DEVELOPMENT OF AN INFORMATION INTERCHANGE SUPPORT SYSTEM FOR CONCURRENT ENGINEERING DESIGN

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NOMENCLATURE

AI	Artificial Intelligence
ANOVA	Analysis of Variance
CAD	Computer-Aided Design
CAE	Computer-Aided Engineering
CAM	Computer-Aided Manufacturing
CAS	Computer Attitude Scale
CDD, Inc.	Computer Disc Drive, Inc. (Fictitious company name to hide the identity of an Industrial Partner)
CE	Concurrent Engineering
DFMA	Design For Manufacture and Assembly
DPs	Design Parameters
FEM	Finite Element Method
IISS	Information Interchange Support System
NPD	New Product Development
OLE	Object Linking and Embedding
P/E	Price / Earning Ratio
RONA	Return On Net Assets
SOP	Standard Operating Procedure

CHAPTER 1

INTRODUCTION

1.1 Problem Statement

While Shigley (1989), Nam Suh (1990), and Pahl and Beitz (1984) have described the sequential engineering design process, none of these authors discuss the engineering design process in a concurrent engineering environment. One reason is that concurrent engineering is a relatively new concept, having emerged in the last few years to improve on the conventional method of engineering design. The review of the sequential design process stressed the need to develop a communication model of the engineering design process in the concurrent engineering environment. Developing this model is the first phase of this research.

In concurrent engineering design, experts from different departments of the company interact together in every phase of product development to design products and processes concurrently. The design team, representing top management, research and development, finance, marketing, manufacturing, and purchasing, works together to make the right trade-offs from the beginning, when mistakes are less costly and easier to fix. According to data from the National Institute of Standards and Technology, Thomas Group Inc., and the Institute for Defense Analysis, concurrent engineering methodologies can reduce development time by 30 to 70%, result in 65 to 90% fewer engineering changes, reduce time to market by up to 90%, and result in the improvement of quality by 200 to 600%.

Many researchers in the product development area (Cooper (1987), DeBrentani (1989), Griffin and Hauser (1992), and Souder (1988)) have stressed the need for inter-department communication for the success of a new product. However, no specific research has been done to explore communication at each stage of the design process. Most of the researchers in the product development area consider product design as one step in the whole development process. No research has been found where the product design is further subdivided into four or six substeps for studying communication patterns. No research has been found that attempts to determine departmental involvement and the degree of involvement at each stage of the process. No research has been found that attempts to determine who should interact with whom, and the degree of interaction and appropriate stage of interaction for successful product design. Hence, the need is recognized here to do detailed research on the involvement of different departments and their interaction during the product design process in a concurrent engineering environment.

This research attempts to answer the following questions:

- What role does each department play during each stage of the product design process?
- How much interaction takes place among the various departments during each stage of the design process?
- What information is exchanged among the various departments during each stage of the design process?

Answers to the above questions will help in developing the "optimum information structure." The "optimum information structure" is defined as the process or mechanisms by which necessary information of all types is brought to bear on design activities. This structure integrates the following key corporate departments into the network: top management, finance, marketing, design, manufacturing, purchasing, quality assurance and research and development. Each department provides information to the designer directly or indirectly in the form of data, expertise, constraints, corporate control, etc. The designer needs this information on a timely basis throughout the design process to keep the design activity from stalling or going astray.

This research explores the roles of each department during different stages of the product design. This research also explores the amount of interaction each department should have with every other department during different stages of the product design. After exploring the involvement of departments and interaction among departments at each stage of the product design, this research establishes the information exchange requirements for seventeen broad categories to ensure that new products are designed to meet market needs, to satisfy customers, to meet cost specification, to utilize appropriate technologies, material and processes, and to manufacture quality products at lower costs. Then a computer-based information interchange support system is built on the basis of the above research findings. This system is tested for two new products designed in a concurrent engineering environment.

A general problem statement for the area of research can be made as follows: this research proposes to develop and validate a communication model for concurrent engineering design and then build and test an information interchange support system by using group communication technology to improve the engineering design process.

1.2 Statement of General Hypothesis

A communication model of the engineering design process based on concurrent engineering concepts and supported by a computer based information interchange support system that integrates design activities with other departments should reduce product development time, result in fewer engineering changes, reduce time to market, and result in quality improvement.

1.3 List of Research Objectives

The major objectives of this research can be listed as follows:

1) Development of a communication model of the concurrent engineering design, and identification of the roles and the information interchange required by the different departments,
2) Validation of the model by a case study approach to new product development project in a company and by sending out questionnaires as a survey instrument,
3) Identification of differences across the stages of the product design process and differences across various departments using statistical analysis methods like ANOVA, and the formation of communication networks using network building techniques,
4) Use of group communication technology to build a prototype information interchange support system, and
5) Testing and evaluation of the information interchange support system.

1.4 Significance of Research

Fast-cycle development has become a major thrust of the emerging literature in technology management and innovation. The goal of this project is to establish an information interchange support system that integrates engineering design activities with other key departments in a manufacturing firm. The emphasis on cross-functional teams to reduce new product development time requires a better way to manage communication processes as well. By providing a model of who should communicate with whom during each stage of the engineering design process and what the content of such an information exchange should be, a technologically based support system can be developed. As a result, valuable meeting time is used to arrive at tradeoffs and to make hard decisions rather than to disseminate and understand available information. This model will also help a product development team develop an organizational memory so that the next team does not have to start from scratch. The resulting model will be applicable across industries.

Since field tests of the proposed communication model of a concurrent engineering design process prove its value, empirically tested arguments can now be made for an extended, integrative role of the engineering design department. In most organizational structures today, the engineering design department assumes a service role; it often takes a back seat to marketing, production, etc. The findings of this research should change this conventional view. While a few firms have already altered their structures to change the role of the engineering design department, empirical evidence of this change has not been established. This research can thus lead to a major addition to our knowledge base in the organizational structures.

As the model establishes a central role for engineering design department at the product design stage, an enhanced design file specification format can be developed. This means that the engineering designer will have to consider not only the traditional design attributes that are stored in a CAD file but also prepare design specifications that are of interest to other functional areas of the organization. The CAD tools may become more "open" to accept this vital non-engineering design information within the design document.

1.5 Managerial Relevance of the Research

The case study approach and the use of a questionnaire should help in evolving a taxonomy of design knowledge. A generalized nomenclature in the design process improves communication within the cross-functional team working in a concurrent engineering environment. Marketing people will understand the language used by designers, and the design people will understand what marketing people want. While concurrent engineering concepts aim to achieve this goal, this research employed groupware technology to realize this goal.

This research can contribute to changes in the design curriculum in two specific areas. First, the courses in engineering design can be enhanced to discuss the role of other functional areas in engineering design at the graduate as well as undergraduate levels. A senior level course may be designed emphasizing the concurrent engineering design process model and the role played by different departments, as discussed in this research. Second, the effective use of group communication technology may be included in engineering design courses at the graduate as well as undergraduate levels. This research should serve as a good starting point in these specific areas.

CHAPTER 2

REVIEW OF RELATED RESEARCH

This chapter briefly reviews work published on topics related to this research. The first part of this research involved developing and validating a communication model for concurrent engineering design. Thus, section 2.1 reviews models of the sequential engineering design process. This is followed by a review of different aspects of the concurrent engineering (CE) concept in section 2.2 and the functional roles of different departments in section 2.3. The model is developed based on the citations given in sections 2.1 through 2.3. The developed model was validated by collecting data on a new product design communication process in CE environment. Research on using questionnaires to collect data is reviewed in section 2.4. The second part of this research involved developing a computer-assisted information interchange support system (IISS) based on the validated model. Related topics reviewed are: Nam Suh's (1990) second design axiom on information (section 2.5), computer-aids for design (section 2.6), artificial intelligence (section 2.7), and groupware technology (section 2.8). The literature review is summarized and new needs are given in section 2.9. The section on computer-aids for design surveys existing aids for design work. Although this topic and the topic of artificial intelligence are not directly related to the present research, they helped this researcher to decide in favor of groupware technology as a tool for developing a computer-assisted IISS.

2.1 Models of the Sequential Engineering Design Process

There are many research papers that discuss various aspects of the design process, as well as many classic textbooks in the subject of "engineering design," written by well-known people in the field of "engineering design." Textbooks by Shigley (1989), Nam Suh (1990), and Pahl and Beitz (1984) discuss the sequential engineering design process. The following is a review of some of the models of the sequential engineering design process available in research papers as well as in design textbooks by the above mentioned authors.

A comprehensive model for design should address the following aspects of the design process: the state of design, the goal structure of the design process, and the role of learning in design. Mostow (1985) has represented these various ideas based on the above aspects to generate better models of the design process. These ideas have been successfully implemented in several research projects by Mostow. A recent goal in Computer Aided Design is to represent a design artifact in a manner sufficient to support all analysis and to determine a realizable design. Eastman (1981) has defined design as the specification of an artifact that achieves desired performance and is realizable with a high degree of confidence.

Dixon (1986) states that a model or models of design process are needed in order to formulate design problems, to acquire and represent design knowledge, and to develop design inference engines. The author views design as a hierarchy of nested iterative processes of 1) decomposition and redecomposition, 2) specification and respecification and 3) design and redesign. Refer to Figure 2.1.

In Figure 2.1 node A designates a complex problem to be solved. Nodes B, C and D represent a decomposition of problem into sub-problems. Decomposition continues until sub-problem size and complexity is reduced to a point where the problem can be managed intellectually without further decomposition. These sub-problems are then solved by a process that the author calls "redesign."

The author developed a working prototype of a program called Dominic that designs and redesigns class problems in several domains. It is essentially a hill climbing algorithm. He gave a tentative architecture of a decomposition node. Refer to Figure 2.2.

If the problem can be solved by redesign, this is done, and the result returned upwards. If not, an initial decomposition is made. Using this decomposition, initial specifications are assigned to the sub-problems created. These problems are then passed to the modules below, which are similar in structure to those being described. The results returned from the various sub-problems are then integrated and analyzed as a complete system. If the complete system result is acceptable, it is passed upward. If not, new sub-problem specifications are assigned, and the process is repeated. If the respecification fails, then a new decomposition must be tried. If the redecomposer fails, the system reports failure up the line and asks for some change in the overall problem assignment.

