulations during the design phase. This is usually not possible for production of special capacitors and magnetics where the NWC transfers the process to the commercial vendor.

The absence of process capability data puts the designs at greater risk since the assumption is that the qualification lot represents the variation of the production process. At AS/KCP, information is transmitted that gives the status of requirements that determine the number of units to be built. This requires an infrastructure be maintained at both Sandia and AS/KCP to support these parts.

Figures A.7-A.9 show the work and information flow diagrams for the NWC designed, industry manufactured, MDE procured business. Figure A.7 shows the work flow, Figure A.8 is the information flow diagram for Sandia, and Figure A.9 shows the information flow at AlliedSignal.

2.2.4 NWC Specified, Commercially Available, AS/KCP Procured

NWC specified, commercially available components constitute the majority of the electronic devices that are developed and procured for War Reserve (WR). Typically, electrical specifications for these devices attempt to reflect the characteristics of a commercial-equivalent device and are based on sampled performance. It is assumed that these samples reflect the supplier's manufacturing capability. Components in this category include:

- capacitors (ceramic and tantalum)
- inductors
- resistors
- packaged and chip discrete semiconductors
- logic families

However, these devices are not truly commercial due to WR requirements. WR components tend to diverge from commercial components due to their reliability, environmental and traceability requirements. In addition, government procurement regulations and DOE quality standards place further requirements on suppliers.

Several disadvantages result from these additional requirements:

- Increased component cost and delivery time.
- Increased development cost and time.
- Deviation from standard, high-volume processes because suppliers may be required to make special manufacturing runs or to operate on separate lines. This potentially results in:
  - Lower quality devices due to additional or non-standard processing that may not be well understood by the manufacturing personnel.
  - Loss of high-volume statistical process and performance information.

As shown in Table 1, the WR component cost is approximately three times higher than the cost of an equivalent high reliability device and is an order of magnitude higher than a commercial-equivalent device. Presently, there is no measure of the improvement in component quality as a result of additional requirements. Thus, it is not possible to determine if these requirements justify the higher cost. Because of the NWC's low production volumes, development activities are also a major contributor to ultimate product cost. Wendel Archer (SNL, Dept. 2251) recently assessed the development cost and time for MDE magnetic components. The development costs for these devices were approximately $125k - $175k, and development activities required 12-18 months to complete.

Analysis of the work and information flow diagrams reveals a distinct division of responsibilities between SNL and AS/KCP. These diagrams also show that information is shared between SNL component engineers, AS/KCP component engineers and suppliers. The customer shares information with the component engineer at his/her site. However, the customer does not communicate with the supplier.

Device Description	SA #	P/N	Hi-reliability Cost (ea.)*	WR Cost (ea.)
47 uF tantalum capacitor	SA1998-6	313937-00	$6.00	$12.00
0.01 uF ceramic chip cap	SA3628-6	444267-106	$1.50	$8.00
39 pF ceramic chip cap	SA3484-36	444194-136	$2.00	$6.00
0.1 uH chip inductor	SA3206-13	319426-01	$10.00	$17.00
MOSFET	SA3483-1		$110 (TXV) $8.09 commercial	$243
Chip transistor (2C2907AHV)		379550-00	$0.20	$0.66
Quad op amp	SA2585-2	412566-00	$0.61 commercial	$5.28 Mil Cls B

* Commercial cost assumes purchase quantities of 1000 each.

Table 1: Cost Comparison of High Reliability and WR Components

The process of turning customer needs into supplier requirements exemplifies how the work flow characteristics affect component development. The design agency focuses on verifying that components meet the customer's needs (as communicated verbally and in Compatibility Drawings, CDs). Compatibility with the customer's needs is generally verified using commercial devices. The Production Agency emphasizes component compliance to a Product Specification (PS) that is primarily based on supplier capability as well as compliance to DOE orders and government regulations. Compatibility to the Product Specification is verified during WR component qualification. Because the acceptance criteria for a device is different in development than it is in production, there is a the risk that the customer's design may be incompatible with the WR component or that a supplier may be unable to meet WR component requirements even though the component may meet the customer's needs.

The component engineers at the design and production agencies work concurrently but key activities occur serially such as establishing customer needs, component characterization and component qualification. Also, when a component transitions from supporting a customer's development activities to supporting production, there are major shifts in responsible personnel, customer focus, component characteristics and supplier requirements (shown in Table 2). These shifts potentially result in increased development cost, increased development time, information loss, degraded customer relations and degraded supplier relations.

Area	Establishing Reqs. & Compatibility	Supporting Production	Undesired Results
Component Responsibility	SNL comp. engr.	AS/KCP comp. engr.	inefficient work flow
Customer's Contact	SNL comp. engr.	AS/KCP comp. engr.	1. loss of customer needs info 2. additional customer effort
Customer Requirements	reflected in CD & in verbal commits	PS is the only requirement	specifications do not always reflect customer's needs
Component Compatibility	verified with commercial devices using customer feedback	verified by PS, seldom receives customer feedback	customer requirements not matched to product capability
Supplier	provides mil-spec or commercial devices	provides WR devices	customer compatibility verified only with development devices
Supplier Requirements	initial surveys, preliminary specifications	must pass quality survey, devices must meet PS	1. DOE requirements limit the available suppliers 2. device may not meet PS 3. surveys are a snapshot in time

Table 2: Problems in the Present Development Process

Figures A.10, A.11, and A.6 show the work and information flow diagrams for the NWC specified commercially available, AS/KCP procured business. Figure A.10 shows the work flow, Figure A.11 is the information flow diagram for Sandia, and Figure A.6 shows the information flow at AlliedSignal.

2.3 As-Is Organization

The organization structure of a company has a direct impact on the effectiveness of the project teams. At the opposite extremes of the organizational spectrum lie functional and autonomous organizations. In strictly functional organizations, the functional manager has a great deal of power and projects are managed by "lightweight" project managers. With this structure, synergy exists within each function as employees are able to stay current with the associated technologies. Project goals can have a lower priority than the development of technologies. In an autonomous organization, project managers are "heavyweight" and have the power to focus resources on projects. There is increased coordination across functions allowing project goals to have priority. Projects can be more accurately planned at the onset so that communication with the customer is not strained. However, the technologies offered may not be the most recently available. The synergy within each functional technology does not exist. A conflict of roles and responsibilities between functional managers and project managers exists if the proper balance of power is not achieved.

2.3.1 Sandia

Sandia's Centers are primarily organized in a functional structure. Examples are: Electronic Subsystems Center, Technology Transfer Center, and Center for ES&H and Facilities. For the most part, departments within the centers are organized by product line. These departments include Programmers Department, Advanced Data Systems Department, and Battery Development Department. The overall management of the project lies within the department responsible for entire system under direction of a lightweight project manager. Each system is usually divided into multiple products (subsystems) and split again for individual components. At each stage there are additional project managers. Most often, funds for each project come in at the system level. The project and functional managers give funds to the subsystem groups who, in turn, allocate funds for associated component organizations. While the project managers at all levels are responsible for coordinating activities and schedules, the authority to allocate resources and evaluate performance remains with the functional line management causing members of the project teams to retain strong ties to their functional departments. The functional/product organization structure allows the team members to remain up to date on the current technologies within their department. However, when priorities change, project goals can be pre-empted by functional managers jeopardizing project success.

2.3.2 AlliedSignal/Kansas City Plant

The AS/KCP is primarily organized in a functional structure at the director level. Typical functions of these organizations include Manufacturing Operations, Engineering and Information Systems, Quality and Program Management. Below the director level is the managerial level. In most cases, the organizations at the director level are functionally organized except for several examples of product organization at the managerial level, such as radars, firesets and microelectronics. These managerial organizations include the functions of engineering,

manufacturing, quality and production control based on the needs of their particular product assignment.

For major weapon programs there is a strong area of project management and responsibility from the Program Management organization. This organization has the authority to set priorities and to clear obstacles that are related to the particular program. Most of the communication with Sandia for a major program occurs through the Engineering and Program Management organizations.

There is a strong use of cross-functional teams that are formed and work together to solve common problems using a Total Quality Management approach. This has helped to reduce the influence of functional organizations and to increase the cooperation and teamwork between organizations. Previously, the functional organization structure required more signature approvals resulting in the involvement of more people.

2.4 As-Is Technology

The assessment of technology in an environment is accomplished by comparing the capabilities of known systems to important characteristics needed for success. The team essentially adopted the Important Technology Characteristics identified in the COSAT software. After identifying the existing information technology systems, the team, using their personal experiences, rated each system against these characteristics. The result was a matrix showing areas where improvements are needed in the technology systems to facilitate the work and information processes used in the electronic component business.

2.4.1 Background

An Important Technology Characteristic of an information technology system is a feature of the system which is likely to affect the work people do, the skills needed to do that work, how people and groups interact, and how they are supervised.[1] These characteristics include ease of use, range of information, maintainability, and flexibility.

Numerous information systems at both Sandia and AlliedSignal were identified. The systems included both technical systems such as Mechanical Computer Aided Design and Inspection Instructions, and administrative systems such as Computer Automated Procurement System and Financial Information System.

Appendix B contains three related tables: Table B.1 identifies the characteristics, describes each characteristic, and defines the rated value for each characteristic. Table B.2 describes the features of known information technology systems as well as identifies desired features of those systems. Table B.3 is the rating matrix which shows each of the systems rated against the characteristics.

2.4.2 Summary

The team concluded that the majority of the systems serve the purpose for which they were created. They are efficient and provide access to a sufficient range of information. However, most of the systems are difficult to maintain and are inflexible. These are common characteristics of systems created to provide point solutions to identified barriers. There is no global mechanism for preventing duplication of efforts. However improved coordination may be possible at Sandia with the creation of the Chief Information Officer and supporting organization. In addition, the interaction of these systems is essentially non-existent. Most systems at Sandia are managed

independent of the others and of the similar system at AlliedSignal. Examples of common systems between the companies are: the Intergraph system used for electrical definitions of products such as printed wiring boards, email used for small file transfer and correspondence, and ProE used for mechanical drawings.

2.5 Analysis of Strengths, Weaknesses, Opportunities, and Constraints (SWOC)

2.5.1 Background

An analysis was completed identifying which strengths, weaknesses, opportunities and constraints have the most impact on the project objectives. The following definitions were used for the electronic component business:

Strengths:	good practices in the existing organization that must be nurtured and protected because of the distinct competence they give or could give to the organization.
Weaknesses:	limitations in resources, skills and capabilities that seriously impede effective performance.
Opportunities:	major favorable situations in the firm's environment. These may also reflect what potential changes are needed to achieve organizational goals.
Constraints:	key impediments to accomplish the organization's goals. These could include problems coming from the environment.

While analyzing the work and information flows, numerous SWOCs were identified at each site. Strengths included skilled staff and the ability to deliver components meeting QC-1 requirements. Accounting systems and definition configuration management systems which are not integrated were identified as weaknesses. Opportunities included partnering with a few critical suppliers and keeping abreast of current technologies. DOE regulations and limited resources in the area of capital equipment and expense funds are examples of constraints. The complete list is included in Appendix C, Table C.1, along with a description of the process used to determine the priorities.

2.5.2 Priorities

Using the prioritization approach described in Appendix C, SWOCs having the highest impact on the enterprise objectives were identified. A positive improvement on these elements will bring the electronic components business closer to meeting the objectives identified in Section 1.6.

- Information Technologies - moving toward a more concurrent engineering environment, including use of past design and technology information insures delivery of the appropriate component for the customer's requirements. Engineering information needs to be accessible before it will be used. Transferring funds automatically and allowing the engineers to initiate appropriate purchases reduces costs and reduces the number of people involved in completing projects.
- Supplier Partnerships and Subscription to a Supplier Management System - selecting a few pre-qualified suppliers greatly reduces the cycle time for delivering a component while assuring up-front the component will be of the appropriate quality for the customer. Subscribing to a supplier management system provides access to large component databases maintained by industry.
- Procurement System - simplifying the procurement systems and allowing approvals at the lowest level reduces the amount of information being transferred and interpreted by different

people. The number of people involved is reduced and the overall cost effectiveness is improved.

- Integrated Definition Configuration Management System - automating and integrating the systems used for definition configuration management improves coordination and reduces errors in product definitions. This allows the appropriate component to be delivered at a reduced schedule.
- Approval Cycle Times - reducing the amount and level of approvals has a direct impact on the delivery cycle time. By having capable processes up front, inspections and other related non-value added steps are eliminated. Again, the appropriate component will be delivered with reduced cycle time.

3. Design To-Be

3.1 Overview - Top View Diagram and Description

The proposed Enterprise is best characterized as appearing as a single entity to the component customer, whether the customer is internal or external. Customers may initiate business with any part of the enterprise, and through a guidance system, they are quickly directed to the person who can provide a response to their requests. A top level view of the Enterprise environment is shown in Figure 3.

In the Enterprise, business decisions are made based on a single strategic plan created for the enterprise. Work that uses competencies within each company is managed as one entity. The physical location of the people, laboratory space, etc., may still be split, but the technology is managed as a whole. Legal agreements are in place at the onset enabling the environment for success.

There is no longer a distinction between design agency and production agency. Each project is completed by a Dynamic Integrated Product Team consisting of the appropriate design and production personnel. Designs are completed concurrently eliminating the need for file transfer between non-compatible systems. Product team members use technology systems to access information such as design definitions, histories, process capabilities, and models from their desks.

The accounting system is integrated and easily accessible by the project leaders for distribution of funds and budget tracking. Similarly, the procurement systems are integrated to allow Product Team members to easily purchase the appropriate materials from the pre-qualified suppliers. Therefore, suppliers only need to interface with one entity for each product as well. Partnerships with key suppliers exist as needed to create the agile environment used to properly respond to customers' needs.

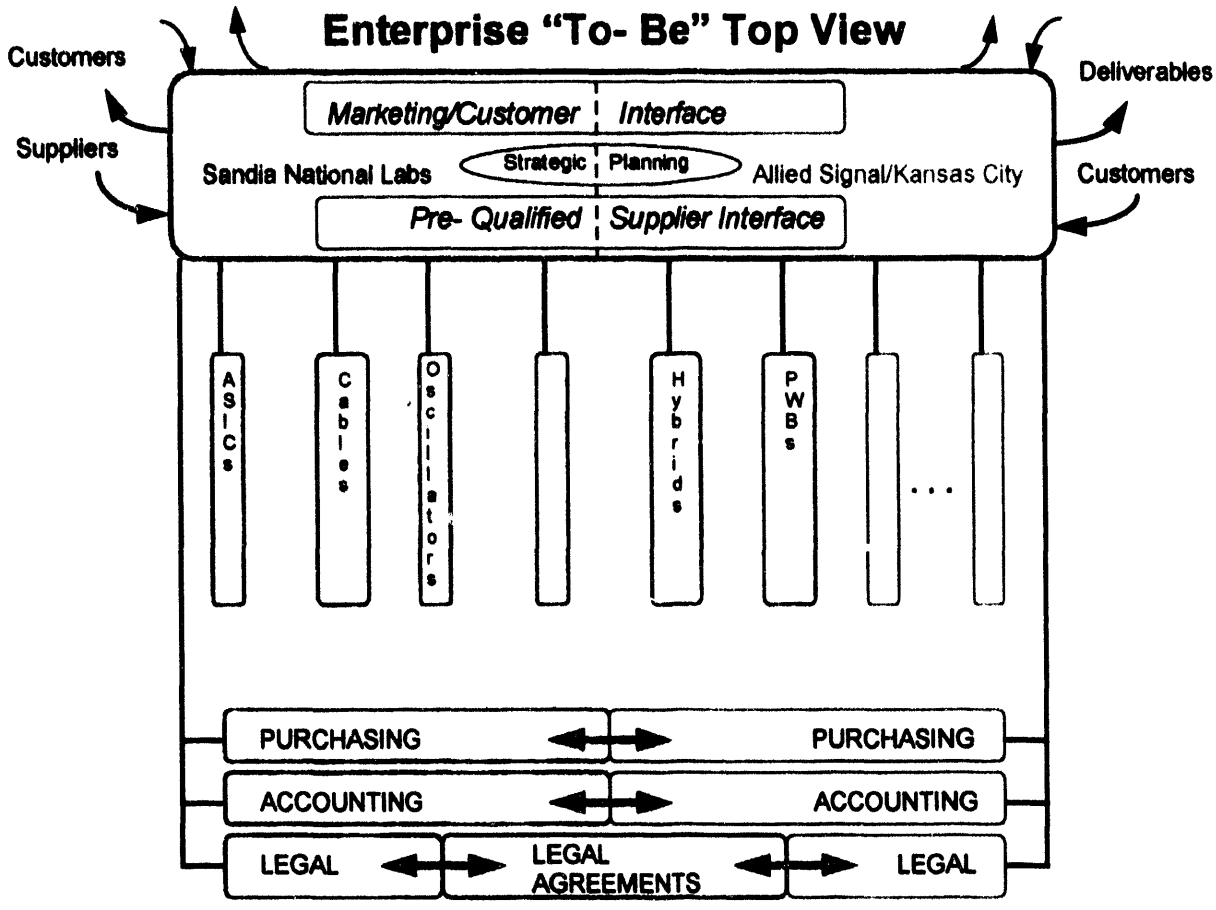


Figure 3: To-Be Top Level View

To-Be Work and Information Flows

The to-be work and information flows are fundamentally different from today's way of doing business and result in of a paradigm shift that emphasizes five things: integrated use of information technology, empowerment of employees, heavyweight project managers, cross-organizational teaming, and pre-qualified suppliers. Using available information technology, the Enterprise Integration Team designed processes that include:

- using information to locate the correct contact for a customer in two steps
- creating an expert system that retains process capability data, design guidelines, previous design and manufacturing experiences
- enabling desktop purchasing
- selecting vendors and scheduling fabrication through comparison of pre-qualified suppliers and internal work loads
- creating continuously updated accounting systems.

Empowerment of employees allows decision making and the resultant activities to occur in a timely manner eliminating a number of non-value added steps. Heavyweight project

management is a term that means the project managers are empowered to access resources to get their job done. Team members' standing in their respective organizations are more influenced by their project managers than by functional line supervision. Cross-organizational teaming builds on the empowerment of employees and heavyweight project management. Overall, the objective is to get the right people involved up front to get the job done right the first time. All the people that are stakeholders in a decision are represented in the decision process.

The use of pre-qualified suppliers and a supplier management system is intended to facilitate access to a group of vendors that make available process characterization data, queue time, and part availability. Pre-qualified suppliers also team with the Enterprise to forecast and make available the electronics components needed by the customers of the future.

Models for the three lines of business in the to-be environment are described in the following sections. The to-be work and information flows for these Enterprise models are shown in Appendix D.

3.2.1 NWC Designed, NWC Manufactured

The Dynamic Integrated Product Team is the focal point of the design and manufacturing product cycle. The Product Team is a cross-functional team of SNL and AS/KCP associates that have a strong project focus and function with heavyweight project management authority and responsibilities. The number of work and information steps is significantly reduced by the elimination of the non-value added activities and systems integration between AS/KCP and SNL. Integrated or seamless systems include scheduling, design, accounting, and procurement. There is a significant increase in information transfer between the team members due to the seamless systems.

The Product Team is responsible for coordinating the project from inception through completion. The project leader has ready access to project personnel and is capable of quickly forming a cross-functional team of SNL and AS/KCP associates. Product Team empowerment allows for quicker decisions and significant reductions in the number of approvals for purchase authority and accounting activity. A guidance system is available which allows the initial contact to find and contact the person who can help the customer and initiate the project. In addition, the expert system provides access to information including process history and capability, design guidelines, qualified suppliers both within and outside of the NWC, and product and process experts.