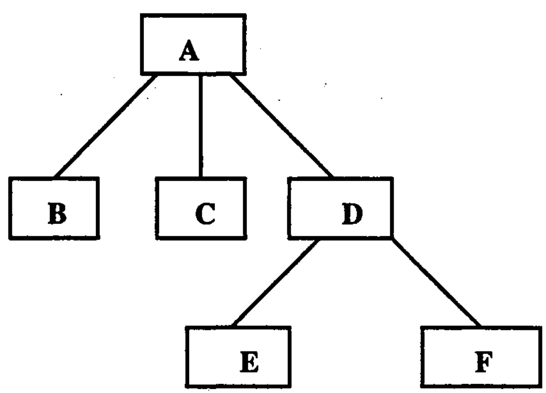


Figure 2.1. Design as a Hierarchy of Nested Iterative Process as Viewed by Dixon (1986)

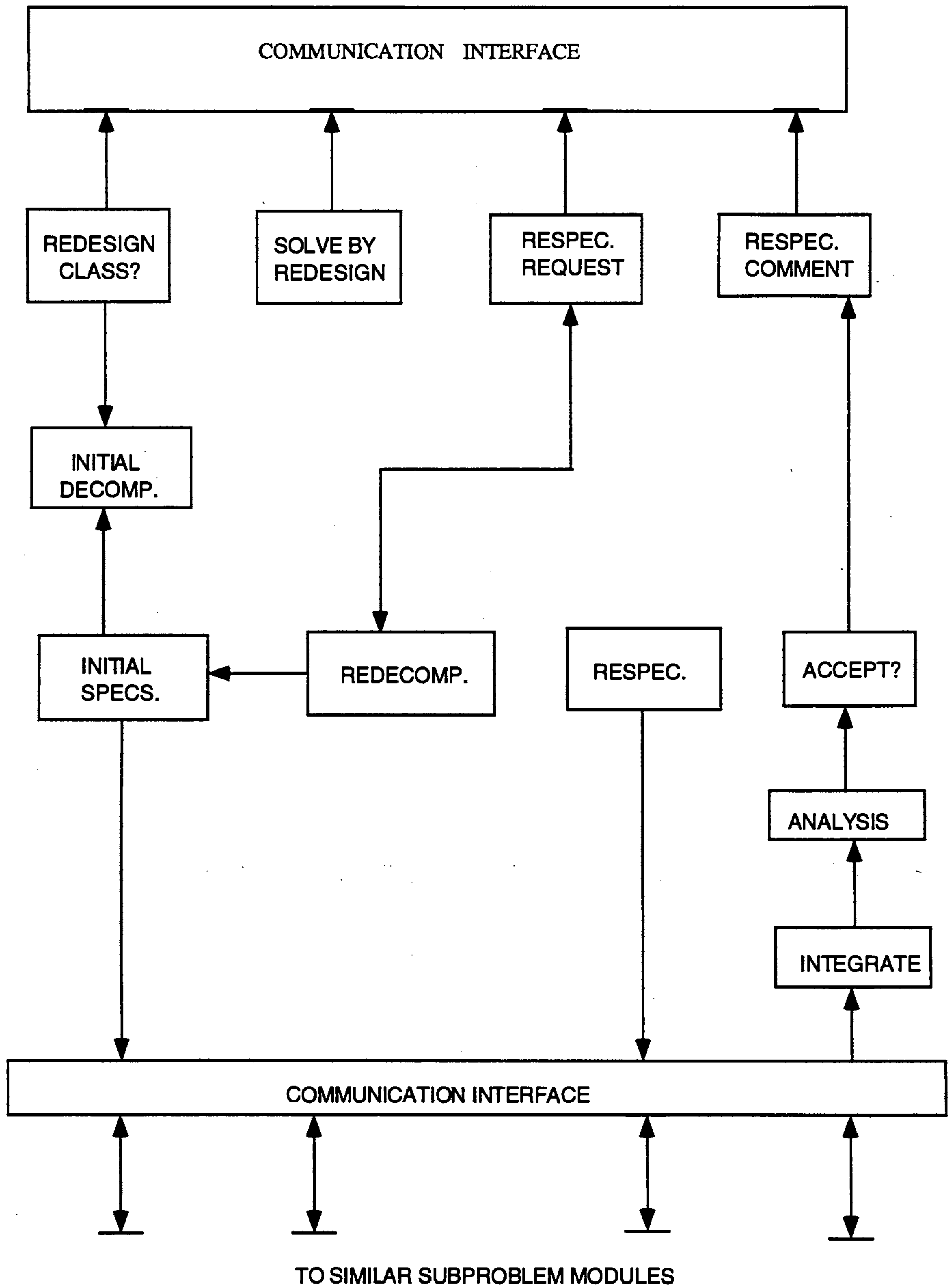


Figure 2.2. A Tentative Architecture of a Decomposition Nod

Shigley (1989) outlines the design process shown in Figure 2.3. His design process begins with the recognition of a need and a decision to do something about it. The definition of the problem is the next step. It must include all the specifications for the thing that is designed. After the problem has been defined and a set of written and implied specifications has been obtained, the next step in this design process is the synthesis of the optimum solution. Synthesis is always followed by analysis and optimization to determine whether the performance of the designed system complies with the specifications. Evaluation is the final proof of a successful design and usually involves the testing of a prototype in the laboratory. Here, it is discovered whether design really satisfies the need or needs, whether it is reliable or not, whether it will sell and make a profit or not. Presenting the design to others is the final important step in this design process.

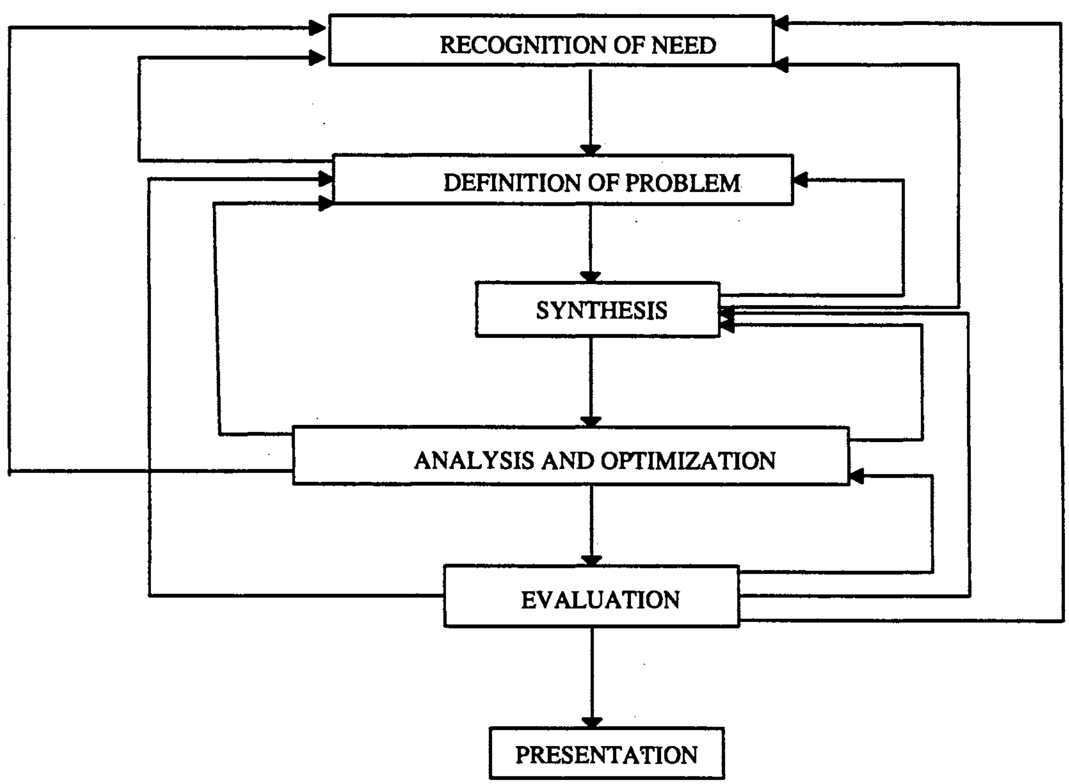


Figure 2.3. Design Process as Viewed by Shigley (198[illegible]

Nam Suh (1990) in his book "*The Principles of Design*" states that the design process begins with the establishment of functional requirements (FR) in the functional domain to satisfy a given set of needs, and ends with the creation of an entity that satisfies these FRs. This is illustrated in Figure 2.4.

As shown in Figure 2.4., the design process begins with the recognition of a societal need. The need is formalized, resulting in a set of Functional Requirements (FRs). The selection of FRs, which define the design problem, is left to the designer. Once the need is formalized, ideas are generated to create the product. This product is then analyzed and compared with the original set of Functional Requirements through a feedback loop. When the product does not fully satisfy the specified FRs, then one must either come up with more ideas, or change the FRs to reflect the original need more accurately. This iterative process continues until the designer produces an acceptable result.

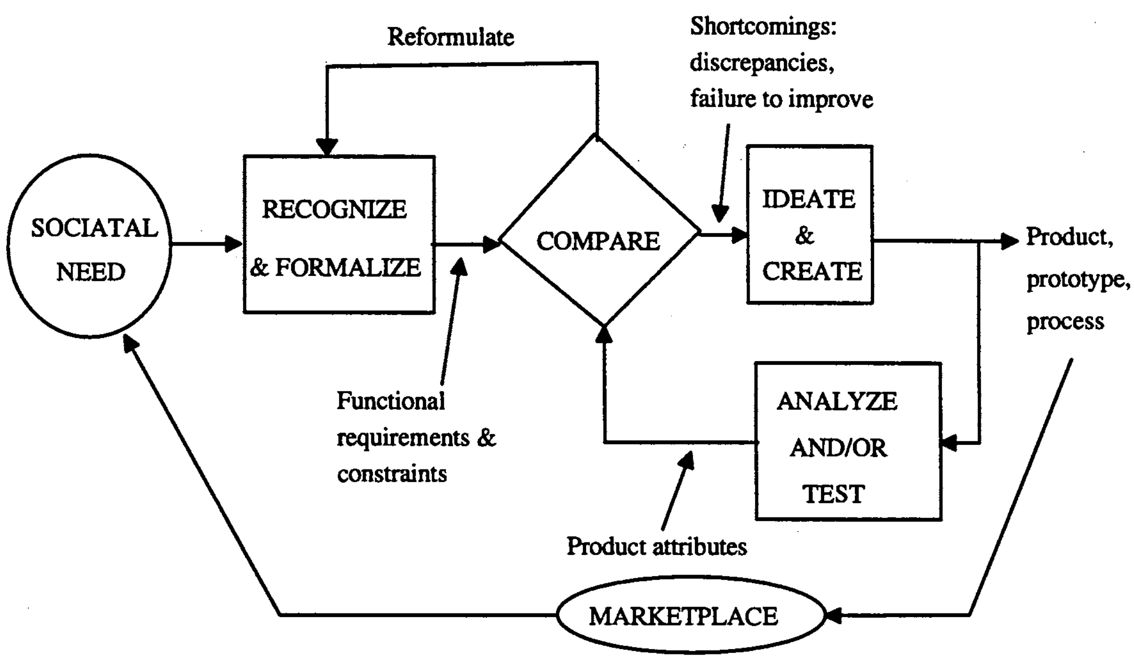


Figure 2.4. Design Process as Viewed by Nam Suh (1990)

According to Pahl and Beitz (1984), the main phases involved in the design process are:

-- Clarification of task

-- Conceptual design

-- Embodiment design

-- Detail design

Figure 2.5 illustrates this process step by step. The model requires that designers decide at every step whether to take the next step or to repeat the previous steps. The model assumes that the obvious decision to stop a costly development will be taken and hence is not shown in the diagram.

2.1.1 Information Exchange in Sequential Engineering Product Development

Dieter (1991) discusses how product design was done sequentially. He states that product concept, product design, product testing, manufacturing system design, process planning and production used to be carried out in distinct and separate organizations with little interaction. Sequential product development takes too long to develop, costs too much to produce, and often does not perform as promised or expected (Winner et al., 1988). The root cause identified by them was that the design of the product is isolated from the design of the manufacturing process employed later. The two functions are separated in time, and performed by quite different persons with little interaction -- sometimes geographically dispersed departments (Winner et al., 1988). Cleétus (1992) points out that limited interaction results in loss of information and intent, and the lack of exploitation of production knowledge and manufacturing constraints early in the development project. The result is suboptimal design of each part of the system.

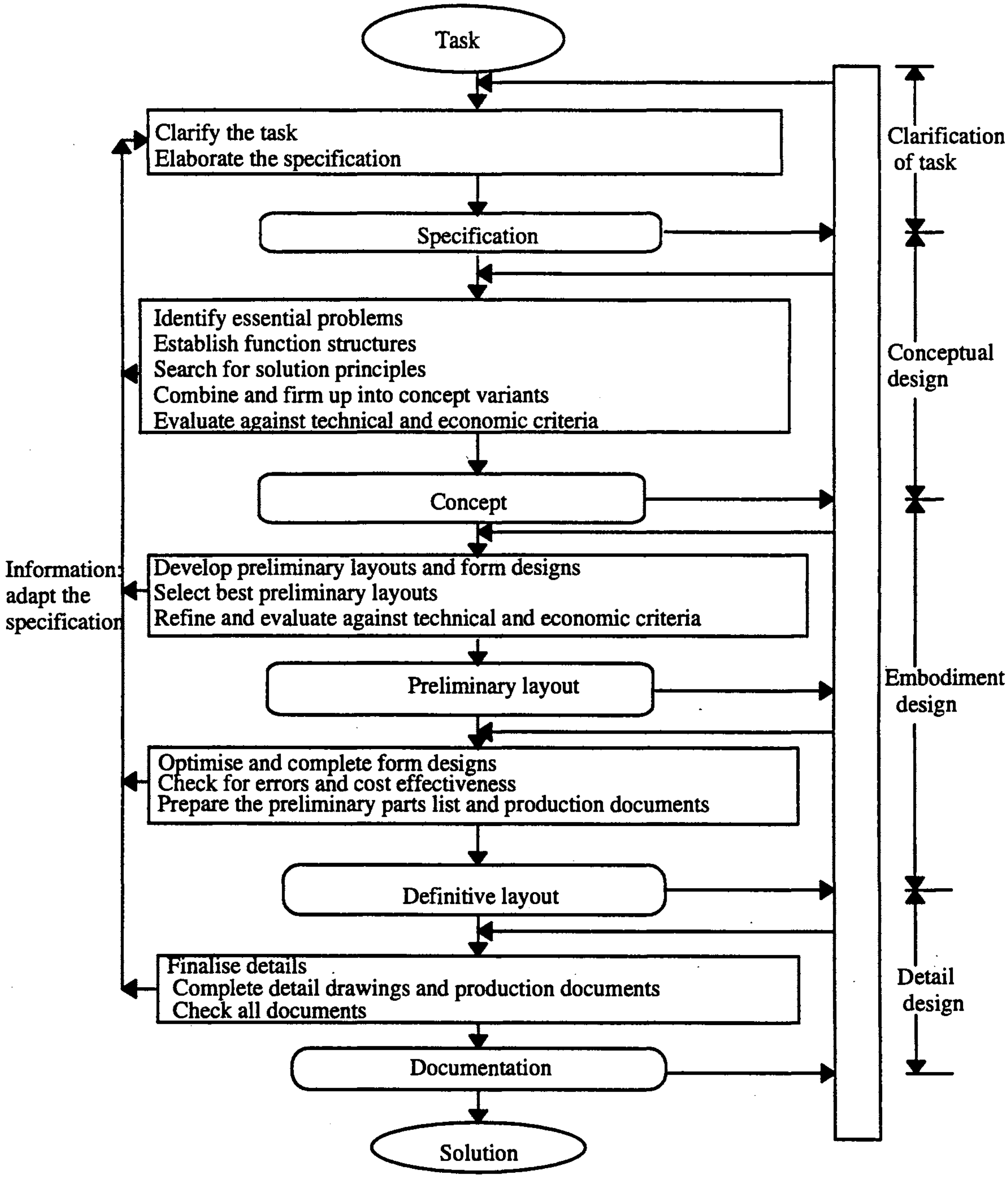


Figure 2.5. "Systematic Design Process" as Illustrated in Pahl & Beitz's Book (198

Information exchange in the sequential product development system is visualized in Figure 2.6. This figure is a modification of the figure given by Brandt and Petro (1992), illustrating the lack of automation in passing engineering information among project disciplines.

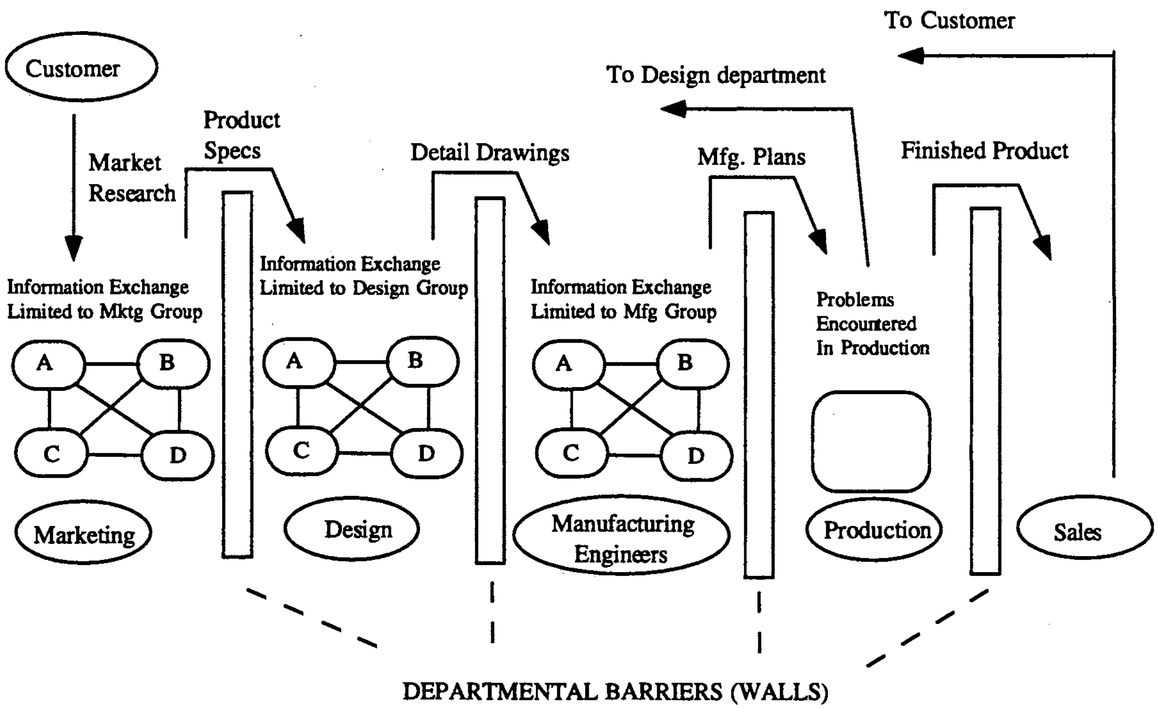


Figure 2.6. Information Exchange in a Sequential Product Development

2.2 Concurrent Engineering Concepts

Most companies have a sequential product development process; that is, the design group completes its portion of the design and hands it to the group that develops a prototype for testing. When the test group completes testing of the prototype, the manufacturing group takes over. Thus, product concept, product design, product testing, process planning, production, and product marketing functions, are carried out serially in separate departments. Without having proper input from different departments, the design team makes certain decisions that may prove costly to reverse. According to Dieter (1991), there is approximately a ten-fold increase in the cost of making an engineering change moving from research and development (R. & D.) to design, to production, to use after sales. Thus, a major goal of concurrent engineering is to move engineering changes back into the early stages of design. Improper design decisions, made in areas such as material selection, fastener selection, and manufacturing process selection, increase the cost of the product significantly. Dieter further states that in an era of increasing automation with high capital costs, it is reasonable to find that products must be designed to fit the factory as much or more than a factory is designed to fit the product.

The last few years have witnessed the growth of a new concept, concurrent engineering, to reduce the drawbacks of the conventional method of product development. Concurrent engineering is a "systematic approach to integrated product (and process) development that emphasizes response to customer expectations and embodies team values of cooperation, trusts, and sharing (Reddy et al. 1993)." Concurrent engineering is a design approach where experts from different departments of the company interact together and work together in every phase of product development. These departments include top management (or law and policies), research and development, finance, marketing, manufacturing, materials and distribution. The design team with the representation of all the needed viewpoints and a knowledge base work together to make the right trade-off right from the beginning, when mistakes are less costly and easy to fix. According to data from the National Institute of Standards and Technology, Thomas Group, Inc., and the Institute for Defense Analysis, concurrent engineering methodologies can reduce development time by 30 to 70%, result in 65 to 90% fewer engineering changes, reduce time to market by up to 90%, and result in quality improvement of 200 to 600%.

According to Wheeler (1991), an engineer needs simple tools such as pencil and paper, some intelligence, and a willingness to work with peers in other functional areas to get started in concurrent engineering. Computer-based tools can be added as the budget permits. Practicing concurrent engineering in Hewlett Packard Co.'s Colorado Springs division for the development of the 54600 oscilloscope yielded remarkable results. From inception to finished product, the time required to finish the product was reduced by one-third with the practice of concurrent engineering. Material engineers helped the designers by advising their choice of components. Manufacturing engineers were closely involved in the design process. Their cooperative efforts made it possible to package the components in just a few modules that can be assembled into a complete unit in a less than 18 minutes. Burnett (1991) points out that his firm, Cisco Systems Inc., underwent dramatic growth because of the practice of concurrent engineering. Revenues jumped from $27 million in 1989 -- when this approach was first adopted -- to $70 million in 1990. In the first half of 1991 alone, the company logged sales of more than $76 million.