The design and manufacturing processes are concurrent with much of the required manufacturing information being created during design resulting in a product realization script. The product realization script includes most of the baseline information necessary to produce the product. As a result, some of the design and manufacturing cycles are replaced with simulations and virtual prototyping, thus reducing costs and cycle time. Manufacturing information such as production simulation, process routing, rough cut travelers, tool information and direct numerical control data are outputs of the product realization script. This produces a smoother and faster transition into manufacturing and results in a significant improvement in customer satisfaction.

Information systems are utilized to a greater extent which reduces paperwork and reduces the overall cycle time. Seamless systems between enterprise members allow much greater access to information such as scheduling, purchasing and accounting functions. Members of the Product Team will be able to charge time to a common account, whether they are AS/KCP or SNL

associates. The Product Team schedules a product in the manufacturing queue from a workstation during the product realization phase and tracks the product through manufacturing from the same workstation.

Figures D.1 and D.2 show the work and information flow diagrams, respectively, for the NWC designed and manufactured business.

3.2.2 NWC Designed, Industry Manufactured

When a customer makes contact, the person contacted determines if the customer has reached the best person to help this customer. For a customer from outside the NWC, the initial contact uses the a guidance system to direct the customer to the right person. The guidance system will be on-line allowing internal customers to access the information required to reach the right person on the first attempt The customer advocate then establishes the technical, administrative, and legal framework to allow a project to be initiated. The customer advocate is also able to negotiate the customer requirements, accept the job, and initiate the cost accounting for the project.

A Dynamic Integrated Product Team is established that will design and build the component. The supplier is selected from among the preferred suppliers. The necessary tools, models, etc are purchased electronically from the desk tops of the team members. Available design tools include: an expert knowledge system, on-line enterprise scheduling and accounting systems, preferred suppliers, supplier schedules, and process capabilities at the preferred suppliers. A contract with the supplier for consulting services brings the supplier into the design process electronically. Reliability and compatibility are forecast using expert systems. The result from this process is a product realization script. A complete design that contains all the information required to start producing the part.

Tool programs, performance models, and process capabilities all join to allow immediate manufacture of the component and eliminate the need to perform acceptance testing once the part has been produced. An order is placed, and the vendor manufactures the component to the schedule that was forecast in the initial design phase. The vendor ships the parts to the designated source and updates the expert system on process capabilities and part performance. The design definition is archived and feeds the expert system with design information and lessons learned. The extensive use of on-line systems has been estimated to reduce the product realization time by at least 50%. Examples are discussed in the Business Cases below (Section 4).

Figure D.3 shows the work flow for the NWC designed, industry manufactured components. Figure D.4 is the information flow diagram for both the NWC designed, industry manufactured components and the NWC specified, commercially available components.

3.2.3 NWC Specified, Commercially Available

Four fundamental characteristics define the envisioned to-be NWC specified, industry manufactured components business:

- Components of the appropriate quality without unique WR requirements (commercial, Mil-STD, and high-reliability only)
- Preferred, pre-qualified suppliers and a supplier management system
- No component characterization or qualification performed by the NWC
- Single-point responsibility for a component (or component family) within the NWC

A supplier management system is one method for accessing large component databases maintained by industry. This type of subscribed system provides low-volume component consumers like the NWC access to many of the advantages enjoyed by high-volume consumers such as component performance information, supplier ratings, technology advancements and lower device prices.

In the proposed to-be environment, the customer works with a component engineer to select the appropriate device(s) based on:

- component capability and statistical component performance information provided by a preferred supplier, a preferred parts database, or by a supplier management system
- component models
- supplier ratings based on past performance

This information is available to the component engineer (and possibly to the customer) through an expert knowledge system. After the customer selects the desired component, the component engineer places an order using a desktop purchasing system. The component engineer also uses on-line, NWC scheduling and inventory information to establish production orders. [NOTE: If the customer's requirements cannot be met with an available component, then the device must be developed as an NWC designed, industry manufactured component and would follow the development process described in section 3.2.2. This results in longer development times and higher costs.]

To achieve the to-be, several changes in the way NWC specifies and procures these types of devices must occur. These changes include:

- Procuring only appropriate-quality commercial, Mil-STD, or high-reliability devices without placing unnecessary WR requirements on the supplier (no WR specifications).
- Establishing partnerships with critical suppliers that complement the NWC's capabilities and anticipated technology needs.
- Subscribing to industry component databases and a supplier management system not only for selecting standard parts but also for obtaining component models.
- Giving integrated product teams the responsibility and authority to manage their components from concept through production.
- Using information technology to:
  - identify the customer's single-point contact
  - track supplier quality
  - keep and provide statistical performance information on components
  - predict reliability and compatibility based on component models and performance history
- Establishing stream-lined, desktop scheduling, purchasing, accounting, and inventory systems.

Figure D.5 shows the work flow for the NWC designed, industry manufactured components. Figure D.4 is the information flow diagram for both the NWC designed, industry manufactured components and the NWC specified, commercially available components.

3.3 To-Be Organization

In the Enterprise, phases of a major project are still functionally organized. At the component level product lines are managed as single entities so that the most current technologies are

available for providing customers' solutions. These product lines could have people and facilities crossing company boundaries. One major difference lies in the authority given to project managers. Heavyweight project management is needed to maintain customer focus. The project managers in the Enterprise have access to the guidance and scheduling systems which identify available resources and allow them to schedule time accordingly. Functional and project managers are jointly responsible for resource management and performance evaluations. Another change lies in the supplier relations. An agile environment exists in which the Enterprise makes and breaks partnerships with suppliers in response to customer needs.

3.4 To-Be Technology

Table B.2 in Appendix B includes a synopsis of known technology systems and describes desired features of those systems. While augmenting current systems to include those features will be an improvement in current business practices, integrating the systems within each company and across the enterprise is necessary to realize the full potential of the enterprise. The technology systems used for accessing information, technical and administrative, are perceived as the most critical to the success of the enterprise.

3.4.1 Description of Enterprise Information Systems

Figures D.2 and D.4 in Appendix D show the information flow for the enterprise model. In the model, six systems are shown to be instrumental for the proper flow of information. A brief description of how each system is used in the enterprise is given below:

- Guidance System - the guidance system provides the means to quickly direct the customer to the people who can provide the proper solution to their request. Any individual within the enterprise can access the system upon contact by a potential customer. While discussing the request with the customer, the individual uses the system to match the customer with the people who have the right skills and technologies to meet their needs.
- Expert Knowledge-based System - the Product Team uses the expert knowledge-based system to gain access to information including process history and capability, design guidelines, qualified suppliers both within and outside of the NWC, and product and process experts.
- Electronic Procurement System - the electronic procurement system provides the interface between the Product Team and the pre-qualified suppliers. Product Team members can access the system, inquire about the availability and costs of desired tools, models, etc., and quickly place an order for needed items. The system provides for electronic funds transfer to the suppliers and each purchase is automatically available for inquiry by the accounting system.
- Accounting System - the accounting system is used to track all costs. All labor charges across the enterprise are input electronically and tracked by the system. The system also has access to each purchase made for a project. Project leaders use the real-time system to track costs and manage budget for their projects.
- Scheduling System - resource availability (people and equipment) is tracked through the scheduling system. In addition, product schedules are maintained in the system and can be accessed by anyone in the enterprise. Project leaders use the system to manage resources and schedule equipment for meeting their project requirements.

- Definition Configuration Management System - The DCM system assists in the coordination and management of component definitions. The DCM guides the creation of the product realization script and tracks definition history. All designs are archived in the DCM system.

In addition to the systems shown, the Product Team operates in a concurrent engineering environment. Design information is available to all members of the team through similar integrated CAE systems. The transfer of drawings is no longer necessary, and information needed by each member is incorporated at the onset.

4. Business Cases

Electronic components business case examples were developed for a NWC designed and manufactured device and for a NWC specified, commercially available device. Typical electronic components were selected to represent each business case. For the NWC designed and manufactured case a thick film network was selected as the example and a capacitor was selected for the NWC specified, commercially available case. The virtual enterprise characteristics (summarized in Section 5) and the generic to-be work and information flows (described in Section 3) were applied to each business case to illustrate how these components would be designed and manufactured in the Enterprise.

After analyzing the differences between the as-is and to-be cases, major benefits and gaps were identified. These are based on the use of the generic models. Additional benefits and gaps could be realized following a re-engineering effort focused on the specific processes used for each device.

4.1 NWC Designed, NWC Manufactured: Thick Film Network

A thick film network consists of a circuit conductor and resistor pattern applied on a ceramic substrate with areas for the mounting of bare or packaged semiconductors. Networks are typically multi-layered and consist of alternating thick film layers of dielectric and conductor material interconnected by vias. The thick film material is most often applied by printing techniques through a patterned screen and subsequently fired at high temperatures. Thick film networks can contain up to 30 layers of dielectric and conductors.

The following assumptions were made for the business case:

- Design tools are available
- Thick film network fabrication processes are developed and may need only minor adjustments
- Fabrication material such as substrates and thick film paste are available in stores

The estimates in the model were based on full implementation of the virtual enterprise characteristics as described in the virtual enterprise characteristics table (Table 3, Section 5). The as-is work flow was divided into 14 work flow steps from the initial customer contact to the shipment of the completed networks to the customer. Cycle times were developed for each one of the steps in the as-is work flow. The total cycle time for the as-is environment is 245 work-days or 49 work-weeks. The work flows are shown in Figure 4.

By utilizing the virtual enterprise characteristics, the number of work steps in the to-be case has been significantly reduced and the associated cycle time has also been reduced to 136 work-days or 27 work-weeks. The to-be process is started with a customer contact and the very quick

formation of a Product Team to plan and manage the project. This is a cross-functional team that includes design engineers, product engineers, process engineers, quality engineers and other functions on an as needed basis.

The team develops the product realization script which includes a significant amount of manufacturing information such as rough cut work instructions, tooling information in a form that can directly interface with production equipment, process flow information, released drawings and a bill of material.

Electrical simulation and virtual prototyping that includes process and material characteristics is performed in a much more thorough and detailed manner. This significantly minimizes or eliminates the fabrication of models to verify the manufacturing processes and electrical characteristics. The reduction or total elimination of physical model fabrication results in a cycle time reduction for overall delivery and also results in significant cost savings.

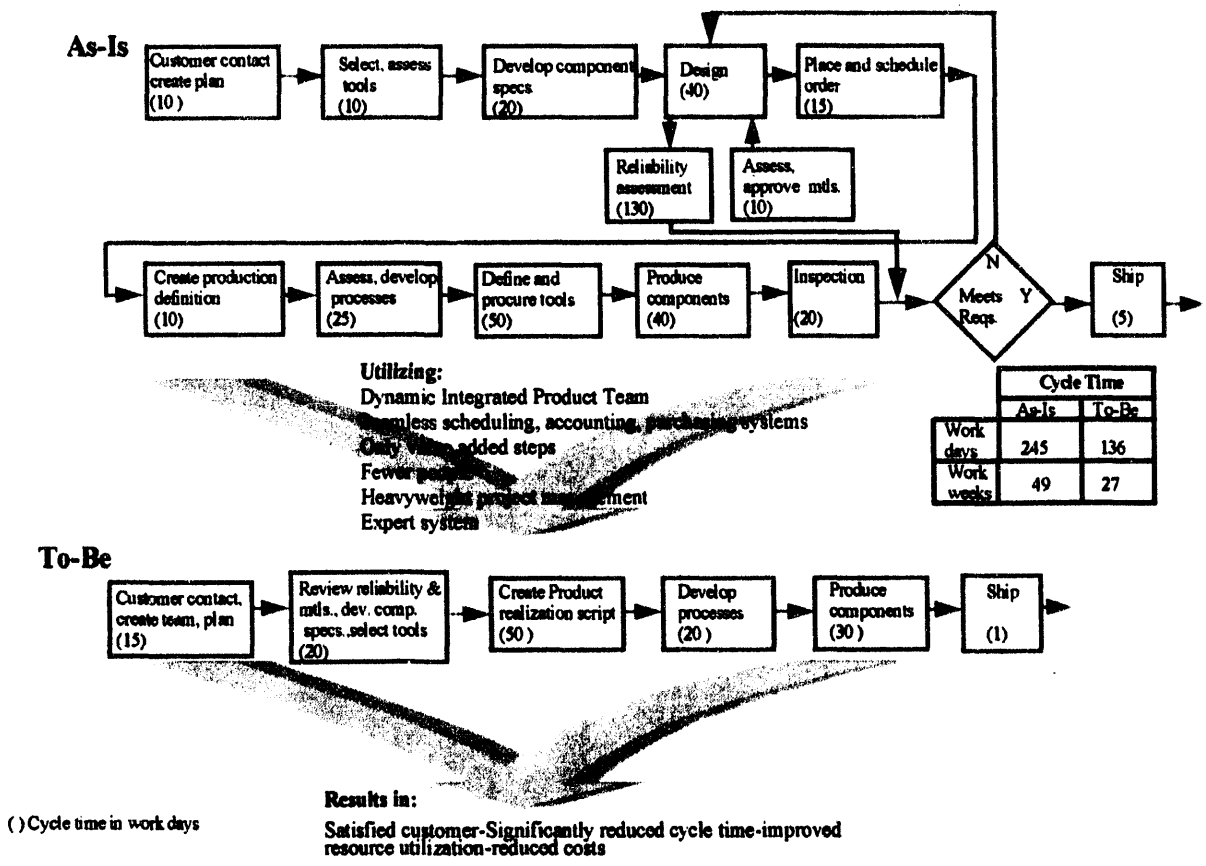


Figure 4: NWC Designed and Manufactured Business Case: Thick Film Network

The major benefits for operating in the virtual environment in order of importance are listed below:

- Enables additional CAE-based design iterations without building components
- Reduces product realization cycle time
- Improves understanding of product capability from process knowledge
- Reduces non-value added activities such as inspection, drawing release, and redundant data entry
- Reduces development and tooling costs
- Eliminates multiple product design definitions by using a single product realization script

The primary gaps in the as-is and achieving the to-be for the thick film network case include the following:

- Expert knowledge system (e.g. statistical data, layout rules, reliability...)
- Seamless systems including DCM, scheduling, and accounting
- Direct tie between computer definition and the manufacturing equipment
- Specific re-engineering focus on thick film networks
- Well understood processes through process characterization and control

4.2 NWC Specified, Commercially Available: Ceramic Capacitor

A business case was selected to illustrate how a virtual enterprise could improve the NWC specified, commercially available component business. The component that was selected for this business case was a standard, ceramic capacitor made by a previously qualified supplier (such as Kemet). The comparative as-is and to-be work flow diagrams are shown in Figure 5.

The team compared the as-is and to-be based on estimates of the typical processes and time required to go from establishing customer requirements to having production components. The as-is work flow requires 12 steps and 67 work-weeks while the to-be work flow requires only 5 steps and 21 work-weeks. Sanity checks were performed in an attempt to validate these estimates. For the as-is, capacitors developed for the MC4033 were used as a baseline. One to two years were required in this application. For the to-be, capacitors used in the Stratcom Secure Recode System (SSRS) were the baseline. While the development process for these devices did not incorporate all of the recommended virtual enterprise characteristics, the SSRS did use AT&T standard parts. The time required to obtain similar devices for the SSRS was approximately 8 weeks. The major driver was the vendor's device flow time. The approach taken for the SSRS was to develop a design that could use commercial components, and emphasis was placed on manufacturability.

For this business case, a two-fold reduction in process steps and a three-fold reduction in development time was achieved by using several virtual enterprise characteristics. In the to-be, the customer works directly with a single-point component contact to select the component based on manufacturing capability, statistical performance information, and component models. Even though component selection is limited to preferred parts and/or suppliers, component characteristics are immediately available. Once the component is selected, the component engineer determines the best supplier for the part based on vendor histories and quality ratings.

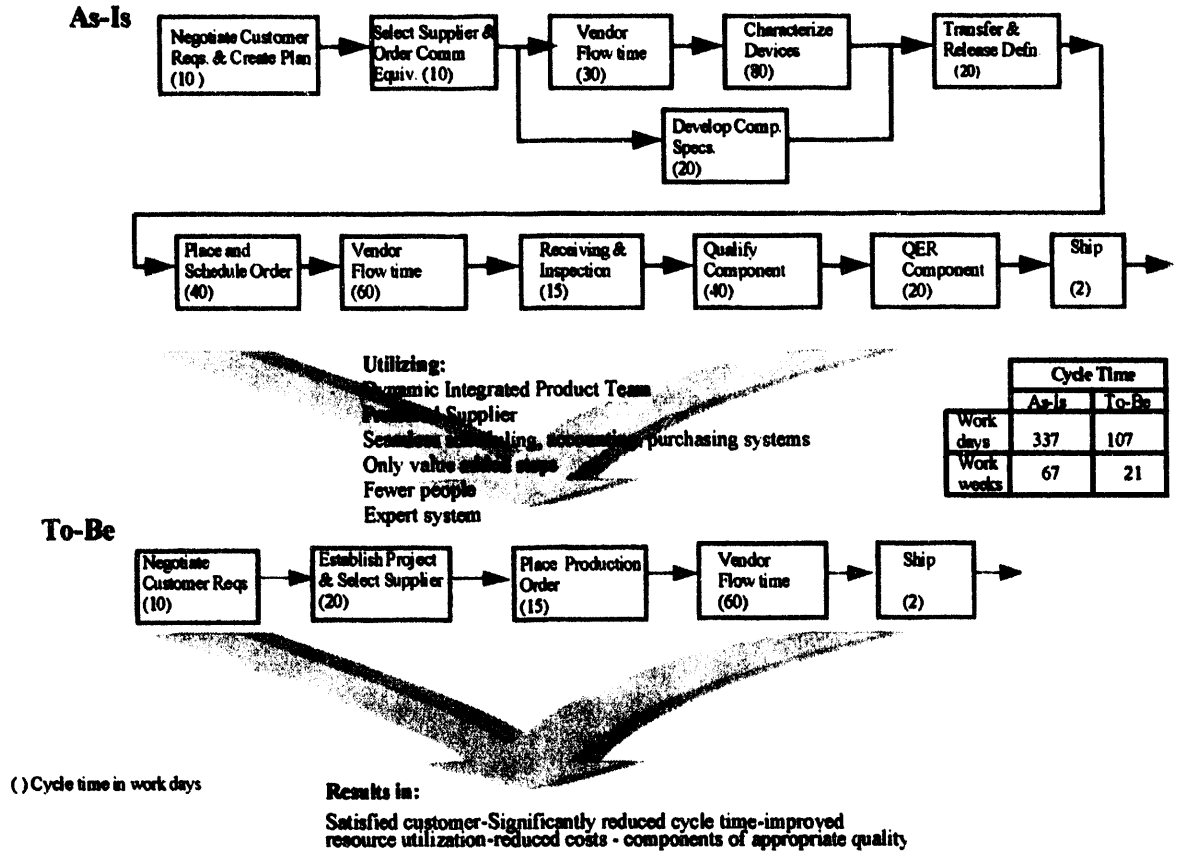


Figure 5: NWC Specified, Commercially Available Business Case: Ceramic Capacitor

After selecting the supplier, the component engineer then schedules and orders the parts for development and production from his/her desktop computer.

The virtual enterprise relies on several information systems being available. This business case requires a customer guidance system to identify the customer's single-point contact, an expert knowledge system that provides device information and determine supplier ratings, and a seamless, desktop system accessing scheduling, purchasing, accounting, and inventory information.

In addition, because the enterprise structure crosses site boundaries, the component engineer can access multiple information sources to obtain funds, establish schedules, and order devices. The elimination of non-value added activities is another important aspect of the virtual enterprise. In this business case, component characterization, specification development, and component qualification are eliminated as a result of re-engineering.