Hall (1991) discusses some classic methods that should be part of the concurrent engineering lexicon.

2.2.1 Quality Function Deployment (QFD)

It was called "House of Quality" in the Mitsubishi Corporation and Toyota Motor Corporation. It is a pair of spreadsheets that show relationships between subjective customer's desires (called Customer Attributes or CAs) to quantitative engineering characteristics (ECs). Where CAs intersect ECs on the first spreadsheet, simple symbols indicate a positive or negative, weak or strong relationship.

The second spreadsheet forms the "Roof" over the house of quality. It shows the relationships between ECs by linking EC columns of the basic spreadsheet in a matrix much like a highway mile chart. Again, simple symbols express the degree of relationship. By touring a house of quality, an engineering team finds out which CAs are important and the set of ECs to be addressed to improve each CA. The team can also observe whether efforts to improve any one CA negatively impact other CAs.

2.2.2 Design for Manufacture and Assembly (DFMA)

Constance (1992) states that the DFMA tool is based on the premise that about 70% of all product development, assembly and production costs are built-in during the design stage. This tool has been saving some companies' production and labor costs for the last decade. At Ford Motor Co., executives saved $1.2 billion worldwide using design for assembly in 1987 alone. General Motors reportedly has reduced manufacturing costs 30 to 60% on certain projects since it started to use DFMA in late 1989. DFMA developed by Boothroyd Dewhurst, Inc., calls for the development of detailed designs for each product's individual parts, based on the combination of various capabilities and limitations inherent in the materials and processes used. The design for manufacturing (DFM) tool kit includes several programs such as assembly system economics and machine simulation, design for manual and printed circuit board assembly, design for robotics assembly, and design for automatic assembly and handling.

The DFM tool kit contains software programs that allow designers to obtain cost information at the concept stage from which they can make judgment regarding the choice of materials, the processes, and the cost of alternative designs. The DFM programs include cost estimating for machined parts, injection-molded components, stamped sheet metal parts, powder metals, and die casting. Boothroyd (1992) advocates the consideration of manufacture and assembly at the earliest stages of product design on a CAD/CAM system. The earlier this is applied, the greater the possible savings on assembly and manufacturing costs.

A reduction in the number of parts in a product or assembly should usually be the first objective of a designer wishing to reduce assembly costs. The difficulty of automatic assembly would be reduced significantly if the housing could be made self-securing. Alternative designs that do not require separate fasteners are preferred for automation.

If separate fasteners are necessary, consideration could now be given to alternative designs of fasteners. For example, rivets or other fasteners that require fewer fastening elements and present less difficulty in automatic assembly might be employed. If, however, because of disassembly considerations, it is necessary to employ screws, consideration could be given to the use of screw points that facilitate alignment and thread-starting. Such designs have been found to reduce automatic assembly problems considerably. The elimination of the nuts, the use of a threaded insert pressed into the diaphragm plate, a thread tapped in the plate itself, and combining the nut and washer -- such designs also help to reduce automatic assembly problems.

2.2.3 Robust Design

Genichi Taguchi developed the concept of robust design at the Electrical Communications Laboratory of Nippon Telegraph. Steven Ashley (1992) summarizes Taguchi's system of quality engineering as designing and developing "robust" products and processes that function well enough to satisfy customers despite random variations in workmanship and operating conditions. In recent years, Taguchi is advocating the application of his design optimization system earlier in the new product cycle at the technology development stage. The result, according to Taguchi, is a higher-quality product delivered faster with fewer downstream faults that must be remedied with costly redesign or rework. Hall (1991) clarifies that robust design is not the same as rugged or conservative design, which adds to the cost by using, for example, heavier insulation or higher reliability components. Robust design seeks to reduce product sensitivity to the sources of variability, through careful selection of design values. Taguchi developed an equation called the quality loss function that calculates cost and shows that the loss of quality increases with the square of deviation from the target value. The cost of quality loss shows up in the form of warranty costs, costs of repair or replacement, and loss in the customer's faith. Besides minimizing deviations within a product, robust design seeks to insulate the product against outside sources of variability called "noise" in manufacturing and use. The goal is to select design values that maximize the “signal” of key product characteristics in relation to reasonably expected “noise.”

Other concepts applicable to concurrent engineering include Ishikawa's Fishbone Diagram, Continuous Process Improvement (CPI), Just-In-Time delivery (JIT), and Total Quality Management (TQM).

Ishikawa's Fishbone Diagram starts with an "effect" as a spine and works backward with each major class of "causes (influencing processes)" added as a rib. The design team can make use of the final diagram to study the array of causes and dependencies to find the critical ones.

CPI is the systematic continuous study of a process, year after year, to find ways of improving it. CPI should help reduce development time and the final costs of products made by the processes.

JIT manufacturing methods provide components and assemblies as they are needed. They make it unnecessary to maintain large inventories, and thus help to cut costs.

TQM applies a set of principles to focus continuous attention on quality at every step of design, development, and manufacturing by everyone in a company.

2.2.4 Engineering Design in the Concurrent Engineering Environment

The creation and maintenance of superior engineering design systems are key elements in the success of any company which designs, manufactures and markets products. Yet, many manufacturing companies do not achieve "superior" design systems. At least two major reasons for this can be cited:

1) Innovation is not strongly encouraged nor even facilitated. On the contrary, many engineering groups are micro-managed by marketing and the customer. In this mode, engineering design simply awaits specifications from marketing for the next modification in the product line.
2) Engineering design can be so isolated from other key company functions that it cannot become involved in strategic decisions in any meaningful way.

In a recent article, LaMantia and Shapiro (1989) stress the need for enlightened engineering designers: "The engineer of the future must become more like a Renaissance man, acting as a technical, strategic, computer-proficient, people-oriented, hands-on integrator." This will allow engineering to "actively reach out in all directions within the company, forming interactive bonds with research and development, marketing, finance, manufacturing and other business functions."

By training and experience, the engineer learns to apply a "systematic" approach to the design process, continually developing alternative solutions and evaluating them against often conflicting constraints (Pahl & Beitz, 1984). The success of this approach is strongly correlated with the designer's fundamental understanding of all ramifications of a particular solution.

Computer technology has allowed the development of sophisticated CAD tools to enhance the systematic approach. However, sophisticated engineering design systems cannot be effective when the basic innovation process must deal with competing goals. Dr. Roland W. Schmitt, in his keynote address to the Design Theory '88 Workshop sponsored by NSF (1989), describes three types of innovation involved in engineering design. The two most common types are "technology-centered innovation" where a fundamentally new technology is applied and product cost is of little concern, and "cost-centered innovation" when a mature technology is used by several competing companies and low product cost is desired.

However, Schmitt further states that both of these innovation types, when practiced over an extended period, induce over specialization of the research and development, marketing and manufacturing functions with each group, losing appreciation for the others' problems and needs. He suggests "design-centered innovation" where a gifted designer is put in charge of the process and invention; marketing and manufacturing are integrated in a supportive manner, providing appropriate guidance to the designer as required. This fundamental change in the design process and the resulting competitive advantage can occur when a company is willing to integrate and manage knowledge across traditional functional boundaries. This is a fundamental objective of the proposed research.

2.2.5 Computer Support for Concurrent Engineering

Since the aim of this research is to develop computer-based information interchange support system, ongoing research on the topic of computer support for concurrent engineering is briefly reviewed.

Finger et al. (1992) talk about creating a computer-based design system that will help designers to consider concurrently the interactions and tradeoffs among different and conflicting requirements. They visualize a system with experts that will do the incremental analysis of the design and will give continuous feedback. They state two roles of the design-system architecture. "First, it provides interactive environment that enables designer to control the available resources that consist of data, knowledge, methods and algorithms. Secondly, the architecture provides a group problem solving environment in which knowledge-based systems contribute to the design process." Their system "Design Fusion" is based on the blackboard model of problem solving (Erman et al., 1980). The four major components of the architecture are the blackboard, knowledge sources, the search manager, and user interfaces.

Reddy et al. (1993) argue, "advances in database and networking technology, groupware, multimedia and graphical user interfaces, and a precipitous drop in the cost of computing, all point the way to creating a truly collaborative environment to transcend the barriers of distance, time, and heterogeneity in computer equipment." They state that a layered architecture of different types of computer technology that must come together to support concurrent engineering. The outermost "activity layer" represents different activities of the concurrent engineering team. The transaction layer is inside the activity layer and identifies six fundamental activities performed by the concurrent engineering team. The activities are look-up, compute, communicate, negotiate, decide and archive. The collaboration services layer is inside the transaction layer. They envision a variety of services to support the fundamental concurrent engineering transactions and the daily activities of team members. These services are collocation, coordination, information sharing, corporate history management, and integration. The enterprise information layer is inside the collaboration services layer. This layer makes available enterprise information that characterizes the product an enterprise is building, the process it adopts to make such products, and the resources available to the organization. The innermost network layer is the foundation for building a computer supported environment. This kernel represents advances in communication technology and distributed computing.

The authors visualize future support for concurrent engineering through a proposed artifact, calling it "CEphone." "This electronically networked artifact would combine the capabilities of an ordinary phone, a TV, a VCR, a videoconferencing facility, and a computer."

Chung et al. (1993) state, "A central component of concurrent engineering environment is a facility for synchronous collaboration such as distributed, workstation-based conferencing facility. The ultimate goal of such facility is to allow geographically separated engineers to view and manipulate shared images, documents, or programs simultaneously while they communicate via audio and possibly video links." They have developed and placed in the public domain a shared window system, called XTV (X Teleconferencing and Viewing). XTV is based on the X window system and lets the user create a conference around one or more arbitrary X applications. Conferees have the same view of shared applications. By following a simple floor-passing protocol, they can control the shared applications. XTV is flexible and robust to accommodate latecomers; that is, new participants should be able to join conferences that are already in progress. It is fault tolerant in the sense that those who become disconnected from a conference should be able to rejoin -- transparent to other conferees.

Cutkosky et al. (1993) and several other research groups are jointly developing the Palo Alto Collaborative Testbed (PACT), a concurrent engineering infrastructure that encompasses multiple sites, subsystems, and disciplines. Their approach has been to integrate existing multitool systems. These multitool systems were developed with no anticipation of subsequent integration. The authors state, "PACT experiments have explored issues in building an overarching framework along following three dimensions:

-- Cooperative development of interfaces, protocols, and architecture,

-- Sharing of knowledge among systems that maintain their own specialized knowledge bases and reasoning mechanisms, and

-- Computer-aided support for the negotiation and decision-making that characterize concurrent engineering."

PACT encapsulates engineering tools and frameworks by using agents that exchange information and services through an explicitly shared model of design. The authors believe that using agents to communicate on a knowledge level is the right way to compose large, complex systems out of existing software modules. Instead of figuratively integrating code, the users can encapsulate modules in agents and then invoke them remotely as network services when needed.

Bowen et al. (1992) argue that the development of the concurrent engineering product development team presents many logistic and scheduling difficulties. They state a way to overcome these difficulties are to use Network Collocation. In this approach, the team members supplement face-to-face meetings with electronic communication over a network. At its simplest, it may amount to a combination of electronic mail and shared access to a CAD database. They argue that something much more sophisticated is needed to succeed in concurrent engineering. Product development teams often find themselves overwhelmed by the volume and variety of information that arises as a design evolves. They stress the need to develop an Intelligent Networked Collocation Advisor (INCA) which relieves the logistic and scheduling difficulties and reduces the problem's complexity. The authors proposed to investigate the use of a constraint network as a basis for building an INCA system. Specifically, they proposed to NSF and were funded to develop a sequence of upwardly compatible constraint-based programming languages;

these languages would be evaluated by their application to a wide variety of concurrent engineering issues on a broad range of product domains. The results of their research were three upwardly compatible constraint programming languages called Galileo, Galileo2 and Galileo3. The authors used these languages to build experimental concurrent engineering applications including Design for Manufacturability, Design for Assemblabity, and Design for Testability. Galileo3 is taught along-side rule-based systems in a graduate course in Expert Systems and Knowledge Engineering at North Carolina State University. NCSU has also offered this course to employees of IBM, DEC, AT & T and Hewlett-Packard companies as well as to students at other universities through Video-Based Engineering Education (VBEE). These students have used these languages to build a variety of concurrent engineering applications.

Over the past five years, Sriram et al. (1989) at the MIT Intelligent Engineering Systems Laboratory have been working on a computer-based architecture program called the Distributed and Integrated Environment for Computer-Aided Engineering, or "Dice." Its goal is to address coordination and communication problems in engineering. The authors give the following list of research issues addressed as a part of the Dice effort:

-- Frameworks (the problem-solving architecture),

-- Representation issues (the development of product models for communicating information across disciplines),

-- Organizational issues (organizing engineering activities for the effective use of computer-aided tools),

-- Negotiation/constraints management techniques (conflict resolution),

-- Transaction management issues (interaction between the agent and the central communication medium),

-- Design methods (a concept generator shell for supporting various design activities),

-- Visualization techniques (user interfaces and physical modeling systems),

-- Design rationale records (keeping track of the justifications generated during design),

-- Interfaces between agents (support information transfer between various agents),

-- Communication protocols (facilitate the movement of objects between various applications).

The authors state, "The Dice system provides cooperation and coordination among multiple designers working in separate engineering disciplines. It makes use of knowledge to estimate interface conditions between disciplines, recording who used any piece of design data created by others and how such data was used, and checking for conflicts among disciplines, Manufacturability, and manufacturing cost and schedule impacts of design decisions." The authors' current research focuses on the following Dice components: the shared data model, symbols for geometry mapping for preliminary designs, query optimization for navigating through engineering databases, the negotiation/constraint-processing framework, the collaborative design rationale, and multimedia user interfaces.

Maloney (1991) states that in 1990's engineers have many more heterogeneous computer resources available. These sources are difficult to use as an integrated system. Engineers need to learn a wide variety of user interfaces, operating systems, and access procedures. The author identifies three trends in computing that have effect on engineers and businesses: distributed or network computing, downsizing, and workgroup software. Distributed or network computing involves integrating transparently various platforms into a single system from the user's perspective. "The concept is to improve access through a single user interface to multiple CPU's and hierarchy of storage devices to create a metacomputer." Users and system administrators have recognized that performing all the data processing on mainframe computers is very inefficient. Hence the process of moving selected applications from the mainframe down to the desktop computer is another computing trend called downsizing. The author identifies groupware as a new class of software and a third computing trend. The author explains, "groupware is intended to let groups of users define and automate their work flow or processes. As the name implies, groupware is also focused on facilitating group computing activities, such as information sharing among a design-build team." According to the author these trends can provide the basis for developing a powerful computing environment to support concurrent engineering. Concurrent engineering requires communication on a much more frequent basis, and to much broader audience. Design data and data associated with the evaluation of the design must be exchanged on a regular basis with the other members of the design team. Author outlines computing objectives to support concurrent engineering as follows:

-- A seamless computing environment to deal with distributed, heterogeneous computing environment,

-- Transparent access to all computing resources, including hardware, software and data,

-- An environment to support the management and sharing of information with the appropriate levels of configuration controls and notification changes,

-- Design-build team data having the appearance of being in a single repository, with individual views into the data to support a variety of users,

-- Support to the integration of various designs and analysis processes.

The author has developed an integrated computing environment, called Access Manager, to facilitate concurrent engineering. The developed system improves user's access to all the resources required to do their job effectively. This includes access to both hardware and software computing resources, access to information, both process knowledge and data, and access to other members of the design team. The current prototype version of this software has an object-oriented Execution Control Server. It communicates directly with an OSF/Motif based user interface, an object oriented-distributed database for local data management and global data tracking, and a communication library based on the OSF Network Computing System (NCS). The Access Manager supports multi-user and concurrent shared processes and data. It integrates applications without the need to modify the source code of the application or the integrating framework using the Application Wrapper. It is flexible to integrate vendor supplied software with in-house developed software or new software with existing software. All the applications and their executions, regardless of their location on the network, appear to be on the user's workstation because of single system image.

2.2.6 Communications in Concurrent Engineering

The proposed research involves developing a model of the design process in the concurrent engineering environment and then developing an information interchange support system. Hence the following components are vital to the research: identifying which functions have a role to play at each stage of the design, who communicates with whom and what information is interchanged, and what is ideal against what is practiced. In this context, it is only logical to review published work on the topics of communication patterns as well as the information transfer among functions during product development.

Griffin et al. (1992) conclude, "Models and scientific evidence suggest that firms are more successful at new-product development if there is greater communication among marketing, engineering, and manufacturing." In particular, the likelihood of product success is enhanced if marketing, research & development, design, and manufacturing share information on customer needs and segments, technology and manufacturing capabilities, competitor strategies, business strategy, and pricing (1987). In a ten-year study of 289 projects, Souder (1988) demonstrates that interfunctional harmony, communication and cooperation are directly related to the degree of success of the new product. Cooper et al. (1984b) and DeBrentani (1989), in separate research, have confirmed findings by Souder. Cooper (1984a) & (1987) identified five basic organization types--technology driven, focused but technologically weak, high-budget shotgun, low-budget conservative, and marketing-and-technology integrated. Cooper finds that only organizations with high percentages of successful projects and sales derived from new products were those integrating technological sophistication and a marketing orientation to develop products with differential advantages for strategic segments. Gupta et al. (1985) find that a lack of communication is the number one barrier in preventing functional interaction in product development. They also find that marketing and research & development perceptions differ both on their levels of involvement and on the value of the information they each provide to the project. Dougherty (1987) gives the reason of difficulties in cross-functional integration. According to him, each function resides in its own "thought word". Engineers speak a technical language of product features and specifications and respond to an engineering culture of problem solving while marketers speak their own language and operate in their customer oriented culture.

On the basis of interfunctional research and other within-function studies of communication, Moenaert and Souder (1990a) have developed two formal models and a number of propositions about communication effectiveness. Both models conclude that the quantity and quality of marketing-research & development interactions are linked causally to new-product development success. Recency and timeliness are shown to be important in the value and use of extrafunctional information during innovation, suggesting the need for continuing interfunctional communication during new-product development. Griffin (1992) represents the first field comparisons of Quality Function Deployment (QFD) and the phase-review product-development process. From their findings QFD appears to encourage the team to become more integrated and cooperative, but more inward looking. There is more communication within the team. The team seems to be more self-sufficient, solving its problems through horizontal communication rather than through management. Most importantly, this new pattern of communication appears to increase team communication on all nonadministrative aspects of new-product development. The only concern authors find using QFD is the degradation of communication external to the team. Authors suggest further investigation of this concern. There is a need for inter-departmental communication and harmony for the success of a new product. However, the unrestricted flow of information in concurrent engineering product development may generate a lot of information. There may be the danger of information explosion and a difficulty in finding appropriate pieces of information. Trapp (1991) illustrates the multi-connected information flow through paper transfer in an "as is" world and then illustrates in another figure how it should be. The uncontrolled information exchange in a concurrent engineering product development system can be visualized as show in Figure 2.7. below. This figure is the modification of a figure given by Trapp (1991).

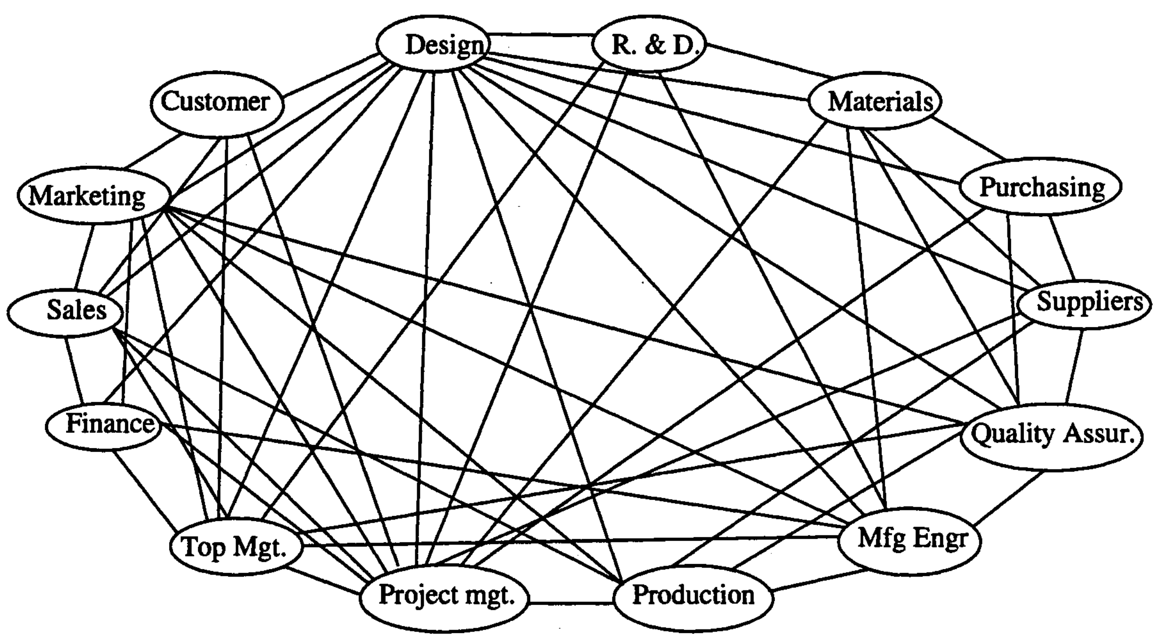


Figure 2.7 Possibility of Uncontrolled Information Explosion in Concurrent Engineering Product Development

2.3 Functional Area Knowledge Bases

The following section summarizes the key considerations of each area of business as it impacts or is impacted by the engineering design function. Some companies have separate legal department; whereas, some companies higher law firms to take care of their legal issues. For present study, legal issues and environmental issues are considered as the responsibility of top management.