For this business case, the virtual enterprise:

- Reduces cycle time
- Reduces component cost
- Delivers components of the appropriate quality

- Increases next assembly flexibility
- Enables CAE-based design analysis without buying prototype components for next assembly
- Eliminates non-value added activities such as component characterization, specification development, and qualification

There are many gaps that must be filled before it would be possible to conduct business as envisioned in the virtual enterprise. For this particular business case, these gaps include:

- Preferred, pre-qualified suppliers and supplier ratings
- Simplified, seamless scheduling, purchasing, accounting, and inventory systems
- On-line device models
- Customer guidance system
- Expert knowledge system containing the supplier's statistical performance data, yields, and reliability information

5. Enterprise Characteristics

5.1 Characteristics

There are many characteristics that distinguish the virtual enterprise from today's electronic components business. Table 3 summarizes these characteristics and identifies the associated initiatives, benefits, and barriers. The initiatives are current SNL and/or AS/KCP activities that have features which could support the virtual enterprise, however, they may not provide complete solutions needed to realize the associated characteristics. Most of these activities would require adjustments if they were to be applied to the enterprise. The benefits and barriers identified in the table are those that have the most impact on the enterprise. These will be discussed Sections 5.2 and 5.3 respectively.

In the description below, the virtual enterprise characteristics are divided into four categories:

- Organization
- Work
- Information Flow
- Technology

Each characteristic is described under the category where it has the most impact. However, because these characteristics apply across the enterprise, they tend to affect all four areas.

Organization

To the customer, the electronic components enterprise appears to be a single business, but it is actually comprised of NWC sites and industrial partners. Enterprise members and our primary customer (DOE) work together to develop the Enterprise's joint strategic plan. Each member's obligations and responsibilities within the virtual enterprise are established through legal and business agreements.

The organizational structure within the electronic component virtual enterprise is based on heavyweight project management. Project leaders have the authority to cross organizational boundaries (both internal and between enterprise sites) in order to ensure their project's success. The project leader works closely with the customer and reflects the voice of the customer

throughout the project. This person also leads a product team comprised of members from across the enterprise. In the Enterprise, team members are influenced by their project managers as well as by their line supervisors.

Work

Concurrent engineering through cross-functional teaming is the fundamental characteristic of how work is accomplished in the virtual enterprise. Dynamic Integrated Product Teams are responsible for a product from concept to completion of production. These teams focus on achieving manufacturable designs based on capable processes. This requires statistical process control information from the manufacturer. In addition, industry-standard manufacturing processes and practices are used where possible. If necessary, manufacturing processes are developed concurrently with the design, and manufacturing engineers are key members of the product team.

The Enterprise is cognizant of industry practices in component design and manufacturing and also keeps current on computer-based tools for engineering, design and manufacturing (CAE/CAD/CAM). To achieve major reductions in product development time, the Enterprise uses modern simulation capabilities and has access to component models. These tools and capabilities support virtual prototyping (simulation-based prototypes) and rapid prototyping activities. Modern manufacturing capabilities such as automated manufacturing using direct numerical control and modular tooling are also established.

In the virtual enterprise, team members can instantaneously initiate procurement activities and perform funds transfers throughout the enterprise. The staff establishes budgets and schedules using various enterprise information systems. In addition, real-time accounting and inventory information is available at everyone's desktop computers.

The design definition within the Enterprise is very different from today's concept. Product realization scripts that cut vertically through the design and manufacturing processes contain all of the information required for the design, manufacture, and maintenance of the product. These scripts include the design layout, tooling definitions, production travelers, direct numerical control data, and acceptance criteria. Another critical element in the creation of the design definition is access to design and manufacturing histories. These histories provide the product realization team with information on known good designs, robust manufacturing processes, and lessons learned which enables incremental, continuous improvement.

The Enterprise has partnerships with key suppliers to enable agility. The decision to partner with suppliers that are not part of the NWC is based on how critical the supplier is to the success of the enterprise and how the supplier complements the NWC's capabilities and anticipated technology needs. In addition, the Enterprise also uses industry-based supplier management systems (such as the AT&T system) and has the infrastructure in place to select, pre-qualify and maintain preferred suppliers that are not members of the virtual enterprise.

Information Flow

In a virtual enterprise, there is a significant amount of information that must be shared electronically. The ability to communicate and exchange information not only within the virtual enterprise but also with customers and suppliers is critical. The information infrastructure used by the Enterprise enables product teams to concurrently plan projects and select/design/manufacture components. Because the information infrastructure is site-to-site compatible within the

Enterprise, members have easy access to shared databases and systems. Team members are also able to share information between multiple computer platforms. This seamless infrastructure brings knowledge to the point of use. In addition, the infrastructure provides electronic ties to customers and suppliers that are not enterprise members through existing communication networks such as Internet.

Getting the customer in touch with the right person is another important aspect of information flow. To achieve this, the enterprise uses a customer guidance system that assists in identifying the customer's appropriate contact. This system allows the customer to be working with the right person in less than one day which minimizes the customer's inconvenience and helps initiate activities in a timely fashion.

Technology

The Enterprise's primary technology characteristics are in information technology. While the team identified technology needs and the required characteristics, it did not identify how the required systems should be implemented. The information technologies that the Enterprise uses include a customer guidance system, an expert knowledge based system, desktop purchasing & scheduling, access to real-time accounting and inventory information, and ties to industry component databases. The characteristics of these systems were described in Section 3.4.

Area	Virtual Enterprise Characteristic	Initiatives	Benefits	Barriers
Organization	o Legal/business agreements for the enterprise that are customer oriented and that clearly define roles and responsibilities	MDE/DDP, MOU for PWBs and HMCs	Enables the enterprise to exist	- Current agreements - DOE mission assignments
Organization	o Strategic Plan for the Virtual Enterprise	EIT	Provides unified direction and establishes joint goals	Current strategic plans are site oriented
Organization	o Heavy weight project leaders that cut across the enterprise		- Provides customer focus - Expedites resource allocation	Current management structure
Work, Information Flow, Organization	o Concurrent Engineering: - enabled through Dynamic Integrated Product Teams (DIPTs) - includes customers, component engineers, technology/materials experts, and suppliers	IMDI, EP401100 ICE, TEAM, IPDS, IDEA	- Reduces cycle time - Reduces design iterations - Ensures proper quality components - Improves communication - Provides customer focus - Establishes traceable decisions at the lowest level	- Current organizational structure - DOE restrictions on supplier partnerships - Electronic communication technology not in place
Work	o Manufacturable designs based on capable processes	KCP-PC&C, TQS	Reduces design iterations	Process capability information is limited
Work	o Cognizant of industry practices in components, design, manufacturing and CAE/CAD/CAM tools.	ECCI, Industry Partnerships, and Supplier Management System	- Incorporates best industry practices into NWC business - Improves customer responsiveness	- Limited data - Proprietary data - Current business practices
Work, Technology	o Modern simulation capabilities: - rapid prototyping of models (stereolithography) - virtual prototyping - on-line component models	Virtual Prototyping Facility (VPF), MUSE, ECCI	- Reduces design iterations - Reduces cycle time - Ensures proper quality components	- Technology not available - Proprietary models
Work	o Modern manufacturing automation: - direct numerical control - modular tooling		Reduces product realization cyle time and cost	Expensive equipment
Work, Information Flow	o Product realization scripts	TEAM	Reduces drawing definition cycle and manufacturing set-up time	- Technology not in place - Incompatibilities with existing technologies - Current business practices

Table 3: Virtual Enterprise Characteristics Table

Area	Virtual Enterprise Characteristic	Initiatives	Benefits	Barriers
Work, Organization	o Mechanism for selecting & maintaining preferred pre-qualified suppliers and for establishing supplier partnerships	Whitestar, Supplier Manager Program	- Reduces cycle time - Reduces costs - Ensures proper quality components	- Cost of membership and maintenance - Rapidly changing components
Information Flow, Technology	o Information infrastructure: - seamless communication w/ e-mail and interactive video - file transfer capability between different platforms	Picture-Tel, SNL CIO Initiatives, EDMA, MDMA, PDES, NIRVANA, ACCORD	- Supports concurrent engineering and teaming - Improves communication and responsiveness - Reduces product realization cyle time and cost	Technology and system standards are not in place
Information Flow, Technology	o Customer guidance system that allows identification of proper contact for each customer		Reduces response time to customer	No database or system shell
Work, Technology	o Instantaneous initiation of procurement activities & funds transfers	JIT System ECCI IPDS	Reduces procurement time	- DOE purchasing regulations - DOE quality requirements (QC-1) - Technology not in place
Work, Technology	o Desktop access to accounting information and ability to set up project cost identifiers	FIS BTCS	Reduces project administration and set-up time	- Internal business practices - DOE regulations
Work, Technology, Information Flow	o Integrated scheduling system	MRP II	- Reduces product cycle time - Quickly secures resources	- Present systems not fully automated - Current business practices - No link between sites
Information Flow, Technology	o Expert knowledge system that captures: - process capabilities - component characteristics - design/development histories	IDEA, Smart processing	- Reduces development time - Improves manufacturability	- System development is not yet complete - Current business practices - Information not compiled - High maintenance costs
Technology	o Integrated Definition Configuration Management system	DCM Project	- Provides traceability - Reduces file exchange errors - Provides archive capability	- System not in place - Incompatible with existing system(s) - Forward compatibility may not be possible

Table 3 (cont'd): Virtual Enterprise Characteristics Table

5.2 Benefits

The benefits resulting from the virtual enterprise must be considered from two perspectives:
1. benefits to the customer
2. benefits to the enterprise members

The enterprise will be successful only if it benefits the customer. In order to thrive, the enterprise must also benefit its members If either of these criteria is not met, then an enterprise should not be established. The team believes that the proposed virtual enterprise model benefits both the customer and the enterprise members.

The benefits to the customer include:
- Delivery of components of the appropriate quality
- Reduced delivery times
- Decreased costs
- Improved communication and responsiveness
- Access to the enterprise's expertise in current technologies and component capabilities

Other benefits specific to DOE (the primary customer) include:
- Expanded technology transfer between government and industry
- Demonstrated leadership in unifying the nation's two industrial bases (defense and general commerce) by establishing a successful enterprise model
- Increased focus on strengths while maintaining a breadth of available enterprise capabilities
- Maintenance of a skilled work force

The members of the enterprise reap the same benefits as the customer as well as additional benefits. The benefits of being a member of the enterprise include:
- Increased repeat/new customers
- Support of the strategic objectives of the individual members
- Increased job satisfaction/challenge for staff
- Increased capabilities
- Decreased time spent on non-value added activities

Enterprise members are able to draw new customers and achieve customer loyalty because working within the enterprise will shorten delivery times and reduce costs while achieving components of the appropriate quality. Being a member of the enterprise also frees up resources allowing businesses to focus on doing work that is critical to their success such as enhancing areas of strength and achieving greater technology transfer.

Enterprise members are also able to leverage the capabilities of the other members. This brings to each member broader market opportunities in areas requiring: rapid prototyping, small lot fabrications, rapidly changing requirements, and low development costs. In addition, individual members will have access to a greater breadth of capabilities and technologies through the enterprise.

The technology infrastructure that supports the enterprise also increases a member's capabilities outside of the electronic components business. These capabilities include increased design

flexibility, improved documentation, and processes for storing/retrieving historical information. The methods used to develop components in the virtual enterprise also apply to other areas such as capturing evolving requirements and reducing design iterations through simulation and virtual prototyping.

5.3 Barriers and Gaps

There are many barriers that must be overcome and gaps that must be filled before it is possible to successfully implement the virtual enterprise model presented in this report. A barrier is an obstruction. To overcome a barrier, one must either implement a change (such as putting a door in a wall) or bypass the obstruction (such as climbing over a wall). A gap is a separation that can be filled by applying time and resources (such as building a bridge). Both barriers and gaps can prevent the success of the virtual enterprise. However, overcoming a barrier generally requires a re-engineering effort whereas filling a gap requires an engineering effort.

The fundamental barriers to the virtual enterprise are the current organizational structure and traditional business practices. The NWC is structured as a group of contractors for the DOE. The roles and responsibilities of each site are defined by mission assignments. The DOE treats each site as a separate business which reduces the complexity of their oversight and auditing role. DOE orders define how we must conduct business within this structure. Orders such as quality requirements significantly impact and constrain the operation of the electronic components business. In addition, federal regulations in areas such as procurement and waste generation/disposal also burden the electronic components business.

The virtual enterprise is an agile alliance of NWC sites and critical suppliers operating under a set of legal agreements. The virtual enterprise also relies on joint strategic planning based on the enterprise's objectives. These basic concepts do not fit in the present NWC organizational structure maintained by the DOE. Within the virtual enterprise, it is impossible to define the site-specific responsibilities that the DOE currently requires. Also, having industrial partners conflicts with federal competitive procurement regulations.

The primary goal of the virtual enterprise is to cost-effectively develop components of the appropriate quality in a shorter time than is now required. The quality and procurement requirements that the NWC presently operates under tend to drive component costs up and increase development time with no measurable improvement in component quality.

There are also barriers at each site that prevent the formation of a successful virtual enterprise. One example is site-specific organizational structure. The virtual enterprise relies on cross-functional teaming. To achieve this, management structures must be established that recognize an individual's contributions to the enterprise as well as to their functional organization. Also, projects in the virtual enterprise are led by heavyweight project managers who maintain focus on customer needs. These project managers must have the authority to rapidly secure resources from multiple organizations. Present funding mechanisms that emphasize projects as opposed to maintaining the technology base also impede the virtual enterprise. This is because the enterprise relies on technologies such as information systems that benefit multiple projects but are difficult to justify on an individual basis. In addition, once these technologies are in place, a funding system for covering the maintenance and operating expenses must be developed.

Working closely with industry and having a good understanding of industry-based processes requires a change in the way we do work. For the enterprise to succeed, there must be a close working relationship with industry. Several methods such as partnering, developing preferred suppliers, or subscribing to a supplier management system can be used to achieve this close-working relationship. However, these approaches require a significant, long-term investment of resources to achieve. In addition, special effort is needed to comply with government procurement regulations for some of these approaches.

There are many gaps in the implementation of the information technologies required by the virtual enterprise. These information systems must be highly coordinated between sites in order to achieve the desired seamless compatibility. In addition, the enterprise relies on a large storehouse of knowledge such as customer contacts, statistical performance data, supplier ratings, and design/manufacturing histories. Significant effort is required to compile and maintain this data. Also, work approaches must be established which simplify how this data is captured.

There are many projects underway today that can help eliminate these barriers and gaps. Even incremental progress in any of the problem areas should be encouraged and must continue. In addition, the corporate re-engineering activities occurring at both SNL and AS/KCP will help break down some of the virtual enterprise's barriers.

6. Recommendations for Implementation

The objective of the Enterprise Integration Team was to create a model for the electronic components business in the future. After the model was complete, the team developed the following recommendations for implementation:

1. Form a Virtual Enterprise Process Management Team
A Virtual Enterprise Process Management Team should be formed with representatives from DOE, AS/KCP, and SNL. The team should include technical, business, and legal representatives. Participation and buy-in from all three organizations is essential for success of the enterprise.

2. Develop an Implementation Road Map
The Process Management Team should formulate an implementation plan based upon the virtual enterprise "to-be" model. This plan, similar to a project plan, should delineate the activities, decisions, and milestones necessary to realize the model.

3. Establish a Benchmark
A company that has successfully integrated their operations with another separate company should be identified and used as a benchmark against which success of the enterprise can reasonably be measured. The benchmark should focus primarily on those elements that the team has identified as part of the to-be model, and those which improve customer success.

4. Integrate Into the Ongoing Re-engineering Activities
The Process Management Team should strive to integrate the Virtual Enterprise development with the SNL Re-engineering Initiative, the AS/KCP Total Quality/Total Quality Speed effort, and the DOE re-engineering activities.

5. Focus Implementation on Key Areas

- The Process Management Team must agree upon the business/legal infrastructure necessary to allow the Virtual Enterprise to operate, without encumbrance, with organizations within the nuclear weapons complex, with customers, and with external suppliers.
- The accounting and purchasing practices is an area where much progress can be realized to facilitate the Virtual Enterprise.
- Personnel and project practices which enable "heavyweight" project managers to have influence across corporate boundaries should be enacted.
- The information infrastructure is rapidly forming, and the best time to influence its development for the benefit of the Virtual Enterprise is now.
- The establishment of a process for selecting and maintaining preferred, pre-qualified suppliers should be a high priority item for the Process Management Team.
- A complex-wide and industry-recognized Definition Configuration Management System should be implemented.
- The Process Management Team must insist on a Virtual Enterprise system which will allow realization of components of appropriate quality.

6. Initiate a Pilot Project

A pilot project that boldly formulates new procedures and systems will serve to fine-tune the Virtual Enterprise model and will, on a limited risk basis, encourage wider buy-in by those unsure about the soundness of the concept. This pilot project should encompass as many key areas from Section 6.5 as possible.

An example pilot project is given in Appendix E. This was extracted from a proposal submitted in response to an Advanced Research Projects Agency (ARPA) Broad Area Announcement for Agile Manufacturing Pilot Programs.

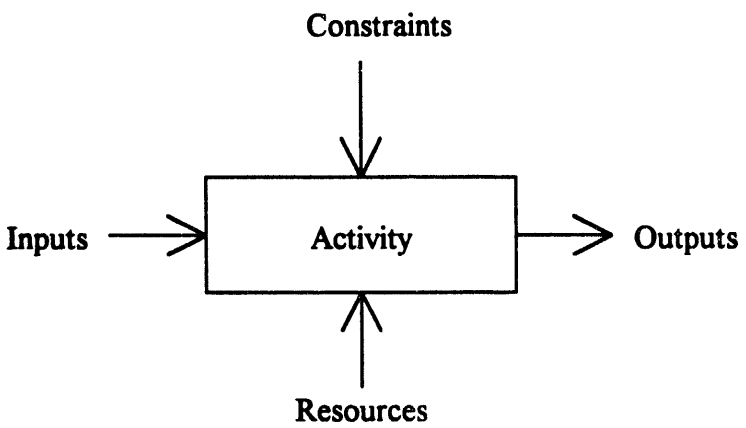
7. References

1. Industrial Technology Institute, *Cross-Organizational STEP Adoption Tool.* Industrial Technology Institute, Ann Arbor, MI, 1994.
2. J. Champy and M. Hammer, *Reengineering the Corporation.* HarperBusiness, New York, NY, 1993.
3. Iacocca Institute, *21st Century Manufacturing Enterprise Strategy*, vol. 1 and 2. Iacocca Institute, Lehigh University, Bethlehem, PA, 1991.
4. W. H. Davidow and M. S. Malone, *The Virtual Corporation.* HarperCollins, New York, NY, 1992.

Appendices

Appendix A: As-Is Work and Information Flow Charts

The work and information flow diagrams illustrated in Appendices A and B are modeled using a modified version of the method described in the COSAT software. For the work flow diagrams, the information in and around the boxes is defined as:



For information flow diagrams, the box contains the name of a person or group of people and the arrows indicate the type of information being transferred between those people.

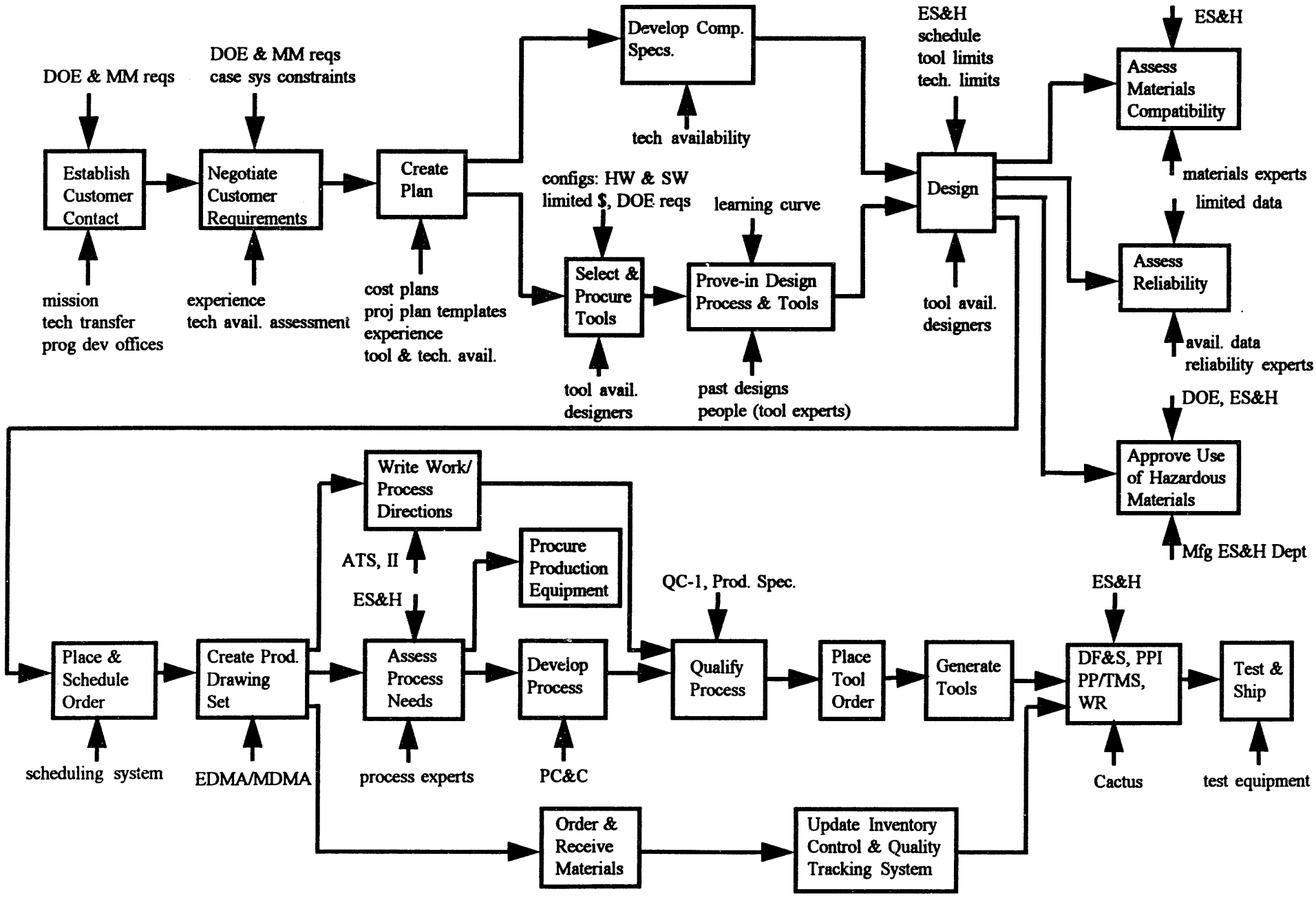


Figure A.1: As-Is Work Flow Diagram - NWC Designed and Manufactured

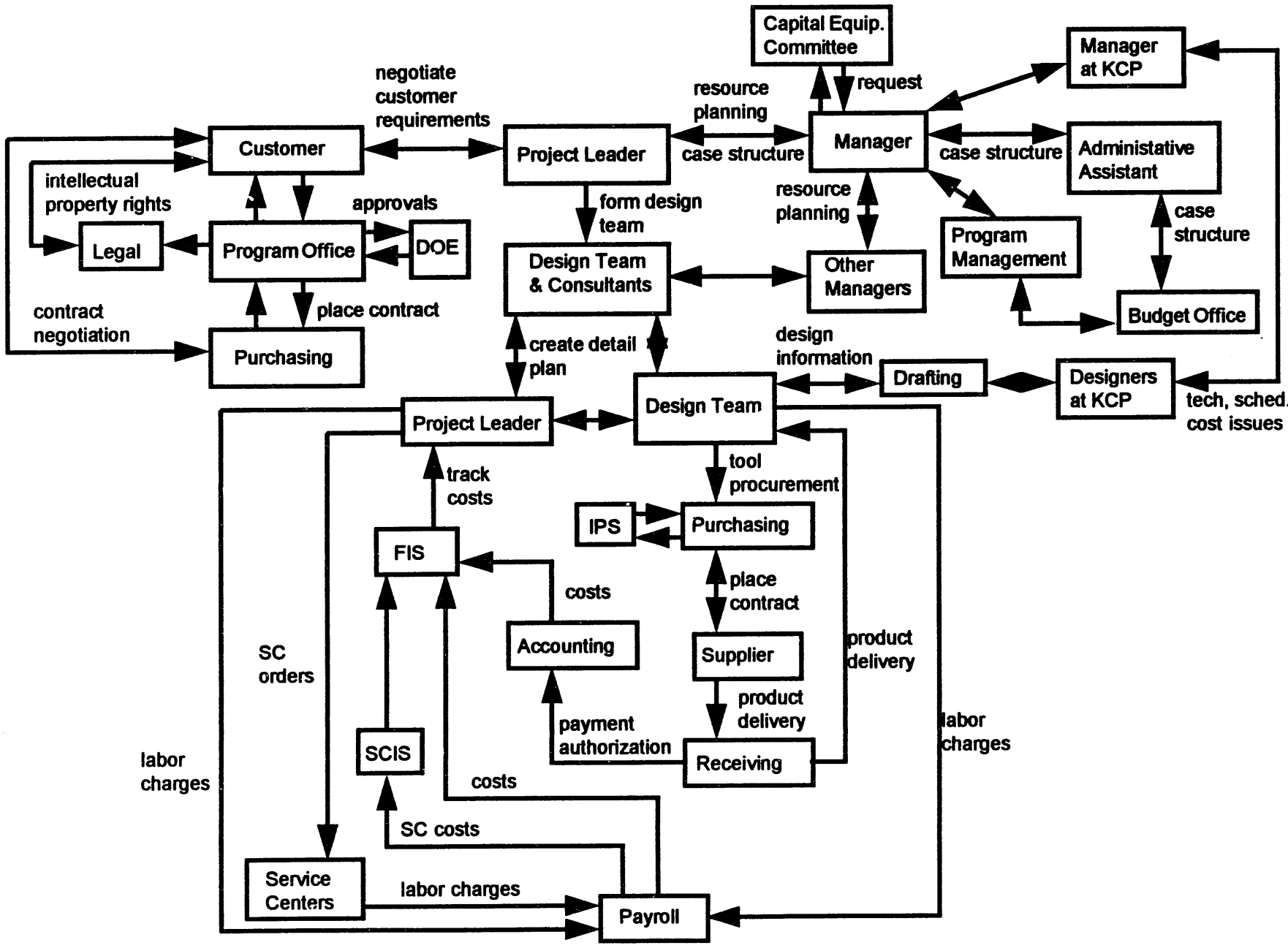


Figure A.2: As-Is Information Flow Diagram (SNL) - NWC Designed and Manufactured

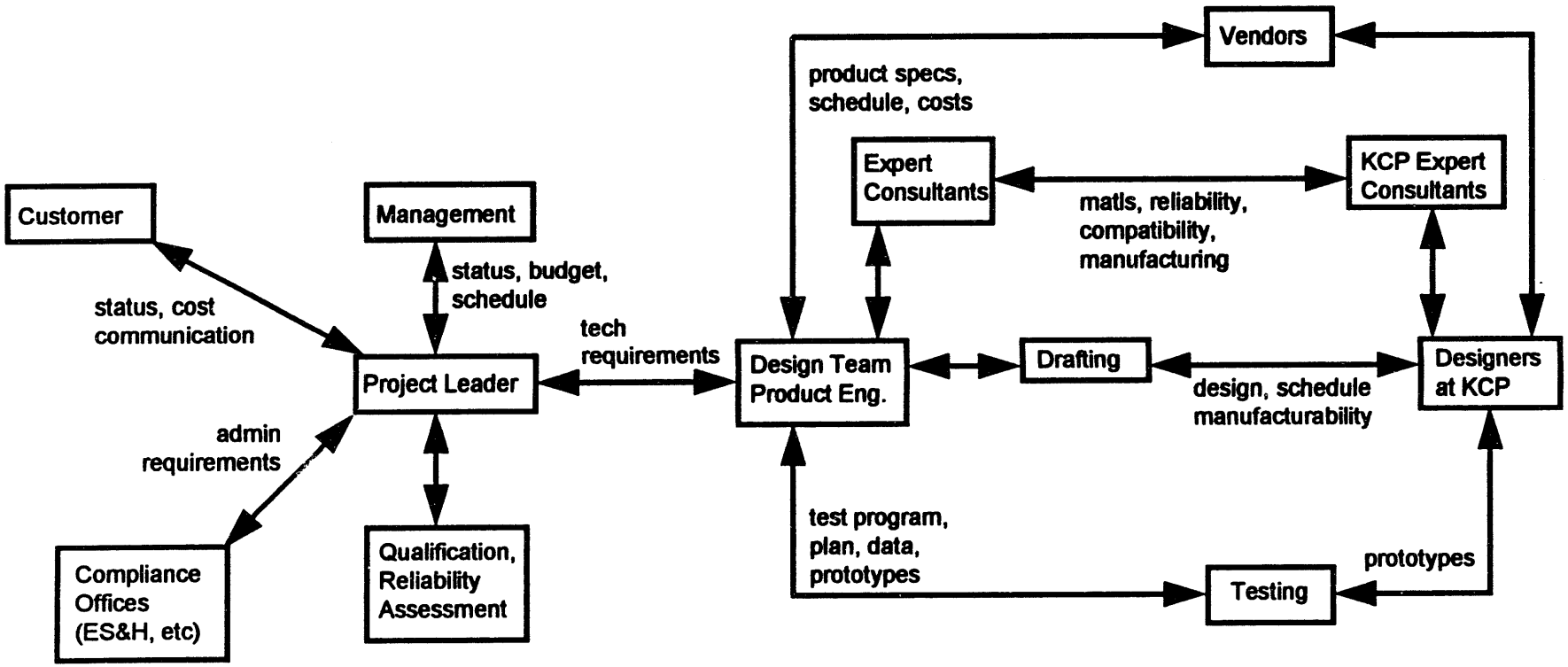


Figure A.2 (cont'd): As-Is Information Flow Diagram (SNL) - NWC Designed and Manufactured

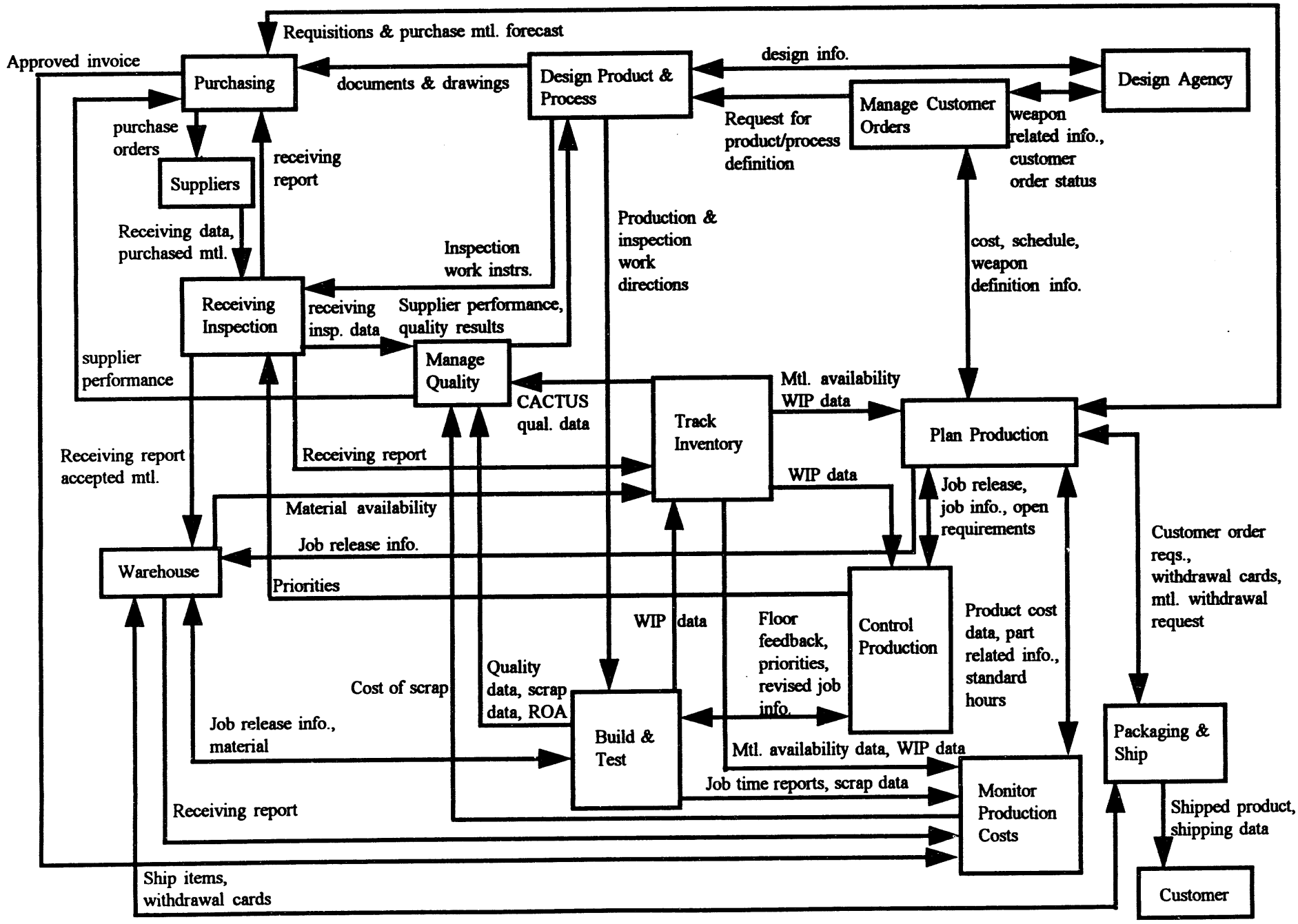


Figure A.3: As-Is Information Flow Diagram (AS/KCP) - NWC Designed and Manufactured

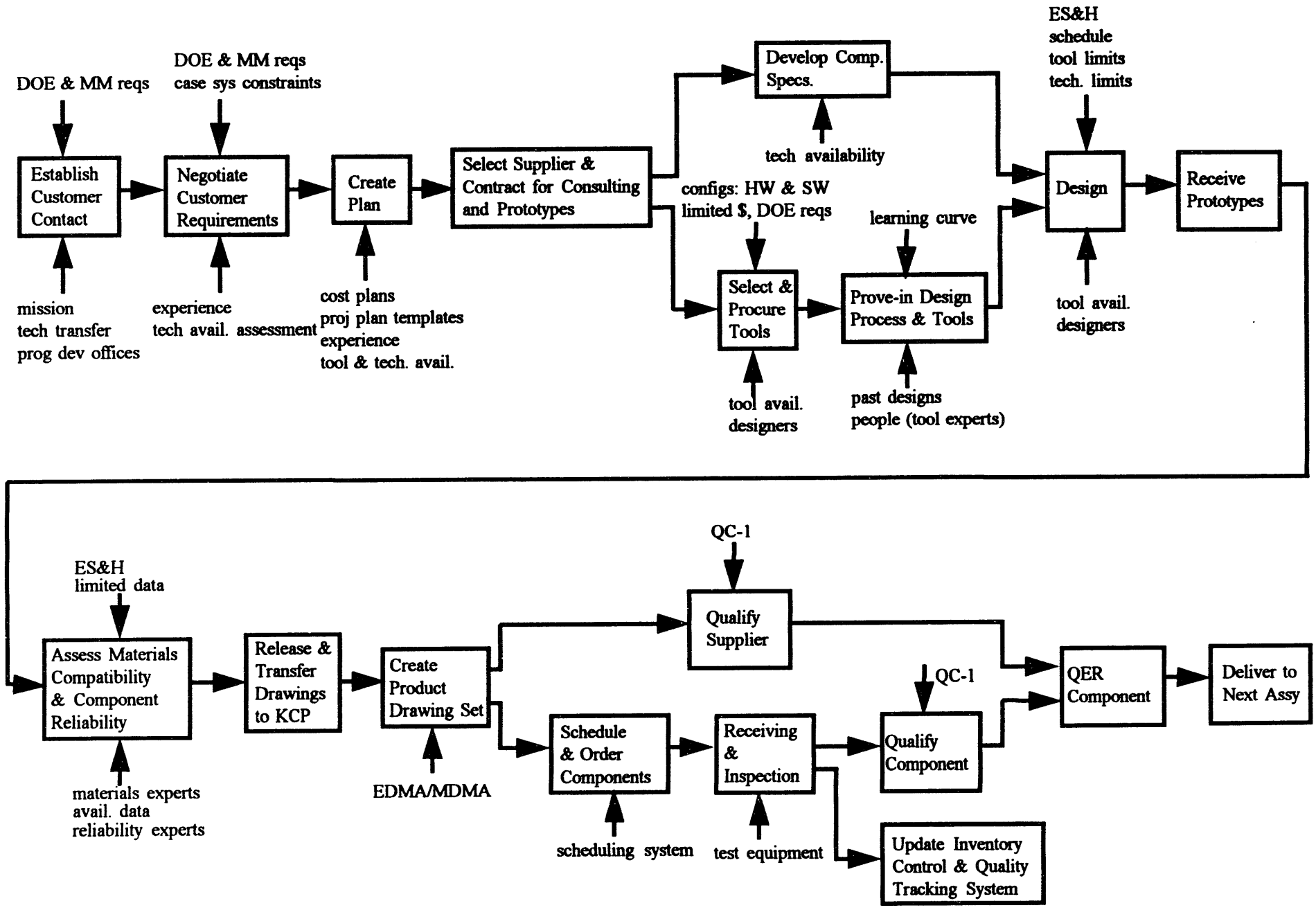


Figure A.4: As-Is Work Flow Diagram - NWC Designed, Industry Manufactured, AS/KCP Procured