2.3.1 Marketing

The role of marketing is to translate the customer's perceptions, preferences, and desires into a usable format so that they can effectively be utilized by the designer in the conceptual phase of the design process (Dowlatshahi, 1993). The marketing department is important because customers' expectations are given far greater weight in CE than with conventional engineering (Hartley, 1992). The marketing personnel on the CE team ensures that sales targets are realistic. The marketing function deals primarily with identifying market demands and customers' needs. Hartley states that the Quality Function Deployment technique is an ideal way of turning the vague preferences of the customer into engineering specifications. In CE settings, marketing personnel will make important contribution in converting customer voice into engineering specifications. The key factors that may be impacted by and have an impact on product redesign include: the product and customer mix, price-volume relationships for each product, S. G. & A. expenses, and market/profit segmentation study results (Sharda and Delahoussaye, 1992). Thus, the marketing function provides both current and forecasted (target) levels for each of these key factors. In addition, marketing must provide the information on key factors for new products. This might include qualitative or quantitative data on the following:

(1) estimates of synergy or cannibalism of the new product on existing products, (2) forecasts of sales volumes, revenues and gross margins for the new product, as well as variances associated with these forecasts, (3) increases in sales force and advertising budgets, and (4) estimates of warranty and service requirements. All of these estimates are used in the economic evaluation of the new product and form the basis for design evaluation, as well as the selection of alternative designs.

2.3.2 Design

Pahl & Beitz (1984) identify the role of the design department at different stages of the product design process. The design department has a major role in forming detailed specifications about the new product. Then the design department uses these specifications to create multiple conceptual designs in the form of sketches, informative notes, etc. These conceptual designs are evaluated based on a variety of factors such as cost, ease of manufacture, ease of use, etc. More than one conceptual design may be chosen to do detail design. At the detail design stage, the design department determines arrangement, form, dimensions and surface properties of all individual parts. The decisions are taken about materials and processes. The technical and economic feasibility is re-checked. Then the drawings and production documents are produced. The design department will communicate about its progress through regularly held design review meetings.

2.3.3 Top Management

Top management deals primarily with the overall strategy of a firm to maximize shareholder investment and satisfy other constituencies (employees, customers, etc.). Thus, the primary factors that might be impacted by and have an impact on product design include the following three broad categories: budgets (e.g., capital, earnings and cost net cash generation), strategic competitive factors (e.g., single supplier dependence, single customer/customer group dependence, single product dependence, threat of substitute products, etc.), and controllable stock price factors (e.g., earning fluctuations, broad financial ratios such as P/E, RONA, etc., Sharda and Delahoussaye, 1992).

Top management provides the historical and current levels, as well as the future targets for each of these key factors. If some targets present conflicting goals, then top management provides qualitative, quantitative or cardinal weighing factors for the attainment of each goal. Management can also include, where applicable, ranges for targets, with penalty functions for falling outside those ranges.

2.3.4 Research and Development

The research & development department's aim is to invent new technologies or to capture new know-how so that the required knowledge will be available for application in specific development projects (Wheelwrite and Clark, 1992). The focus of the research and development department is the creation of knowledge -- know-how and know-why -- as a precursor to commercial development. The invention of new technologies by this department may establish a new core product and a new core process. This may create a whole new product category for the business or spearhead the entry of the firm into a new business. The research and development department, in a technology driven company, may engage in researching and testing new raw materials that might be attractive to engineering design. The primary information supplied by the research & development group to engineering design consists of the availability of new technologies, the characteristics and test results of new materials, and the expertise available for recommending a certain technology or material given a set of specifications.

2.3.5 Finance

The finance function deals primarily in capital funding and economic evaluation. Thus, the primary factors that may be impacted by and have an impact on product design include: working capital (inventory, accounts receivable and accounts payable), cash flow projections and financial evaluation criteria (e.g., hurdles rates for capital investments, etc.) (Sharda and Delahoussaye, 1992). The finance organization is responsible for all cost-estimating and control activities and for maintaining the cost baseline for production configurations. The finance organization is the only official source for cost data and the final authority on the audit trail (Michaels et al., 1989). In addition, the financial function may be responsible for gathering and analyzing data concerning the performance evaluation of division management by top management. Therefore, the finance function provides information on historical and current levels of working capital as well as approved target levels for working capital requirements and cash flows. In addition they provide the appropriate, broad-based assumptions, the rules-of-thumb, the methodologies and the criteria used in financial evaluations.

2.3.6 Purchasing

The purchase function handles the ordering and scheduling of raw materials into the plants and the warehousing and shipping of finished goods to the customers. Constraints that can be impacted by and have an impact on engineering design include the plant's storage capacity for raw materials, company-owned/leased shipping capacities, common carrier shipping contracts, and warehouse space (Sharda and Delahoussaye, 1992). The key factors include inventory levels for both raw materials and finished goods, supplier concentrations, raw material specifications, etc. In a large purchasing department, purchasing activities can be separated into the following four areas (Fearon, 1971): 1) buying and negotiating, which would concern relations with the vendors, the interchange of information between the buyer and vendor, and the actual choice from among alternatives, resulting in purchasing agreements, 2) expediting the follow-up necessary after an agreement with the vendor has been reached to assure that the quality and the delivery terms of the original agreement are met, 3) purchasing research, the collection, classification, analysis, and interpretation of data necessary for sound decision making, and 4) administration, which would consist of the clerical detail needed to implement the purchasing process, and the record keeping necessary to provide a constant measurement of the results.

2.3.7 Manufacturing

The manufacturing function deals primarily with implementing the product design and, as such, is perhaps the most critical link to the engineering design process. Manufacturing constraints include the current capital budget, the size and qualifications of manufacturing's labor force and available plant space (Sharda and Delahoussaye, 1992). Changes in product design can have significant direct and indirect impacts on any of these constraints, as well as on other key manufacturing factors such as production efficiency, inventory levels, and setup costs. Thus manufacturing must provide both the current and forecasting levels for each key factor and quantitative or rule-of-thumb estimates of the potential changes in these key factors due to design changes.

In addition manufacturing must provide information to the production scheduling module to generate feasibility studies for production schedules; i.e., to answer questions concerning whether the proposed product design can be integrated into existing schedules without violating current constraints or, alternatively, which constraints must be violated and why. The latter information provides feedback to engineering design to enhance the selection of alternative designs. Dieter (1991) has summarized various tasks manufacturing engineers do before the product goes into full scale production. Some of the tasks performed are as follows: 1) specifying the production plant that will be used (or designing a new plant) and laying out the production lines, 2) planning the work schedules and inventory controls, 3) planning the quality control system, 4) establishing the standard time and labor costs for each operation, and 5) establishing the system of information flow necessary to control the manufacturing operation.

2.3.8 Quality Assurance

The quality assurance department establishes criteria for the inspection of processes. Through cause and effect diagrams, pareto diagrams, and process control charts, the quality assurance department leads the investigation of the special causes of failure in product quality and search for the solutions. Its activities have a dramatic effect on the company profits. Every dollar saved in reducing scrap and rework directly adds to profit. Nowadays there is less emphasis on sampling inspection. Instead, today's emphasis is on designing and manufacturing quality into a product rather than sorting out defectives after they are created (Scholtes, 1988).

The designs need to be reviewed to assure, where possible, that an item can only be assembled the right way; that the production equipment and tooling are capable of the precision desired; and that operators have the training to know what tolerances they must hold, and why. The suppliers of materials and parts are essential partners in the activity of the quality assurance department. Modern practices at more enlightened firms are to develop long-term relationships with suppliers and to insist that the same methods of designing and manufacturing quality into a product be employed there, too. Suppliers are chosen more on the basis of demonstrated product quality than on insignificant differences in their last bid price.

2.3.9 Sales

The sales department's primarily responsibility is to create revenue by selling the product through various avenues. The department collaborates with marketing in developing publicity, advertising program, direct mail program and other communications program for the new product. It prepares literature that goes with the product. The sales department can obtain feedback from dealers as well as directly from lead customers. It can give following information to the cross-functional design team pertaining to new product: distribution channels, dealer's list, inventories, mode of transportation, cost of similar sales.

When the proto-type has met the specifications and the top management has approved the design for mass production, then the sales department in collaboration with marketing plans product promotion and takes some decisions in that regard. The sales department deals with following promotion decisions: list price, discount, allowances, payment period, credit terms, customer advertising, trade advertising, demonstrations, sales aids, premiums, coupons, product samples, displays, publicity, manuals and technical services.

At this point, it can give a fresh estimate of expected selling and promotional costs. It can also find out whether the selected brand-name matches with a target customer.

2.3.10 Project Management

Every design/development project needs a "unifying agent" of some type that bears primary responsibility for the project. Many companies have separate project management departments. Depending upon the importance of this department to the company, project management may deal with following types of tasks (Kerzner, 1992).

1. determining and specifying a project's priority relative to other activities,
2. defining the work to be performed by supporting departments in terms of cost, schedule and performance,
3. controlling the project's budget,
4. scheduling and holding design reviews,
5. establishing responsibility for follow-up actions,
6. controlling and approving changes,
7. reporting regularly to the top management about a project's status and any factors inhibiting progress on the project.

The above list may not be complete. The number of tasks that project management has to deal with may vary from company to company and from project to project.

2.4 Mail Questionnaire: A Data Collection Technique

The research proposes to validate a communication model for concurrent engineering design process. The use of mail questionnaires is an important and popular technique for data collection. This section reviews the mail questionnaire technique of data collection to validate the model. The Program Evaluation and Methodology Division (PEMD) of the United States General Accounting Office (GAO) in transfer paper 7 states, "Writing questionnaires is the science and art of asking the right questions of the right people in the right way. It is a science in that it uses many scientific principles developed from various fields of applied psychology, sociology, and evaluation research. It is an art because it requires clear, concise, and interesting writing and the ability to trade off or accommodate many competing requirements."

2.4.1 Advantages and disadvantages of using Mail Questionnaires

The advantages and disadvantages of mail questionnaires against other methods of data collection such as the telephone and personal interviews, a review of records, and the use of extant data and field observations can be listed as follows. Mail questionnaires 1) are more versatile, 2) are more compatible with survey designs, 3) are less costly, 4) have less response bias, 5) have no interviewer bias, 6) permit a wider distribution of the sample, 7) provide easier access to the data sources and 8) provide a greater opportunity to collect detailed data.