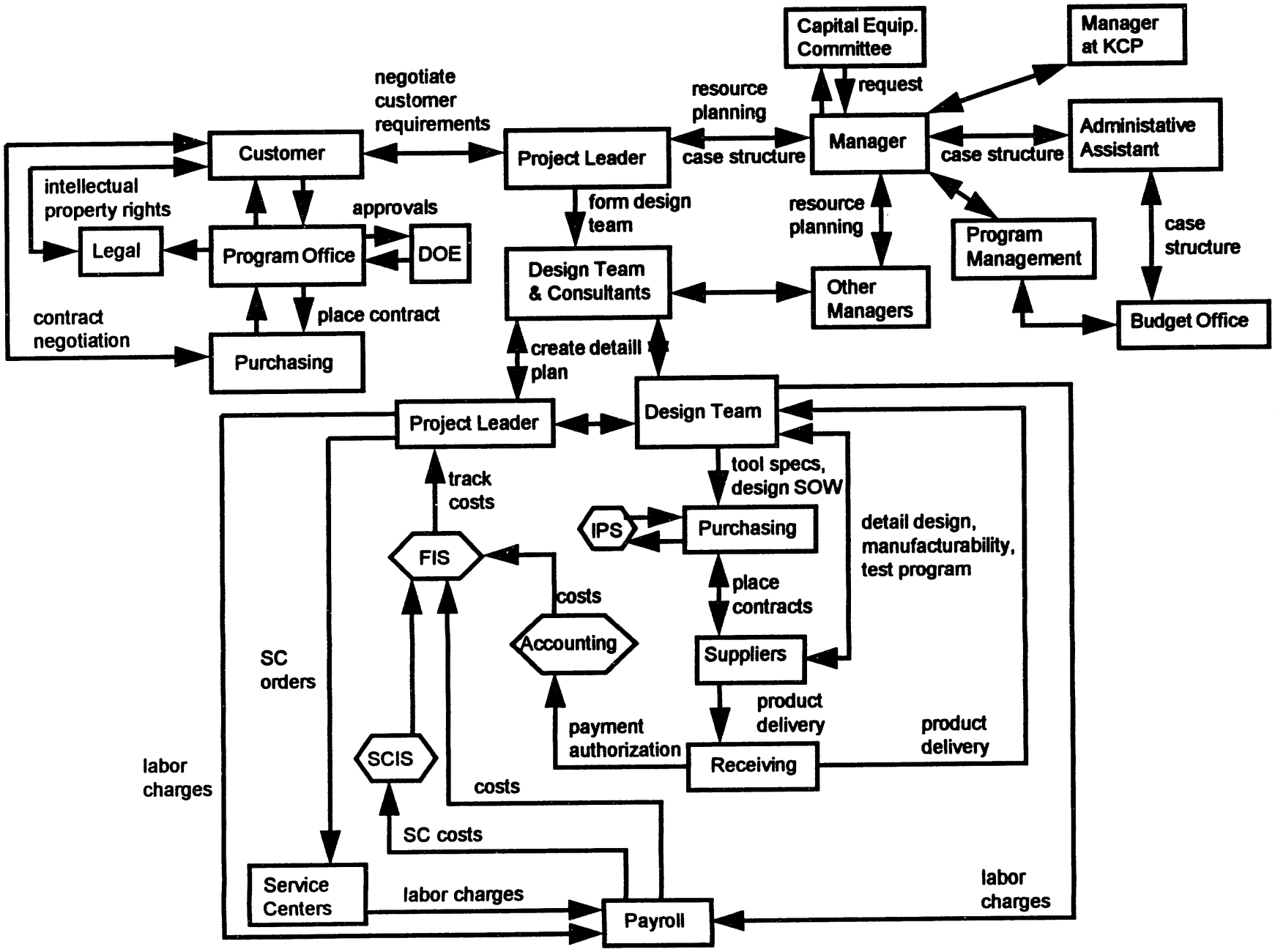


Figure A.5: As-Is Information Flow Diagram (SNL) - NWC Designed, Industry Manufactured, AS/KCP Procured

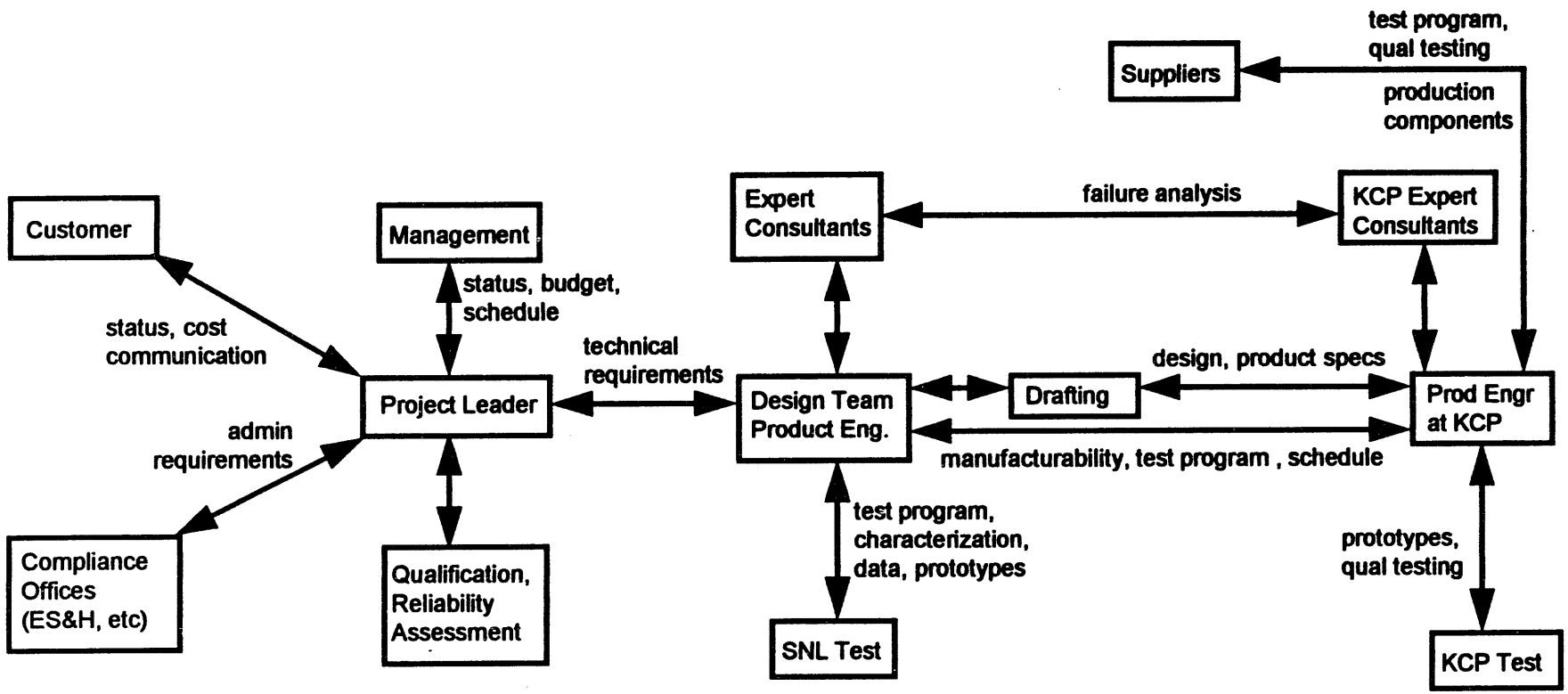


Figure A.5 (cont'd): As-Is Information Flow Diagram (SNL) - NWC Designed, Industry Manufactured, AS/KCP Procured

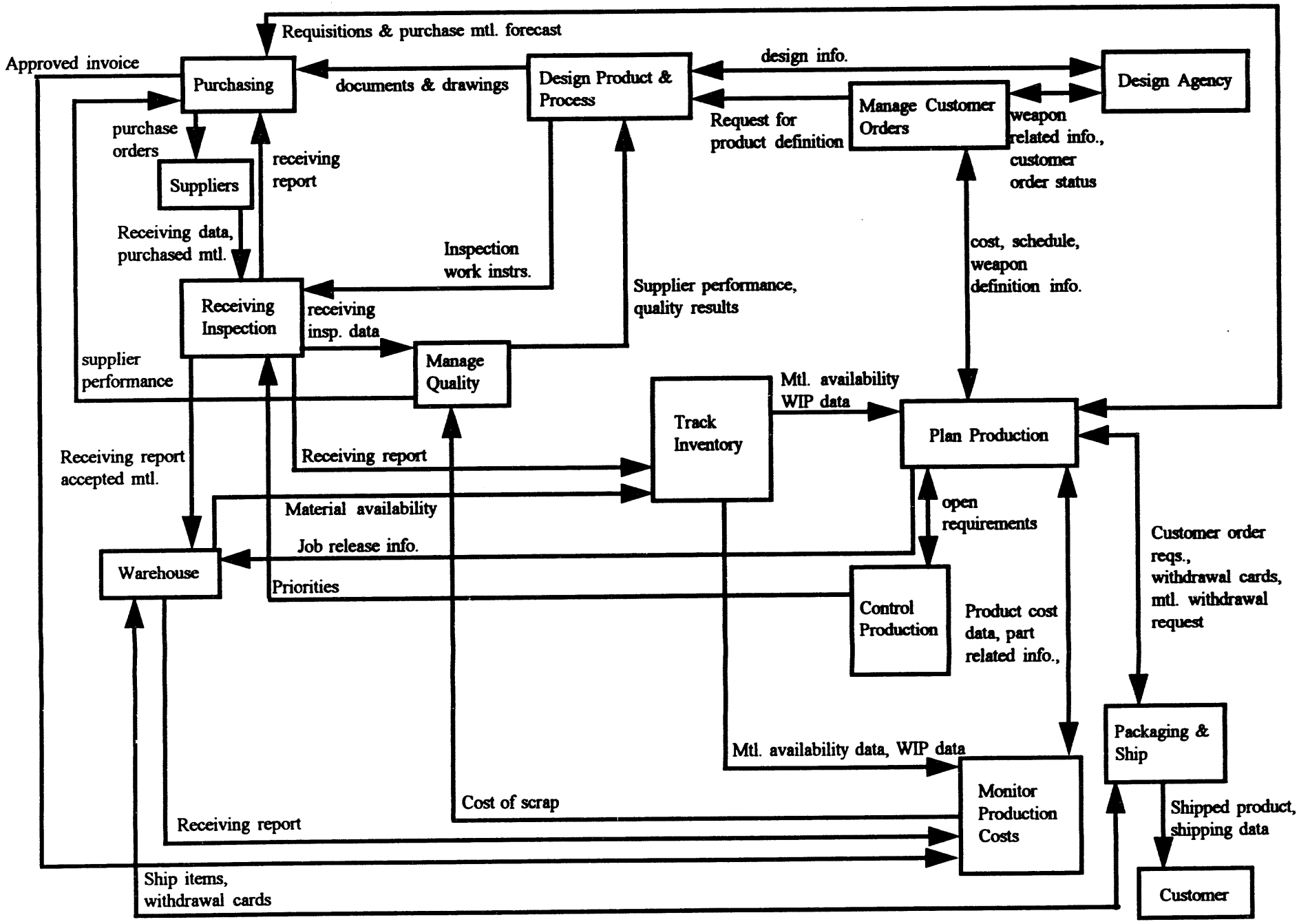


Figure A.6: As-Is Information Flow Diagram (AS/KCP) - NWC Designed/Specified, Industry Manufactured, AS/KCP Procured

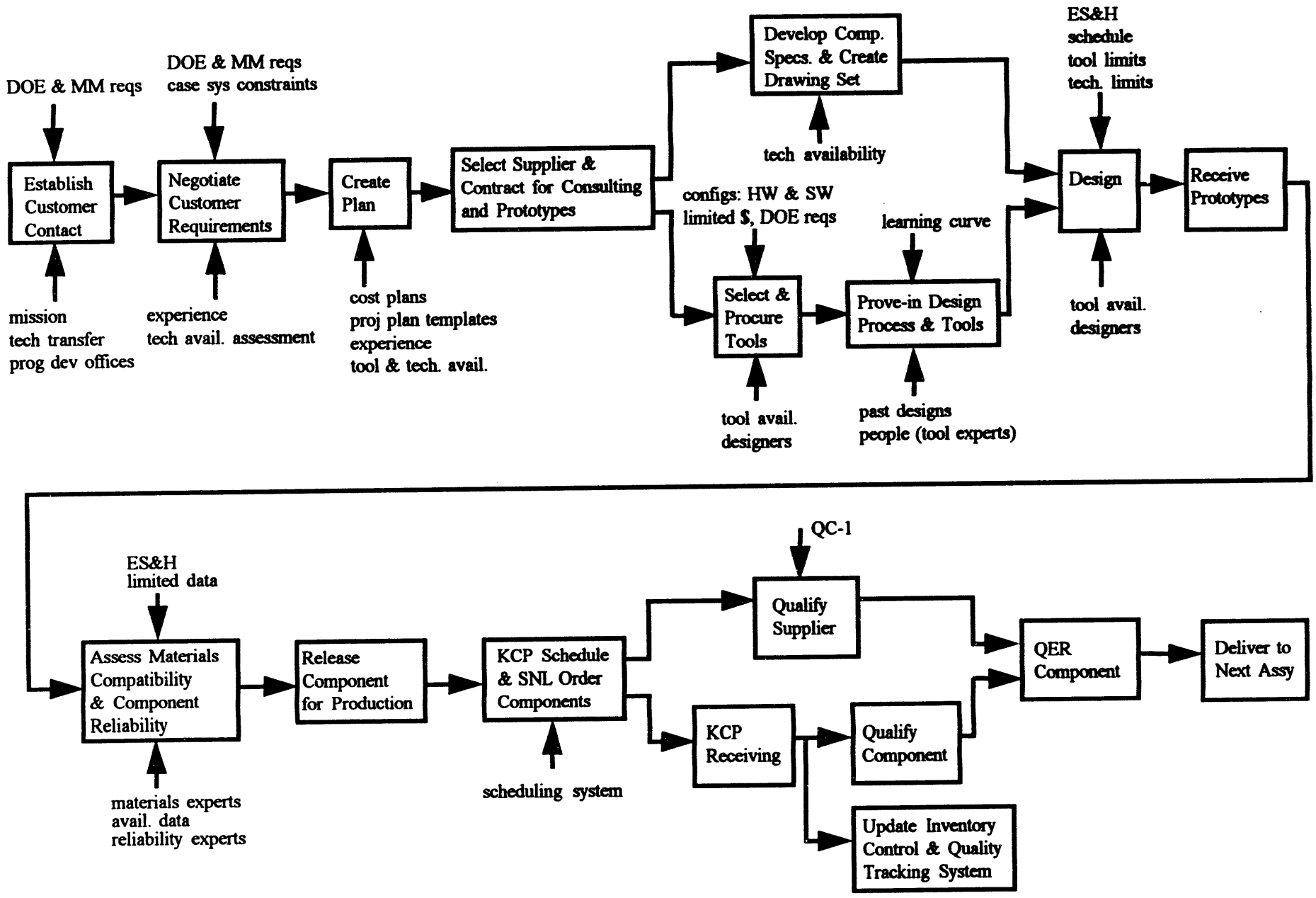


Figure A.7: As-Is Work Flow Diagram - NWC Designed, Industry Manufactured, MDE Procured

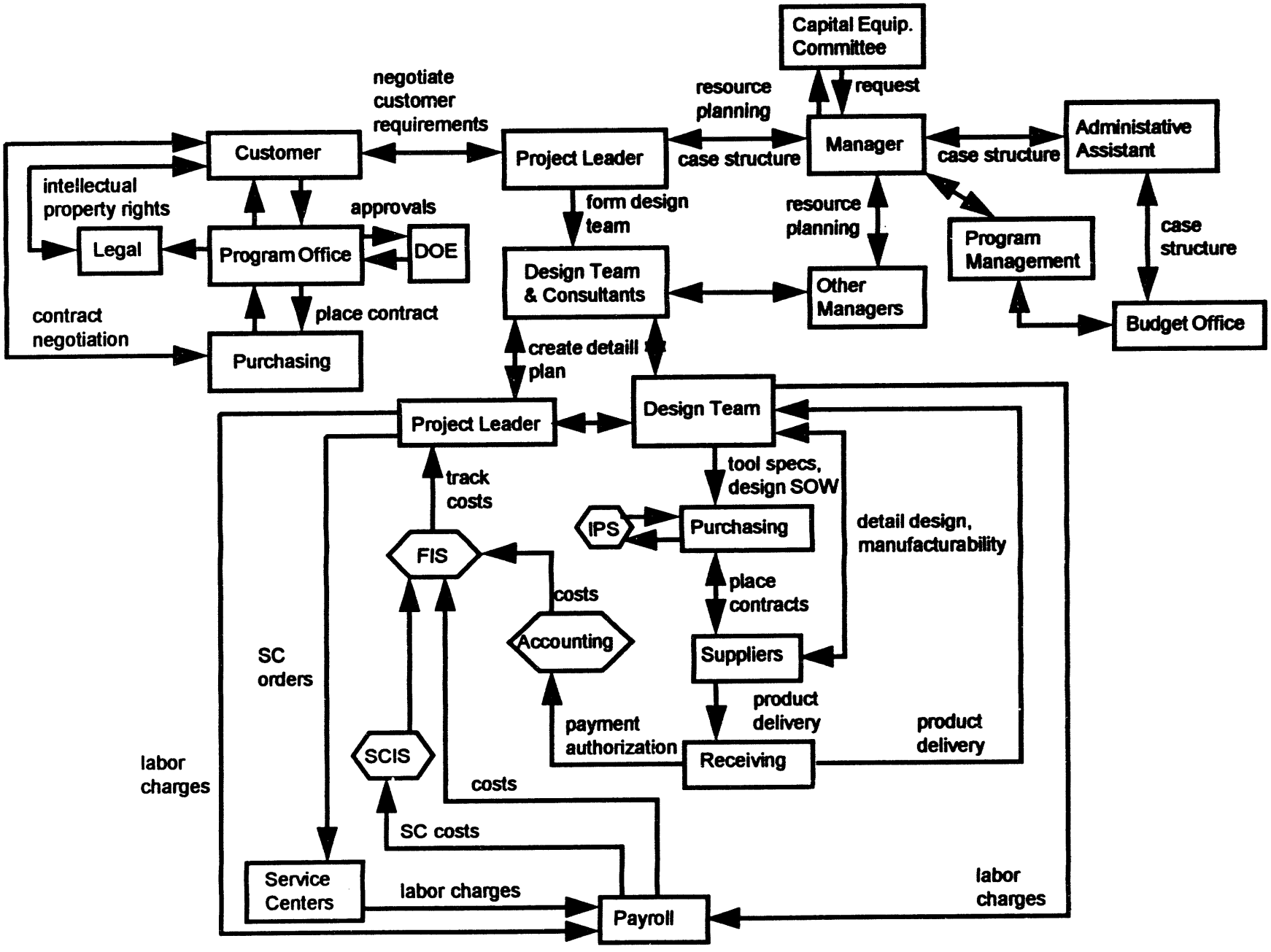


Figure A.8: As-Is Information Flow Diagram (SNL) - NWC Designed, Industry Manufactured, MDE Procured