On the other hand Mail Questionnaires have 1) more uncertainty as to the respondents' identities, 2) longer turnaround times, 3) the problem of nonresponse, 4) difficulty in identification and location of knowledgeable respondents, 5) difficulty using complicated methods of inquiry, and 6) difficulty if nonresponse is focused or concentrated.

2.4.2 Tasks Involved in the Development and Evaluation of Questions

According to GAO's Program Evaluation and Methodology Division, the sequence of major tasks is as follows: 1) initial planning of the questionnaires, 2) developing the measures, 3) designing the sample, 4) developing and testing the questionnaire, 5) producing the questionnaire, 6) preparing and distributing mailing materials, 7) collecting data, 8) reducing the data to forms that can be analyzed, and 9) analyzing the data.

2.4.3 Formatting Questions

There are several formats available to pose questions in the questionnaire. Each of the formats serves a specific purpose and this should coincide with the information and data analysis needs.

1) Open-ended questions --> Open-ended questions are very easy to write and require very little knowledge of the subject. For example, questions such as "What factors do you consider when you choose a place for a vacation?" It is very difficult to use answers to these questions in the analysis. One cannot machine-process open-ended questions. To analyze open-ended questions, one must use a complicated process called "Content analysis."
2) Fill in the blank questions --> Each questionnaire usually has some fill-in-the-blank questions. They are not open-ended because the blanks are accompanied by

parenthetical directions that specify the units in which the respondent is to answer. This type of questions should be reserved for very specific requests. The instructions should be specific. Sometimes, several fill-in-the-blank questions are asked at once in a row, column or matrix format.

3) Yes/No questions --> This type of question is ideal for dichotomous variables. It is also very good for filters in the line of questioning and can be used to move respondents to the questions that apply to them. Most of the questions that are asked deal with measures that span a range of values and conditions and yes/no questions are not suited. They do not give much information. They are difficult to write and are prone to bias and misinterpretation for several reasons.

4) Single-item choices --> In single-item choices, respondents choose not "yes" or "no" but one of the two or more alternatives. If used carefully, the single item choice can be efficient. It often serves to filter people out or skip them through a part of questionnaire.

5) Free choices --> In free choices, there are more than two choices available than just yes/no. In yes/no, implied no, and single-choice questions, the respondents are forced to answer one way or the other. By putting the population into just two camps may oversimplify the picture and give error, bias, and unreliable answers. Hence in addition to yes and no there will be more choices like "Probably yes", "Uncertain", "Probably no" and may be "Not applicable."

6) Multiple-choice format --> The most efficient format and the most difficult to design are the multiple-choice questions. The respondent is exposed to a range of choices and must pick one or more. Multiple-choice questions are difficult to design because the writer must provide a comprehensive range of nonoverlapping choices. They must be a logical and reasonable grouping of the types of experiences the respondents are likely to have encountered. There should be no doubt in the respondents' minds about how they should answer. In addition to all the possible choices that respondents may

answer, this format can be made even more flexible by posing one choice as "Specify if none of the above________."

7) Ranking questions --> "Ranking formats" are used to rank options with respect to their priority, importance, size, or cost. Respondents are asked to tell which alternative is the highest priority, which is the second highest, and so on. Ranking formats are difficult to write and difficult answer. They give very little information and are very prone to errors that can invalidate all the responses.

8) Rating questions --> Ratings are assigned solely on the basis of the score's absolute position within a range of possible values. For example, more than adequate, generally adequate, inadequate, very inadequate. Ratings' scales are easy to write, easy to answer, and provide a level of quantification that is adequate for most purposes. If they are used in appropriate circumstances, they produce reasonably valid measures.

9) Likert and other intensity scale formats --> Likert and other intensity scale formats are usually used to measure the strength of an attitude or an opinion. An example of the intensity scale can be as follows: Strongly agree, Agree, Undecided, Disagree, Strongly disagree, and No basis for judging.

10) Quantifying amounts and frequencies --> Many questions ask the respondent to quantify either amounts or frequencies. These formats use adjectives and adverbs to describe the amount, frequency, or number of items that they are measuring. For example, Seldom if ever (0 to 10 % of the time), Sometimes (about 25% of the time), often (about 50% of the time), very often (about 75% of the time), and always (about 90% of the time).

2.5 Axiomatic Approach To Design

A literature review in the subject of engineering design is not complete without studying the principles or axioms of design as stated by Nam Suh (1990). He gives fundamental principles that can be applied in all design situations. He states that design is being done as an art. He cites many prominent engineering design failures of the mid-1980s and attributes them to poor design practices. He further states "Some failures might have been averted had we a more rational approach to design than the current dependence on trial and error, intuition, empiricism, and so-called handbook method. What is needed is a firm scientific basis for design, which can provide designers with the benefit of scientific tools that can assure them complete success." He gives a scientific basis to design. Just as there are many design solutions, there may be many diverse approaches to "design science." Nam Suh proposes that the axiomatic approach may be one of many possible avenues toward this goal. He explains, "The basic assumption of an axiomatic approach to design is that there exists a fundamental set of principles that determines good design practice." He adds, "The only way to refute this assumption is to uncover counterexamples that prove these axioms to be invalid. The knowledge in a given field can be axiomatized when a set of self-consistent logic based on the axioms can yield correct solutions to all classes of problems." "So far" he says, "no one has come up with evidence that design axioms are invalid."

According to Nam Suh, one must determine the design's objectives by defining it in terms of specific requirements, which will be called functional requirements (FRs). Then to satisfy these functional requirements, a physical embodiment characterized in terms of design parameters (DPs) must be created. The design process involves relating these FRs of the functional domain to the DPs of the physical domain.

The "function" means the desired output. The "physical" means all those things that generate the desired output. FRs are defined to be a minimum set of independent requirements that completely characterize the design objective for a specific need. In the final analysis, if a physical solution does not satisfy the perceived needs, a new set of FRs must be tried. Nam Suh defines design as the creation of synthesized solutions in the form of products, processes or systems that satisfy perceived needs through the mapping between the FRs in the functional domain and the DPs that satisfy the FRs. There can be an infinite number of plausible design solutions and mapping techniques. The design axioms provide the principles that the mapping technique must satisfy to produce a good design, and offer a basis for comparing and selecting designs.

A good designer should satisfy the perceived needs with a minimal set of independent FRs. As the number of FRs increases, the solution becomes more complex. Therefore, it is necessary to satisfy only the absolutely essential functions at a given stage of the design. Then these FRs should be independent of each other, since two or more dependent FRs introduce unnecessary complexity without providing additional benefits.

In addition to FRs, designers often have to specify constraints. There can be many different kinds of constraints such as cost, line voltage, geometrical size or weight and appearance. Often these constraints have a limiting effect on the design. The constraints differ from FRs in that, as long as the product designed does not exceed these constraints, then the solution is acceptable. There are two kinds of constraints: input constraints and system constraints. Input constraints are the constraints in design specifications. They are expressed as bounds on size, weight, materials and cost. System constraints are constraints imposed by the system in which the design solution must function. These constraints are interfacial bounds such as geometric shape, capacity of machines, and even the laws of nature. Constraints do not have to be independent of other constraints and FRs. They do not have tolerances associated with them; whereas, FRs typically have tolerances. What used to be DPs at a higher level of the hierarchy may become constraints at a lower level of the DP hierarchy.

The FRs and DPs have hierarchies, and they can be decomposed. The FRs at the i^{th} level cannot be decomposed into the next level of the FR hierarchy without first going over to the physical domain and developing a solution that satisfies the i^{th} level FRs with all the corresponding DPs. That means one should travel back and forth between the functional domain and the physical domain in developing the FR and DP hierarchies. A good designer must have ability to choose a minimum number of FRs at each hierarchical level of the FR tree.

2.5.1 Design Axioms

2.5.1.1 Axiom 1 The Independence Axiom: Maintain the independence of the FRs. Alternate Statement 1: An optimal design always maintains the independence of FRs. Alternate Statement 2: In an acceptable design, the DPs and FRs are related. A specific DP can be adjusted to satisfy its corresponding FR without affecting other functional requirements.

2.5.1.2 Axiom 2 The Information Axiom: The best design is a functionally uncoupled design that has a minimum information content.

Design is separated into three groups: uncoupled, coupled and decoupled designs. An uncoupled design satisfies Axiom 1; whereas, a coupled design has some functions dependent on another functions, and thus violates Axiom 1. When the coupling is due to an insufficient number of DPs against the number of independent FRs, the design may be decoupled. This is done by simply increasing the number of design parameters.

2.5.2 Nam Suh's Definition of Information

To be able to complete a given task, information is required. The information content of a design may be defined quantitatively as a logarithm of the probability of fulfilling the specified FR. If the FR is to have a shaft length of 4+/-0.1m, then the probability of being within the tolerance defines the information. If a uniform probability density along the length of the shaft is assumed, the probability, p, of producing an acceptable shaft is given by the ratio of tolerance to the dimension.

$P = 2(0.1)/4 = 1/20$

Information contents 'I' is defined in terms of probability as

Information $= I = \log_2(1/p) = \log_2(20) = 4.32$ bits

Overall probability is the product of probabilities of all associated events.

$I = \log_2(\text{range/tolerance})$

(Assuming tolerance is uniformly distributed over the range).

The information content associated with the FRs of an uncoupled design can be obtained by simply adding the information associated with each of the FRs at each level of the FR hierarchy. However, in the case of a coupled design, any one DP can affect all the other FRs. Therefore, the information content cannot be defined a priori since it will depend on a particular path.

2.5.3 Scope of Axiomatic Approach to Design in Present Research

Nam Suh (1990) gives fundamental principles that can be applied in all design situations. These axioms apply in designing structures, products, software, manufacturing processes, systems and even organizations. He states two design axioms and derives many corollaries as a direct consequence of the axioms. Some of the derived corollaries that match with the principles of Design For Manufacture and Assembly (DFMA) are: the integration of physical parts, the use of standardization, the use of symmetry, the use of the largest allowable tolerance, and a minimum number of parts in the design. DFMA is a core part of concurrent engineering practices. Hence reviewing Nam Suh's design axioms, corollaries and theorems were useful to the present research.