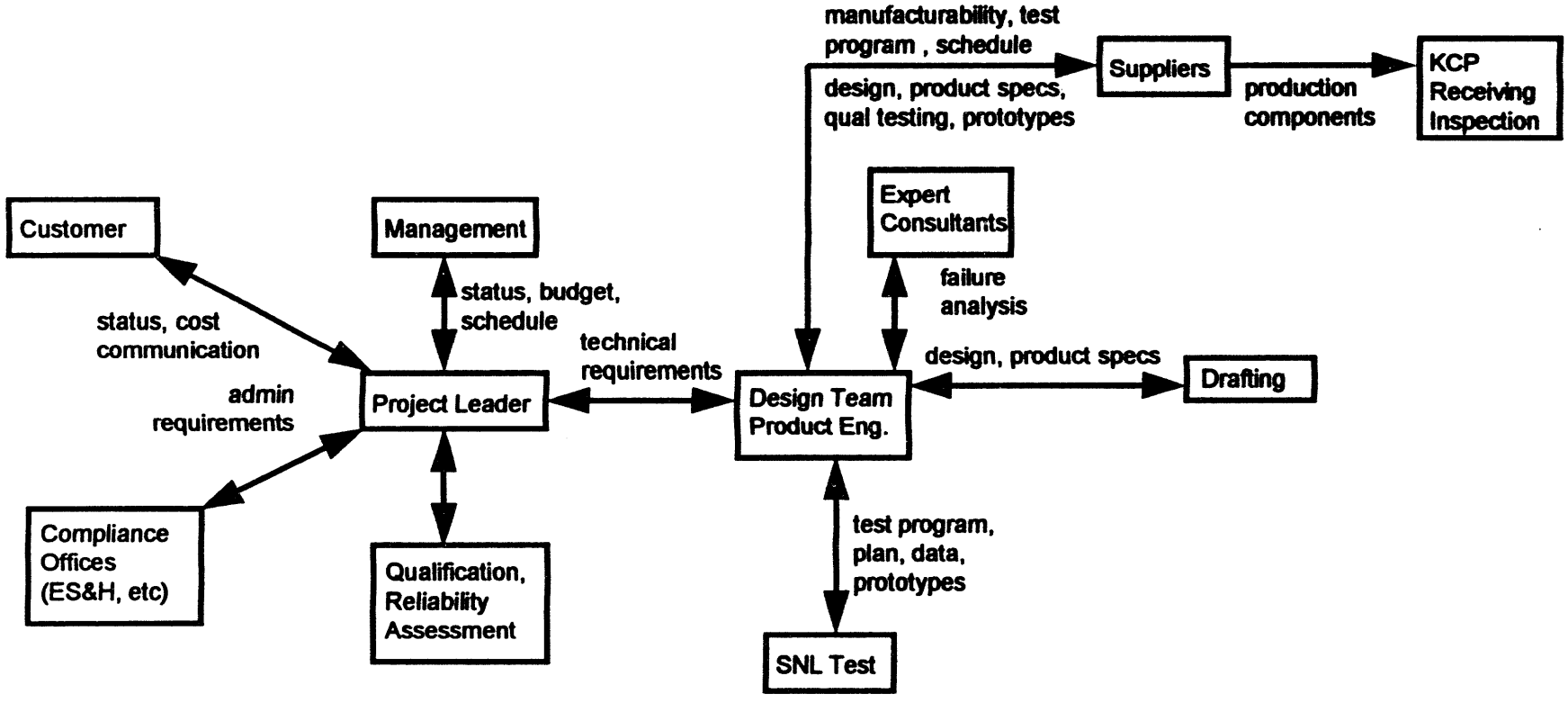


Figure A.8 (cont'd): As-Is Information Flow Diagram (SNL) - NWC Designed, Industry Manufactured, MDE Procured

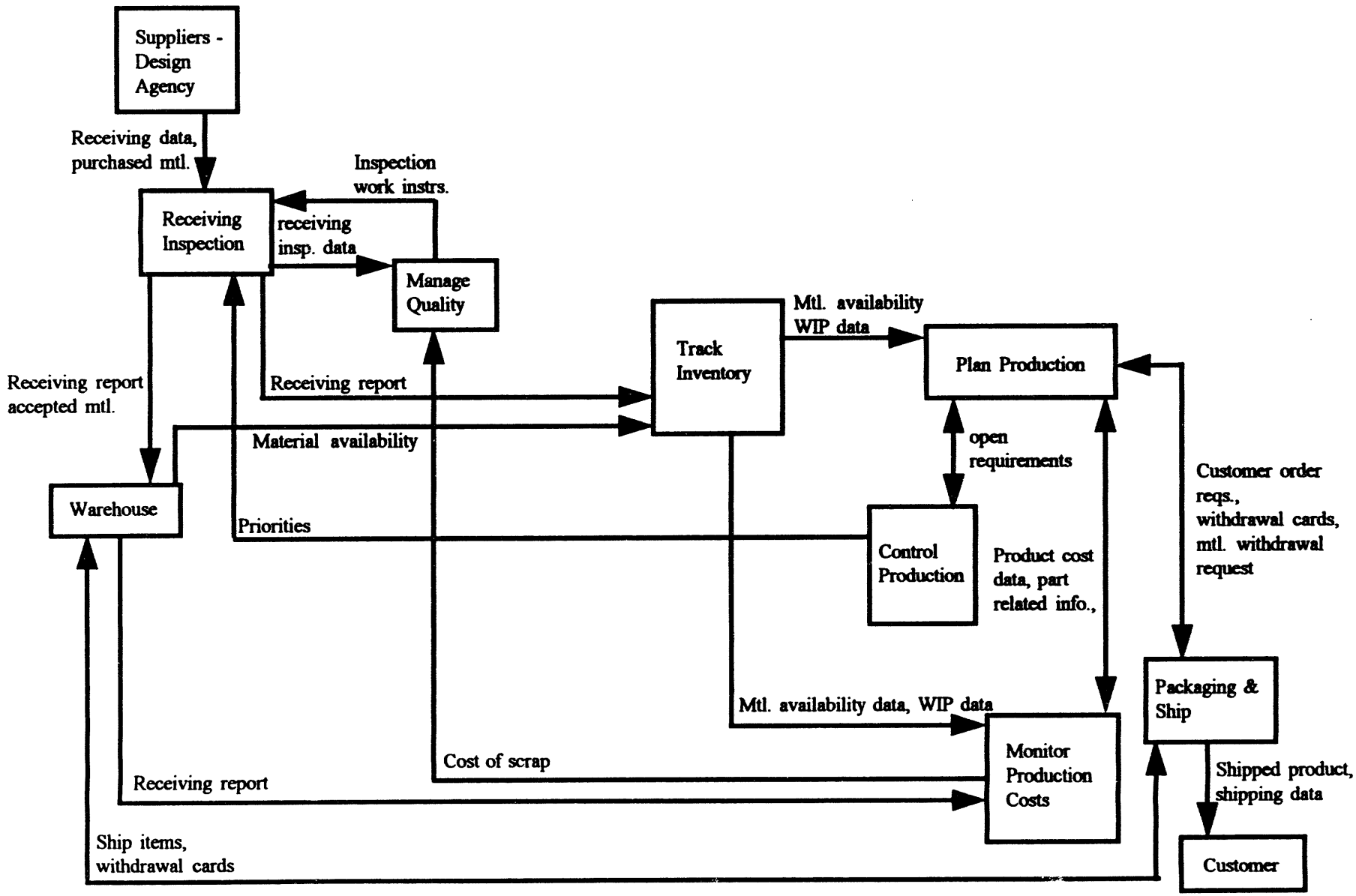


Figure A.9: As-Is Information Flow Diagram (AS/KCP) - NWC Designed, Industry Manufactured, MDE Procured

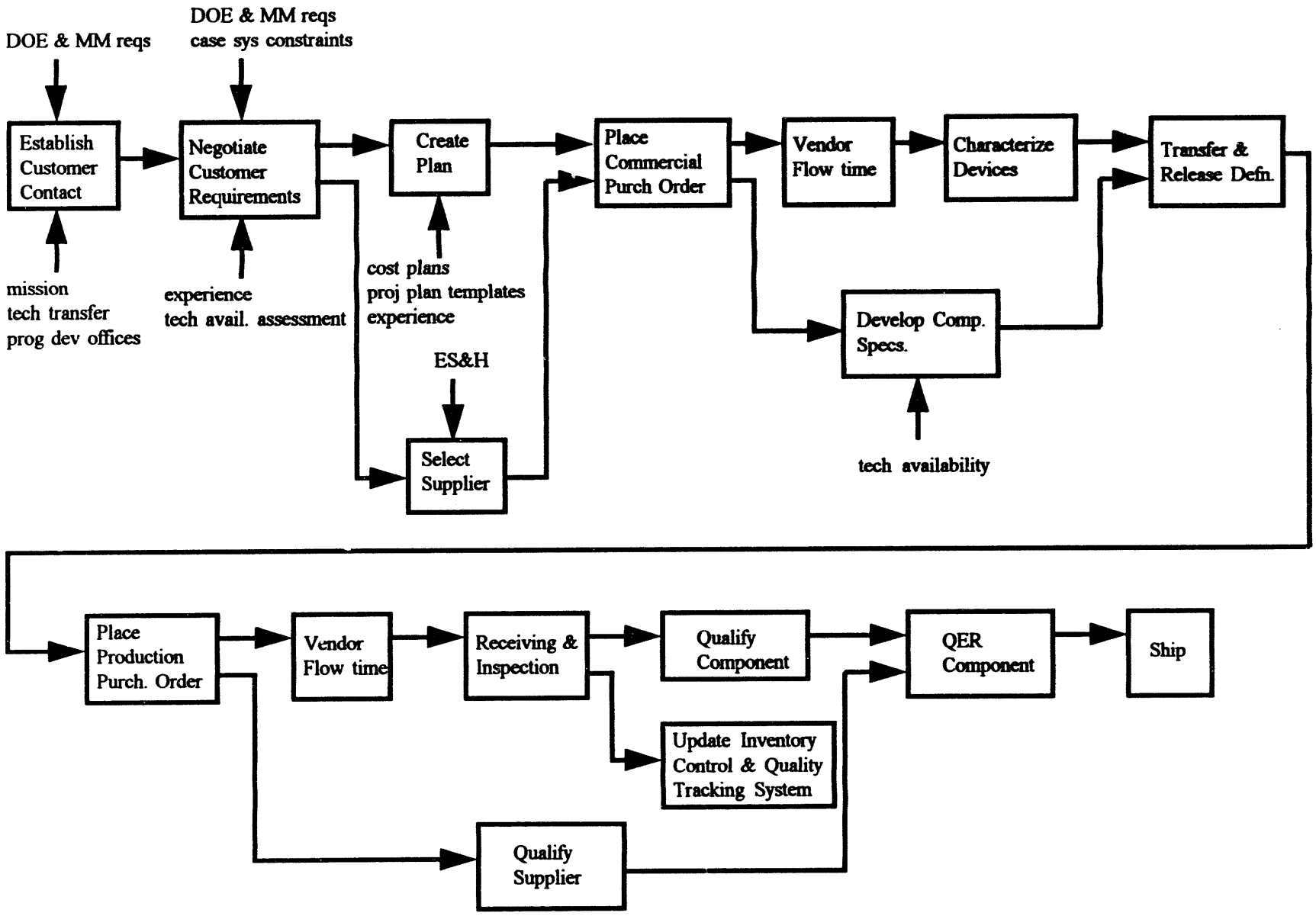


Figure A.10: As-Is Work Flow Diagram - NWC Specified, Commercially Available, AS/KCP Procured

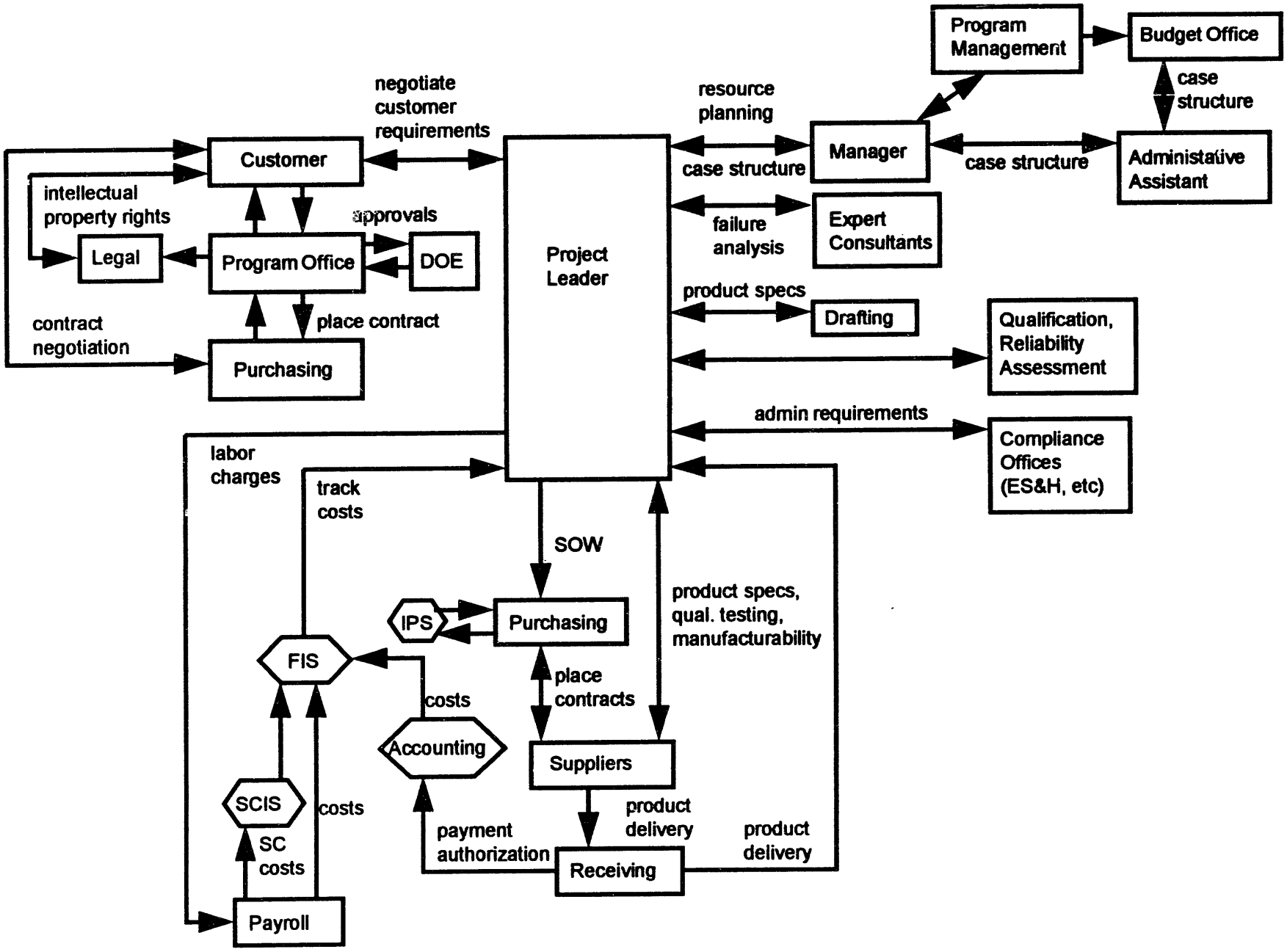


Figure A.11: As-Is Information Flow Diagram (SNL) - NWC Specified, Commercially Available, AS/KCP Procured

Appendix B: Important Technology Characteristics Tables

ITC	Description	Rated Values	
Range of Information	• depth and diversity of information • extent of the archived database • existence of information libraries • applicability of information across life cycle	Low Medium High	narrow, little depth or diversity some depth or diversity considerable depth and diversity of info.
Reliability	• consistency of the system across time and applications • stability and resistance to minor changes • consistency of meaning and the use of the data across company and geographic boundaries • a reliable system rarely fails	Low Medium High	fails frequently and without warning; inconsistent; unstable fails occasionally, perhaps with brief warning, moderately consistent, stable rarely fails, and if it does, provides warning; very consistent and stable
Self Sufficiency	• can be used as a standalone, without system • need to interface with other systems to perform typical work • completeness of the database • extent of necessary utilities to avoid relying on external software	Low Medium High	user frequently has to go to another system to perform typical work user occasionally has to go to another system user can do nearly everything needed with the system at hand
Fault Tolerance	• capability to tolerate mistakes by having internal features to protect against human or system error • has backup options to recover from operator, software, hardware or power failures • a fault tolerant system is not subject to harm from its own mistakes	Low Medium High	errors (system or human) cause major disruptions errors cause minor disruption errors cause little, if any disruption
Maintainability	• ease of keeping the system operating • easy to add new capabilities, minimum impact • includes ease of maintenance, serviceability, and availability	Low Medium High	difficult or time consuming to get assistance with problems or new capabilities some assistance readily available, but may be incomplete or moderately effective easy to obtain effective assistance with problems or new capabilities

Table B.1: Important Technology Characteristics

ITC	Description	Rated Values	
Flexibility	• adaptable to multiple or expanded uses • modularity of the software • options available • ability to incorporate upgrades without having to maintain or lose existing information	Low Medium High	system limited to specific uses; not daptable system capable of being extended or modified, but only to a limited degree system allows easy addition of capabilities without loss of existing information
Information Integration	• ability to exchange data with other systems and to coordinate shared data • ability to work with legacy systems	Low Medium High	very difficult or unable to exchange data with other systems or between applications exchange data w/ other systems, but w/ difficulty easily exchanges data with other systems
Data Integrity	• ability to protect the character and meaning of data with those data are shared across applications • involves open communication systems that accommodate interoperability	Low Medium High	character and meaning of data is often lost when moving between applications character and meaning of data is occasionally lost or slight changes occur which have little impact character and meaning of data is maintained
Access Control and Configuration Management	• maintaining a secure, up-to-date and consistent database • capability to handle file and data version control as well as control of who can access the data and who can modify the data	Low Medium High	serious problems w/ security, control, access control occasional problems which may result in only moderate costs when they occur rare problems or easily controlled at a low cost
Ease of Human Use	• ease of understanding and learning • ease of work tasks for which the system is used, like programming and drafting • ergonomic soundness	Low Medium High	substantial effort to learn; remains difficult to use; substantial ergonomic problems significant effort to learn, but becomes easy to use for experienced user ease to learn and use
Efficiency	• general operational efficiency • includes required user training and ramp-up time, ongoing operational requirements	Low Medium High	substantial effort require to accomplish any task moderate effort to accomplish moderate sized task little effort required to accomplish any task

Table B.1 (cont'd): Important Technology Characteristics

Systems	Currently Used Features/Functions	Desired Features/Functions
Purchasing (Integrated Procurement System)	Desk top JIT purchases, online, forecasting, order status	Qualified vendors, electronic contract placement, electronics fund transfer, integrated with the financial system, distributed data entry, access control for read and write
Financial Information (FIS)	online, updated weekly, archives financial information, cost planning	continuously updated, automatically track committments, integrated with the purchasing system, access contrl read and write, distributed data entry, budget in smaller increments, consistent accounting practices (service centers and direct organizations)
Service Center Information System (SCIS)	time accounting in 1 min. increments, cost accounting in $.01 increments, indirect costing to distribute the costs of essential support activities (training, maintenance, etc.), reflects true costs, flexible, easy to open, modify, and close cases	Improved reporting features, more user-friendly, continuous updates
CAD (Design Simulation) - Electronic	schematic capture and simulation,	facilitate concurrent engineering,
Electronic Layout	physical design definition, used to generate artwork and tool paths	coupled w/ CAD package, easily transferable files between electrical & mechanical (includes stress & thermal simulations)
CAD - Mechanical Simulation (Pro-E)	solids modeling,mechanical design definition, digital design (?)	Pro-E and Pro-M be interconnected, want to be able to realize virtual reality to easily assess fit/function
Mechanical Layout (Pro-E)	solids modeling,mechanical design definition, digital design (?)	
CAM (Pro-M, Anvil, etc.)	2-d model, user friendly and can be used by machinists	want 3-d model, needs to be able to design more efficient tool paths, more intelligent common standards between designers and suppliers

Table B.2: Features of Technology Systems

Systems	Currently Used Features/Functions	Desired Features/Functions
Component Information (Whitestar, ECCI)	outdated information, incomplete technical information, limited parts, limited models	current information (continuously updated by suppliers), device models, cost & schedule information, easily searchable, electrical characteristics, physical parameters
ICE	facilitates concurrent engineering	facilitates concurrent engineering, needs to be compatible with all CAD/CAM systems
IDEA	expert system, provides knowledge across project lines, difficult to capture the knowledge, may be expensive to maintain	integrated in work practices so that the system is refreshed and maintained
Supplier Performance	limited information, micro systems within Sandia that are not shared outside the local department, ratings are based on past Sandia performance	general system that is on-line and updated with ratings based on clearly explicit criteria
MUSE (multi-media user ...)	allows mechanical models to be placed in a multi-media environment to improve concept visualization	want to be user friendly, training tool on manu. floor, easy to set up & manipulate files
e-mail	send files and messages	easy universal access; consistent user IDs and system setups; better directory; reliability
EPs	joint (NWC) required engineering procedures	need prompts to tell you when you should use them, need to be easily accessible
DOE Orders	Overarching operating requirements for NWC	very complex, difficult to get because Sandians operate from derivative documents
Factory Management-CACTUS	Provides shop tracking, display of work directions to operators, time reporting, scrap reporting	Input several operations at once, display graphics, SPC functions, training and certification/qualification verification lockout

Table B.2 (cont'd): Features of Technology Systems

Systems	Currently Used Features/Functions	Desired Features/Functions
ATS-Automatic Traveler System	Work instruction system for assembly and fabrication of product	Need to be combined with all plant work instruction systems, more user friendly, improved editing
II-Inspection Instructions	Inspection work instruction system to define feature and function measurement	Combine with ATS system
OR-Open Requirements	Displays scheduling information for 18 months and planning beyond 18 months, shows attrition, runs daily	Improve accuracy-too many changes
CAMPS- Computer Automated Procurement System	Procurement system that is feed from signed requisitions or from the open requirements system	Input orders and approve from a workstation
Contract Order	Inputs orders and integrated with the open requirement system	Ability for a customer to view and input orders
Design Configuration Management - paper system (not included in ratings matrix)	Paper system (ICO, ACO, FCO, SXR, etc)	need to be able to convert older files to be compatible with new systems; needs to solve legacy issues, needs to be well-controlled

Table B.2 (cont'd): Features of Technology Systems

	Technology																						Observations		
	Individual Systems																								
ITC	IPS (Purchasing)	FIS (Financial Info)	SCIS (Service Centers)	CAD - Electronic**	Electronic Layout**	CAD - Mechanical Sim (Pro E)	Mechanical Layout (Primarily Anvil/some Pro E)	CAM (ANVIL AND SMALL AMOUNG OF PRO E)	Component Info**	ICE	IDEA	Supplier Performance	MUSB (Multi-media..)	e-mail	EPs	DOE Orders	Factory Management-CACTUS	ATS - Automatic Traveler System	II- Inspection Instructions	OR - Open Requirements	CAMPS - Computer Automated Procurement System	Contract Order	Information-related	Organization-related	People-related
Range of Information	M	H	H	M	M	H	H	H	M	H	H	H	N/A	H	M	H	M	L	M	M	H	M	E-CAD models not always avail., but are good when have them.	No standard across SNL for E-CAD	
Reliability	H	M	H	M	M	M	M	H	L	?	M	M	H	M	N/A	N/A	H	M	M	M	M	M			
Self-Sufficiency	H	L	M	M	H	M	M	M	L	H	M	L	M	H	L	L	M	M	H	M	H	M		e-mail self suff. dependent on internet and other gateways	
Fault Tolerance	M	M	M	L	L	M	M	HL	M	M	H	L	H	M	N/A	N/A	H	M	H	M	M	M			
Maintainability	M		L	L	L	L	L	M	M	H	L	M	H	M	L	L	M	M	M	M	L	L			
Flexibility	L	M		H	H	L	M	M	L	M	H	M	H	H	L	L	M	L	L	L	L	L			
Information Integration		M	M	M	M	M	M	M	L	H	H	M	H	H	N/A	N/A	M	M	L	M	M	M	e-mail not sufficient conversions to go across UNIX		
Data Integrity	M	H	H	M	H	H	M	M	L	H	M	M	H	M	L	L	H	H	M	M	M	M	EPs & DOE orders subject to interpretation		
Access Control & Conf Mgmnt	M	H	H	M	M	L	M	H	M	M	M	H	N/A	L	N/A	N/A	H	H	H	M	M	M			
Ease of Human Use	H	M	M	M	M	M	H/M	M	M	H	M	M	H	H	L	L	M	L	M	L	M	M			
Efficiency	H	M	H	M	H	M	M	M	M	H	H	M	H	H	M	L	M	L	M	M	M	M			
** NO CORP SYSTEM																									

Table B.3: Important Technology Characteristics Ratings Matrix

Appendix C: Strengths, Weaknesses, Opportunities, Constraints Table

The prioritized SWOC elements are shown in Table C.1. The enterprise objectives were rated by importance (1=low, 2=medium, 3=critical) and the impact of each SWOC on each objective was discussed. In order to distinguish the priorities, SWOCs with a strong relationship (positive or negative) were given a score of nine, those with a moderate relationship are scored at three, SWOCs with a weak relationship to the objective are given a score of one, and those with no impact are scored at zero. Once all the relationships have been correlated, the scores were multiplied by the importance weight and summed to identify the impact of each SWOC on all of the goals. These numbers are shown in the Priorities row.

		Enterprise Objectives						
		Improve cost effectiveness	Reduce component delivery cycle time	Provide components of the appropriate quality	Involve a minimum number of people	Broaden the customer base		Priorities
	Objective Importance (1-low, 2-medium, 3-critical):	2	3	3	1	3		
Strengths:								
	Meets QC-1 requirements	9	9	3	9	1		66
	Use of common CAD systems	3	9	3	3	0		45
	Hire and nurture skilled staff	3	3	3	3	3		36
	Invest in technology support	1	3	3	1	3		30
	Stability in design workforce	3	3	3	1	0		25
Weaknesses:								
	Accounting systems not integrated between facilities	1	3	0	1	0		12
	Do not work to common DOE rules	3	3	3	3	3		36
	Long cycle time (e.g. inspection, non-value added work, long approval chains)	9	9	3	9	3		72
	No integrated definition configuration management system	3	9	9	3	3		72
	Scheduling systems are not integrated	1	9	1	3	3		44
	Complex procurement systems	9	9	3	9	3		72
	Many design and fabrication iterations	9	9	1	3	3		60
	Inflexible workforce	3	3	1	1	3		28
	Parties affected by decisions aren't present in the process	9	3	3	1	1		40
	Culture does not emphasize program planning	3	3	1	0	1		21
	Stability in production workforce	3	3	9	3	1		48
Opportunities:								
	Few supplier partnerships	3	9	9	3	3		72
	Few common corporate objectives	1	3	1	1	9		42
	Keep abreast of latest tech. & capabilities by partnering w/ tech. development suppliers	3	3	3	1	3		34
	Seek to improve and update processes	3	3	3	1	3		34
	Establish an infrastructure that includes a process for using lessons learned	3	3	3	1	1		28
	Do up front assessments (mfg, compatibility, reliability, benchmarking)	3	3	9	1	1		46
	Do cost/benefit analysis (ES&H, program planning, etc)	9	1	3	1	1		34
	Information technologies (funds transfer, IDEA , ECCI, ICE, etc.)	9	9	3	9	3		72
Constraints:								
	Limited resources (capital equipment and expense funds)	1	3	3	1	3		30
	Government, DOE regulations (procurement, ES&H, etc)	9	3	1	9	3		48
	Union contract	3	3	0	3	1		21
	Physical separation of manufacturing and design	3	3	1	3	1		24

Legend:
0=no relationship
1=weak relationship
2=moderate relationship
3=strong relationship

Table C.1: Prioritized Strengths, Weaknesses, Opportunities, and Constraints Elements

Appendix D: To-Be Work and Information Flow Charts

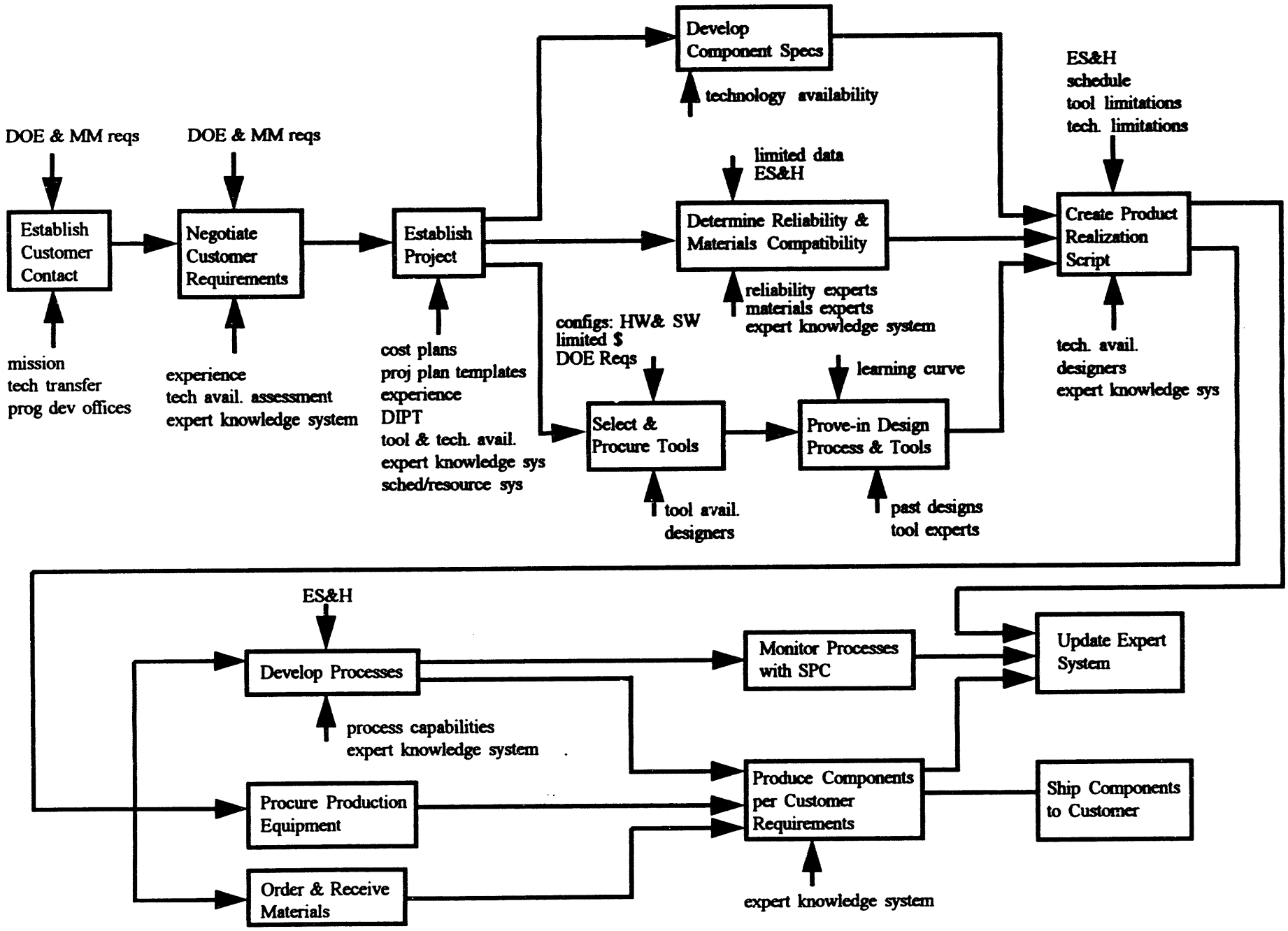


Figure D.1: To-Be Work Flow Diagram - NWC Designed and Manufactured

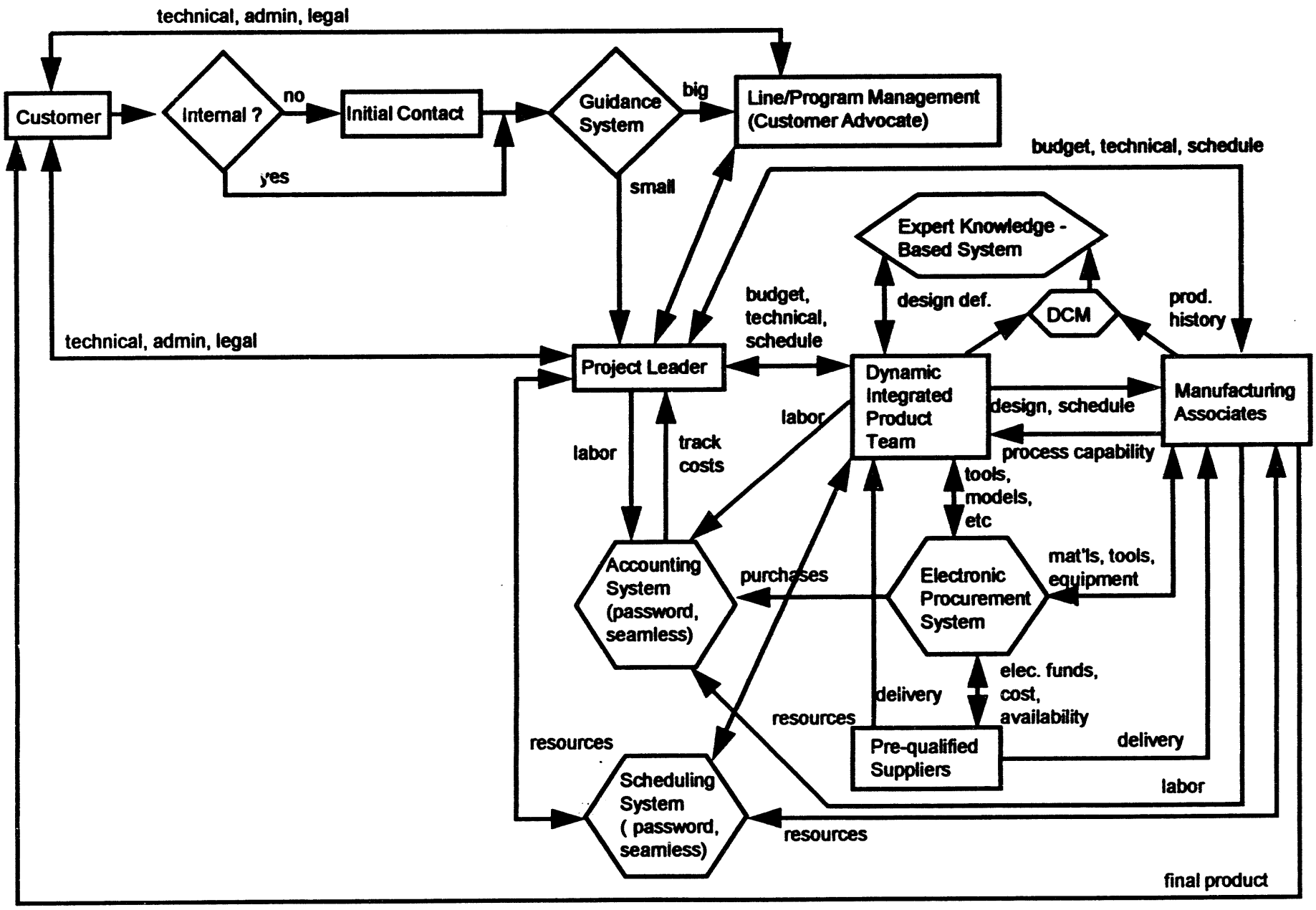


Figure D.2: To-Be Information Flow Diagram - NWC Designed and Manufactured

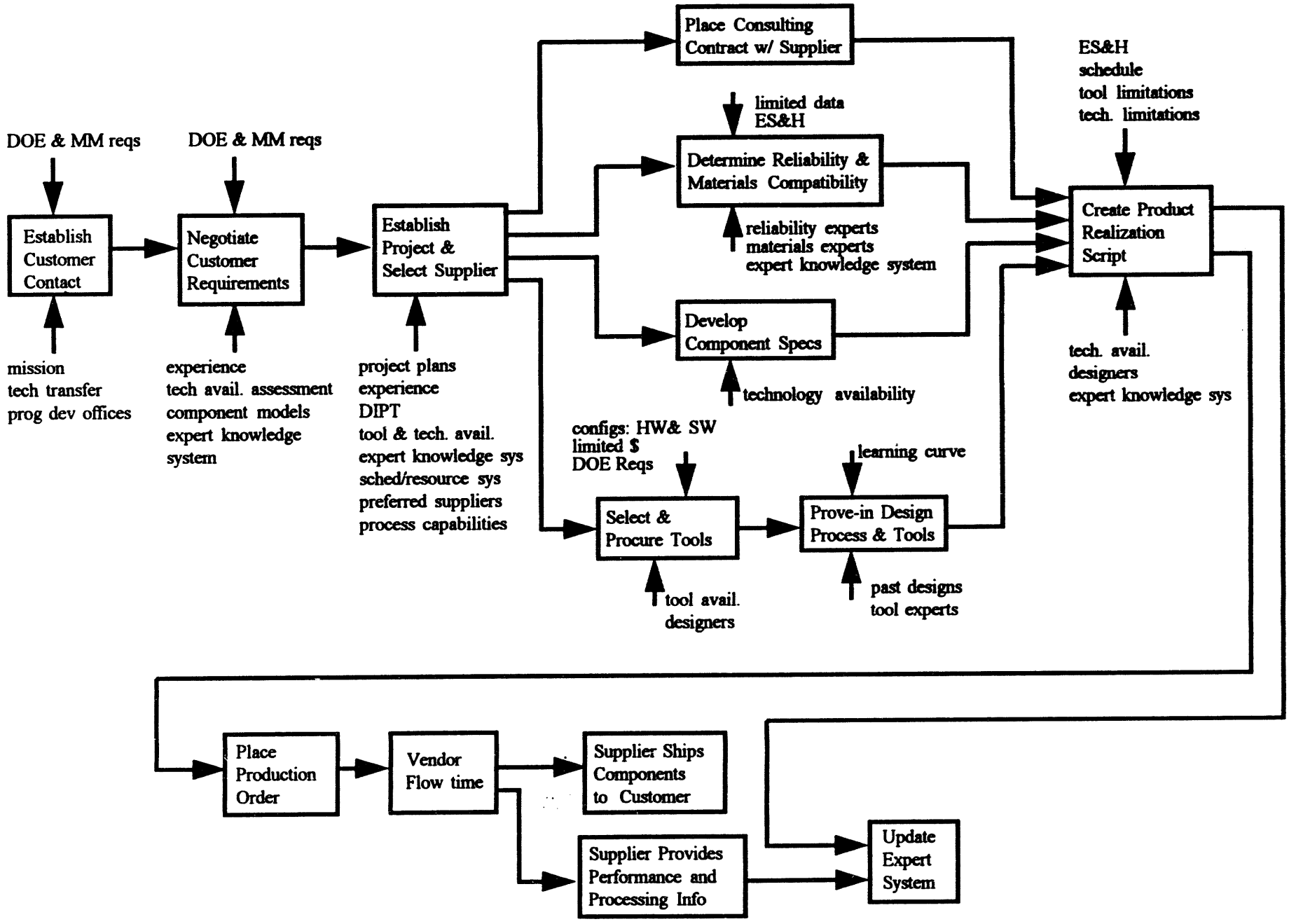


Figure D.3: To-Be Work Flow Diagram - NWC Designed, Industry Manufactured

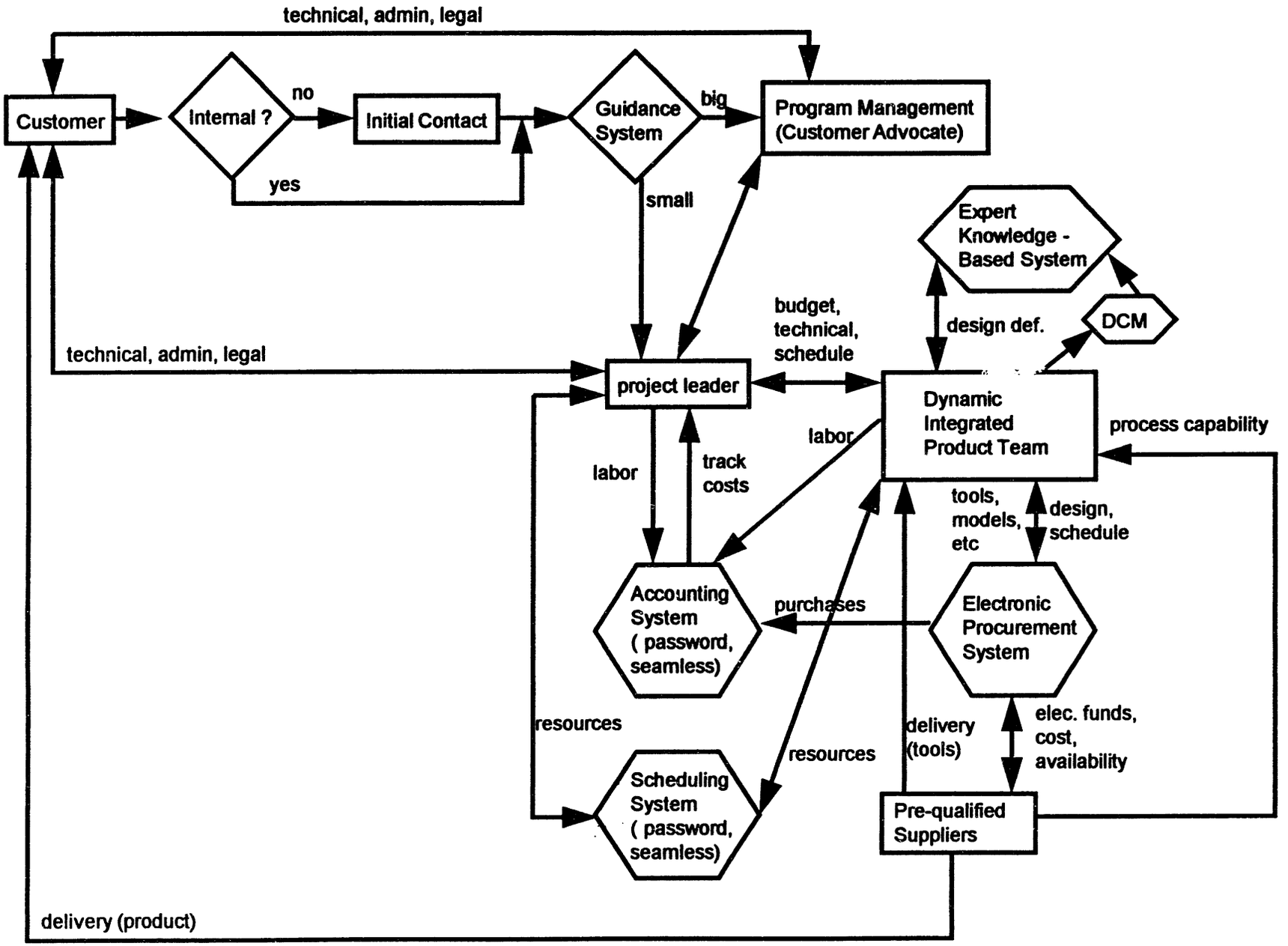


Figure D.4: To-Be Information Flow Diagram - NWC Designed/Specified, Industry Manufactured/Commercially Available

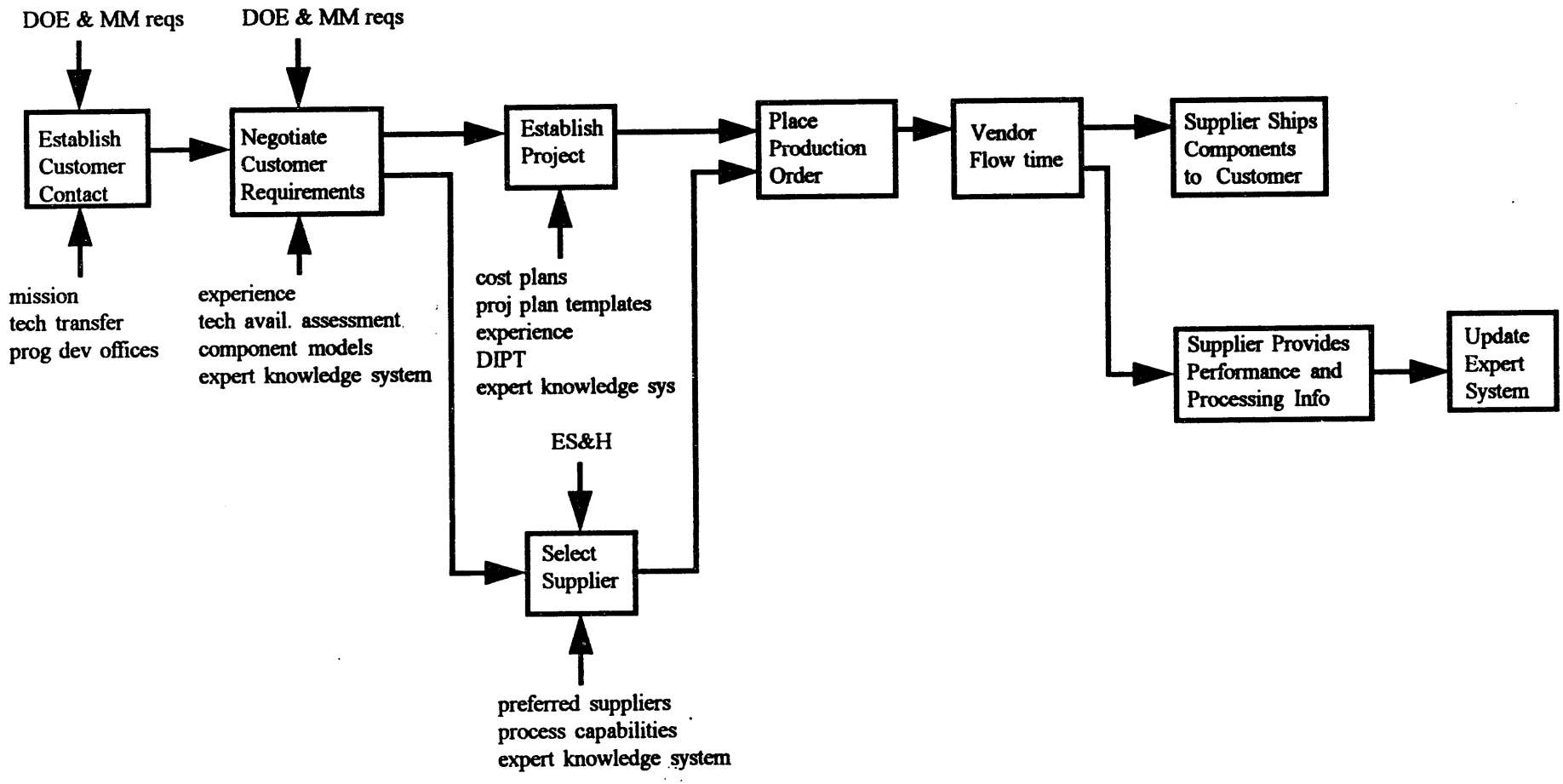


Figure D.5: To-Be Work Flow Diagram - NWC Specified, Commercially Available

Appendix E: Pilot Project Example

Section II - Summary of Proposal

A. Innovative Claims for the Proposed Research

The proposed project will demonstrate a virtual enterprise model for moving organizations to an agile manufacturing posture. The concept of agile manufacturing (Iacocca Institute's *21st Century Manufacturing Enterprise Strategy Report*) implies needs for new and innovative ways of conceiving and implementing business organizations for manufacturing. An approach to be demonstrated in this project is to meld theories and principles from new concepts of the manufacturing enterprise to help agile manufacturing happen. Specifically, the project will develop ways to apply the characteristics of the *virtual enterprise* (Davidow and Malone; Hammer and Chumpy) to agile manufacturing. Relevant thoughts and experiences in defining the virtual enterprise, as well as implementing enterprise integration and business-process reengineering will be brought to bear on creating a virtual enterprise. That enterprise will consist of the Sandia National Laboratory; the Allied Signal/Kansas City Facility; their customers; and their suppliers. The purpose of the virtual enterprise will be to partner for the selection, evaluation, development, procurement, and manufacture of electronic components.

An approach to such an enterprise-building venture has been initiated at Sandia. Tools and methods developed by the Industrial Technology Institute and by the NIST Manufacturing Technology Centers offer ways to operationalize and help organizations through the change process toward the virtual enterprise. Two such tools, the Cross-Organizational STEP Adoption Tool (COSAT) and the Human Resources Assessment Package (HRAP) are expected to form the cornerstone for the proposed enterprise development at Sandia.

The major benefits of the virtual enterprise model for agile manufacturing will be:

- Faster provision of electronic components to the field
- Less expensive procurement and manufacture of electronic components
- Higher quality components through the joint strategic and tactical integration between providers

For longer-term users beyond the demonstration site, the virtual model can be exp to offer a method for integrating technologies, organization and people for agile manufacturing.

Deliverables

1. *Packaged and tested tools for organization and human resource assessment.* COSAT and HRAP, as applied to, and refined by the virtual enterprise application will be documented for dissemination, along with orientation materials for training other companies to use them.

2. *Description of the Virtual Enterprise model and process.* The characteristics of the Sandia/Allied-Signal Virtual Enterprise will be described. This report will also articulate the process by which the enterprise evolved, so that other firms may replicate, or customize that process.

3. *A formative implementation analysis.* As the virtual enterprise is designed and implemented, the project will document the activities and the accompanying facilitators or barriers to effective change. This analysis will offer implementation guidance to future groups moving toward an agile manufacturing environment.

4. *Summative evaluation of the value of the virtual enterprise model.* Outcome data will be gathered from a six-month pilot implementation/demonstration to test the value of the new agile approach. That evaluation will rely upon relevant outcome criteria for the Sandia/Allied operation, and comparisons of results from the virtual enterprise with other traditional forms of organization. Criteria will include cost, quality, delivery, service and morale.

5. *A dissemination model for building more virtual enterprises.* A process will be developed and reported by which government agencies can foster more widespread adoption of virtual enterprises for design, manufacture and provision of resources to the armed forces and civilian manufacturing sectors. This will include guidance on how Agile Manufacturing Pilots can embrace the virtual enterprise approach and benefit from it.

C. Cost, Schedule and Milestones

TASK	MONTHS	PERSON-DAYS	MILESTONE
Review objectives	1	20	-
Set strategy & guidance	1-2	30	-
Review other EI efforts	1-3	40	Report
Complete As-Is assessment	1-3	100	Documentation
Design To-Be Virt. Ent.	2-4	220	Doc/Report
Assess Implement'n Gaps	4-5	60	Ass't Report
Plan implementation	5-6	50	Action Plan
Establish success criteria	6-7	40	Documentation
Design evaluation	6-7	40	Report
Implement and evaluate	7-15	400	Monthly repts
Report and recommend improvements	15-18	60	
Disseminate model	15-18	35	
Project management	1-18	100	
Total		1195	

Estimated Costs	ITI	Sandia	Allied	Perc.	Total
Year 1	$234K	218	210	75	737
Year 2	$95K	65	65	20	245

D. Technical Approach, Rationale, and Strategy

Overall Technical Approach

Our approach will be to use existing tools to link the concepts of the virtual enterprise strategy with the realtime task of building an integrated team for agile manufacturing of electronic components. The work will involve reengineering the business process for component procurement and manufacture and providing the operational tools to accomplish that integration. Development of the enterprise will be pursued by the members of the design, manufacturing and business team that cuts across the two components-producing organizations (Sandia and Allied). ITI will facilitate the assessment, design, implementation and evaluation phases of the project. Perceptronics will provide their PERCNET process modeling and simulation software tool and expertise.

Rationale

It is a premise of this proposed research that transferring the concepts of the virtual enterprise to agile manufacturing requires structured tools and technical assistance. Simply reading the books (e.g., *The Virtual Corporation* and *Reengineering the Corporation* will not suffice to know how to plan and implement change for agile manufacturing. Tools, which have already been developed, can provide both a structured change process, and a knowledge base of expertise on the elements of an agile manufacturing enterprise.

The virtual enterprise mandates a new level of heightened and immediate *responsiveness*. Through the development of new seamless structures and processes, the virtual enterprise can serve as a base for adaptation to emerging and changing market considerations, materials developments and product configurations. It can also provide for the optimum utilization of resources throughout the enterprise, based on thorough communication and coordination.

The virtual enterprise is comprised of three central components: information processing, organizational dynamics, and manufacturing systems. It links services with a manufacturing based economy. The enterprise is viewed as involving an ever-changing set of activities within a *common* fabric of relationships among the partners. The enterprise will be based on innovation and trust (instead of competition). It will be dedicated to the removal of waste throughout the product life cycle. And, the members of the enterprise will be empowered to act.

Those concepts will be embedded in the Sandia/Allied virtual enterprise by selecting and strengthening business practices and communications methods for effective provision of electronic components.

The application of the model to the Sandia/Allied Signal integration team will allow transformation to the virtual enterprise from a situation where potential design and manufacturing redundancies or conflicts can result in less than ideal utilization of resources and relatively inefficient processing of business information.

Technical Strategy

1. *Review objectives and progress* - The Sandia/Allied-Signal team has already begun to plan for development of an integrated enterprise. They have established mission and vision and have begun to assess their as-is operating environment. Initial thinking has also identified some preferred directions for future enterprise development. ITI helped Sandia/Allied begin the process by providing an overview of how the COSAT tool could be applied to their endeavors. This project will allow further facilitation and development. The initial activity will be to review objectives in the context of the virtual-enterprise basis for this project, and to bring the project team up-to-speed on progress and directions.

2. *Set a continuous improvement strategy* - This task will layout an overall strategy and process for enterprise development and improvement. We will review the team approach for that improvement and establish a process for problem-solving much like that associated with Continuous Improvement User Groups, and what we have developed as a process for Continuous Improvement Through Teams. The method will be described and the enterprise team will establish any guidance functions that may be appropriate.

3. *Review other enterprise integration efforts* - This will entail a review of literature and practice in enterprise integration that are relevant to the focus at Sandia/Allied Signal. The virtual enterprise concept is sufficiently new, so that there will not be a deep literature base. However, we should be able to identify some research and case studies of enterprise integration, and sociotechnical organization design that will offer some best-practice guidelines for the virtual enterprise effort.

4. *Complete the As-Is assessment* - This task will complete the as-is assessment of the organizational and technical environment for the virtual enterprise. That assessment will include description and understanding of work flows, information flows, organization, and technology. These elements will be synthesized as a basis for developing specifications for the new

enterprise: what aspects of the as-is will change and to what forms will they change? The assessment will be accomplished through facilitated team discussions and presented in schematics that allow the team to understand what currently happens in selecting, procuring and making components.

5. *Design the "To-Be" virtual enterprise* - Using parallel considerations to the as-is assessment (work-flow, organization, etc.), the team will continue to establish the desired characteristics of the new enterprise. The Sandia/Allied team has already developed some initial concepts and work-flow ideas for the "To-Be" scenario. The enterprise characteristics are likely to include, to some degree, the following:

   - Work - modern computers, concurrent engineering, simulation and modeling, instant procurement procedures, modular tooling and direct numerical control, desktop accounting and costing, product realization strategies, CAD/CAE systems, and capable manufacturing systems.

   - Information - readily available design histories, project plans, realization scripts, guidance systems.

   - Organization - clear roles and responsibilities, teams, heavyweight project leaders, legal agreements, preferred suppliers, strategic plans, maximum flexibility.

   - Technology - common integrated desktop systems, integrated scheduling, forward compatible for design and manufacturing, e-mail, interactive video, file exchange, expert systems for processes and component designs.

6. *Assess capabilities and socialize the laboratories* - Given the design for the virtual enterprise, attention must be paid to providing the resources and support for implementing the change. Early in the process of assessment and design, champions will have been established. With those champions the virtual-enterprise team will help orient and attune other key members of the organizations to the emerging partnership. We will also conduct an assessment and possible redevelopment of the human resources necessary to implement the enterprise. While the virtual enterprise offers promise for optimum resource utilization, it also stimulates challenges for processes, skills, and measurement. The Human Resources Assessment Package will offer indications of any needed developments in education and training, empowerment, leadership and related functions.

7. *Plan the implementation* - As a natural follow-on to the socialization activities, the team will establish the specifics of the implementation plan, including the work-area focus (e.g., a subset of components), the timetable,

sequenced activities and responsibilities, and operations for monitoring continuous improvement.

8. *Establish success criteria* - Feasible measures of desired enterprise outcomes will be established as a means to measure the effectiveness of the endeavor. Those criterion measures are likely to represent each of the five "CQDSM" areas: cost, quality, delivery time, service and morale. The measures will be designed for maximum ease of collection and interpretation, with the expectation that measurements will be publicly posted and updated in the working areas of the enterprise to inform and motivate the team.

9. *Design evaluation* - Demonstrating the Virtual Enterprise business practice requires a sound evaluation of its effectiveness. The design, to be elaborated by the team, is likely to involve both some form of experimental/control comparison, and comparison of measures across time in the virtual enterprise. Since the program is new, and the laboratories' involvement in component design and manufacture is broad, it may be possible to establish an experimental group for the virtual enterprise in, for example, printed wire boards, while holding out a control group for other components (oscillators, cables, hybrids, etc.).

10. *Implement and evaluate* - The virtual enterprise will be implemented based on the action plans of the team. Although the implementation will-be for a longer period, we will track measures for evaluation over the first six-eight months (with possible followup measures later). The magnitude of the enterprise change is unlikely to yield major impacts in so short a time. However, within the eight months, we should have some short-term results impacting the process of doing business, and a program developed for Sandia and Allied-Signal to continue their internal evaluation.

11. *Report results and recommend improvements* - A project report will detail the process and outcomes of the virtual enterprise experiment at Sandia/Allied-Signal. It will describe the model, events, and results in sufficient detail to determine the value of the approach and to generalize the approach to other organizations.

12. *Develop the dissemination model* - An adjunct to the research report will consist of a model for disseminating the virtual-enterprise approach throughout the electronics industry, and potentially other ARPA-relevant manufacturing sectors. That model will recognize this as a seminal venture toward a modern, interacting coordination of Technology, Organization and People, with no component driving or inhibiting the others. The National Lab demonstration is geared to expansion to other manufacturing and design environments. The model will include emphasis on core values, leadership,

and enablers (Gunn, *21st Century Manufacturing*). Key features of the virtual enterprise will be operationalized for partnerships: structures, agreements, support requirements, and teams.

Appendix F: Acronyms/Definitions

AS/KCP	AlliedSignal Corporation/Kansas City Plant
BTCS	Business Terminal Control System
CAD	Computer Aided Design
CAE	Computer Aided Engineering
CAM	Computer Aided Manufacturing
CIO	Chief Information Officer
COSAT	Cross-Organizational STEP Adoption Tool
DCM	Definition Configuration Management
DOE	Department of Energy
DDP	Delegated Design Project
DIPT	Dynamic Integrated Product Team
ECAD	Electronic Computer Aided Design
ECCI	Electronic Commerce of Component Information
EIT	Enterprise Integration Team
EP401100	Engineering Procedure entitled "Qualification of Process and Production Under Demonstration Programs"
FIS	Financial Information System
ICE	Interactive Collaborative Environment
ICO	Integrated Contractor Order
IDEA	Integrated Design Environment and Assistant
IMDI	Integrated Manufacturing and Design Initiative
IPDS	Integrated Product Definition System
IPS	Integrated Procurement System
ITC	Important Technology Characteristic
ITI	Industrial Technology Institute
JIT	Just In Time
MCAD	Mechanical Computer Aided Design
MDE	Manufacturing Development Engineering
MOU	Memorandum of Understanding
MUSE	Multi-Use Synthetic Environment
NWC	Nuclear Weapons Complex
PC&C	Process Characterization and Control
PPL	Preferred Parts List
QC-1, QC-2	DOE's Quality Criterion
SNL	Sandia National Laboratories
SWOC	Strengths, Weaknesses, Opportunities, Constraints
TEAM	Technologies Enabling Agile Manufacturing
TMS	Tool Made Sample
TQ	Total Quality
TQS	Total Quality Speed
VEPMT	Virtual Enterprise Process Management Team
WR	War Reserve

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