This research proposes to design an information interchange support system for concurrent engineering design. The second design axiom itself is called "The Information Axiom" and states that the best design always has a minimum information content. This is going to be a key axiom in designing the information interchange support system. The cross-functional design team would not like to get overwhelmed by the massive amount of information that all functions are capable of bringing. On the other hand, they will need the important information on a timely basis as the product moves on through various stages of development. Nam Suh gives a quantitative definition of the information of a design system. He defines the information of the design system as the sum of the information of each design parameter of the system. The information of the design system represents the logarithm of probability meeting the design specifications through proper control of the design system. This definition of the information of the design stresses the need to properly control the design system in order to increase the probability of meeting design specifications. For example, when the designer's specifications can be satisfied by a manufacturing system 100% of the time, the probability is 1. When the specifications cannot be satisfied by the manufacturing system, even an infinite amount of information supplied to the system will not yield a satisfactory result. The meaning of proper control of the design system can be interpreted as bringing to the system appropriate information at the appropriate time and place. The information provided by different functions on a timely basis will help the design team to design products within the manufacturing limitations of the company. The proposed information interchange support system (IISS) will give necessary control over a design system. It will tell functions what information is required at various stages and when to give that information. Then, the design team can design the product to the specifications acceptable to most of the systems or functions. After this, the probability of meeting, the design specifications will increase. This will decrease the information content and the design system will be based on the second axiom of minimum information.

Thus a review of Nam Suh's book and design axioms stressed the need for proper control over the design system to maximize the probability of systems meeting the design team's specifications. However, he does not mention any methods to properly control the design system. This need to control the design system through an information interchange support system forms the basis for this research.

2.6 Computer-Aids for Design

The availability of affordable, high-performance computer workstations with enhanced graphics processing and display technology has expanded the role of CAD/CAM and CAE throughout the design and manufacturing process. Today CAD software implies more than drafting. David Ullman (1992) classifies software tools used in design into four categories: general purpose analysis tools, special-purpose analysis tools, drafting or visualization tools, and expert systems. First three categories are briefly reviewed in this section; whereas, a fourth category is reviewed in detail in a separate section under the title of "Artificial Intelligence and Its Scope."

2.6.1 General Purpose Analysis Tools

Ullman describes these tools as mathematical word processors. They are domain-independent and allow the evaluation of whatever can be modeled in terms of simple equations.

2.6.1.1 Spreadsheets: The most common type of analysis tool is the spreadsheet, a multidimensional grid to collect data and calculate data. They have been available since the late 1970s. Formulas can be entered into the grid and the results easily plotted. In design work, spreadsheets can be used for analysis. For example, they are often used to explore the sensitivity of one or more parameters to variations of another parameter. They can be used for making design decisions using a decision matrix. The goal is to iteratively compare concept options on a matrix-type grid. The use of spreadsheets for developing decision matrices makes the iteration very easy. In developing a program plan, a grid relating tasks and personnel to time is generated. The use of a spreadsheet to represent this grid makes for rapid iteration during the evolution of the plan.

2.6.1.2 Equation Solvers: These are used for more complex analysis. These tools greatly ease the evaluation of product designs. There are two groups of evaluation solvers: numeric and symbolic. Numeric equation solvers can find a solution for much more complex equations than do spreadsheet. They can perform matrix and calculus operations and can plot the results. Symbolic equation solvers are much more powerful than the numeric systems. They treat each variable as an object with a known relationship to other variables. At present, the "Mathematica Program" has very good symbolic processing capabilities.

2.6.1.3 Parametric or Variational Design Tools: Parametric design tools operate by keeping track of the constraints on geometry. They are very useful during the design process as they allow for quick geometric changes. However, they can only operate on geometric information. On the other hand, the variational design tool is a combination of a parametric design tool and a symbolic equation solver. Designview is an example of this type of the tool.

2.6.2 Special Purpose Analysis Tools

These tools can be applied only to a specific field or to a small set of fields.

2.6.2.1 Stress and Strain Analysis Tools: There are two categories of stress and strain analysis tools. The first category, which calculates the stress or strain for a given load and geometry, is itself composed of two types: classical, strength-of-materials-based programs and finite element methods (FEM). Classical-type codes are limited to common shapes, for example, beams, plates, hoops and tubes. FEM is used to model complex shapes, shapes composed of different materials, and components that behave nonlinearly. The second category of stress analysis tools allows the user to input the state of stress or strain and calculate potential failure.

2.6.2.2 Kinematics and Dynamic Analysis Tools: Kinematics and Dynamic analysis tools are used to evaluate the path, velocity, acceleration, and forces involved in the movement of mechanical systems. They can be used to generate a set of linkages to meet a set of requirements. Dynamic analysis requires geometric information and data on joint, mass and stiffness properties. Hence it is difficult to apply for complex systems.

2.6.2.3 Fluid and Thermal Analysis Tools: These tools are used to solve fluid problems for the potential compressible and viscous flow around plates, cylinders, wedges, and other standard shapes. The geometry should be kept simple in using the classical methods. For more complex problems, like the free convection air flow through an electro-mechanical device, a numerical method must be used.

2.6.3 Drafting and Visualization Tools

Models and geometry created in the design phase are used to drive other engineering and manufacturing functions, from analysis and quality control to tool design, machining, and process control. A major advantage provided by most three-dimensional computer-aided design systems is the ability to rapidly evaluate a number of alternatives, in terms of form, fit, and function, early in the design process before committing to a final design. The Computer-Aided Design has a significant role to play in concurrent engineering practices. It will provide designers with the ability to increase productivity and decrease the product development cycle time -- two important goals of concurrent engineering product development.

2.6.3.1 Geometric Modeling System: Geometry is a branch of mathematics concerned with the shape and spatial relations of the objects. Engineering drawing, which includes two dimensional (2 -- D) projection drawing, is widely used in design and manufacturing, and from assembly to inspection in production industries.

Taking advantage of computers in the 1960's, many computer companies developed computer systems that have replaced the routine engineering drawing. Almost all CAD systems were based on the 2-D wire frame geometric model. The internal representation of a 2-D wire frame is a list of lines and arcs, which can replace the engineering drawing and produce the point to point NC (Numerical Control) codes for drilling and punching operations. In 1970, 3-D wire frame systems appeared, which could represent segments of 3-D space curves. With 3-D wire frames, it became possible to store only a single three-dimensional model and generate all needed two dimensional views from it.

Unfortunately, even a collection of three dimensional lines is not sufficient for representing a shape, because some collections of lines may have several interpretations in terms of solid objects. This is called wire frame ambiguity. To solve the hidden line and hidden surface removal problems, 3-D objects are presented as models. This popular method to represent the 3-D objects is called Solid Modeling. Using this method, we can create an unambiguous, complete and unique model in a computer to describe the real world object.

2.6.3.2 Solid Modeling System: Solid Modeling means an "informationally complete" representation of the physical object of which some properties, like volume or surface area, should be calculated automatically without human help. In 1970, the solid modeling system became more popular since it could not only offer more new utilities but could also link CAD/CAM together. Generally there are three types of models: a decomposition model, a constructive solid geometry model, and a boundary representation model.

Thrailkill of Bleck Design (Puttre, 1993) says, "Solids are an effective way of gauging complex shapes in proximity with one another. At Bleck Design, designers use solid models to understand all of the basic issues related to product function. Once designers understand what product features are desired by the client, these features can be refined in steps and can be worked into the solid model to determine any effect it might have on other features. The designers go back and forth between the latest detail and features already developed, making modifications where necessary. This sort of up-front engineering helps us establish the basic configuration of the product."

Colgate's Crawford (Puttre, 1993) stated that his group's conceptual designers use computers to refine raw ideas with initial engineering analyses. The industrial design group either scans its sketches into Intergraph's I/Design software running on Clipper workstations or draws them from scratch. The designers use 2-D drawing functions to develop the raster sketches into vector geometry and to build on the initial idea. From there, a 3-D model can be built. The I/Design system has parametric associativity so that changes in the dimensions will automatically change the drawing.

Computers can be connected to databases through networks that contain information useful to the conceptual designers. Libraries of the heights of store shelves and sizes of stock caps can be accessed to determine if the intended product conforms to standards. Human factor data bases provide on-line information relevant to the design of grips and containers.

The users of computer-aided Conceptual design software are nearly unanimous in pointing out its limitations (Puttre, 1993). There is a phase in the design process between the product specifications and putting preliminary ideas on the screen where designers rely exclusively on pencil, paper, and imagination. The most often-cited reason for not using the computer for this kind of work is that the interface is not appropriate for sketching very basic ideas.

2.6.4 Computer-Aids for Design, Its Limitations and Its Scope in Present Research

Computer tools can be a significant aid to product evaluation. There are many general purpose analysis tools and special purpose analysis tools available to evaluate a product design.

Computer tools are difficult to use in generating concepts or products. The techniques for generating concepts and products are not well enough understood to be codified on a computer. The existing computer tools need a very refined representation of the object on which to operate; thus, they are poor at handling the abstract information used in the conceptual design phase. Kinematics is one of the few areas in which concepts can be generated according to given requirements. In most of the other areas, designers rely exclusively on pencil, paper and imagination at the conceptual design stage.

There has been an increasing use of computers during the development process. Apart from the evaluation of a design, design teams seek information stored in computer databases, send messages and seek the opinion of an expert through electronic mail. There is the emergence of a new class of software, called as Groupware, to share useful information on the network. This is further discussed in a later section of this chapter. Although computer aids have their limitations in generating conceptual designs, a design team can make use of computer aids for analysis, information storage and retrieval and quick message passing. As discussed above, there are various packages available for analysis and they will generate information in various formats. There is need for an information interchange support system to determine which function will need what information, at what stage of the development process and where they can find that information. The review of computer aids in the design or development process has given a general overview of the various packages available for analysis purposes and the types of information they can generate. The proposed research will determine an effective way of using this information.

2.7 Artificial Intelligence and Its Scope

Artificial Intelligence means human created intelligence for computers. Computers can think. It means a computer executes a thinking program or an intelligent program. According to H. Schildt (1987), an intelligent program is one that exhibits behavior similar to that of the human when confronted with a similar problem. It is not necessary that the program actually solve, or attempt to solve, the problem in the same way as human would.

The field of artificial intelligence is composed of several areas of study that can be listed as follows: a) Searching (for Solutions), b) Expert Systems, c) Natural language processing, d) Pattern recognition, e) Robotics, f) Machine learning, g) Logic and h) Uncertainty and "fuzzy logic".

Some of the areas represent final applications, such as expert systems; others such as natural language processing and solution searching, are AI building blocks that are added to other programs to enhance their performance.

a) Searching -> When applied to AI, the term searching refers to search for a solution to a problem. For example, we can use AI-based searching in a program that attempts to find the best material to minimize the cost without sacrificing strength of the given product, or that proves a mathematical theorem.

b) Expert systems -> They are AI's first commercially viable product. An expert system has two primary attributes. First it allows one to enter information about a subject into the computer. This information is sometimes called the knowledge base. Second, it allows you to interrogate this knowledge base and it acts as though it were an expert on the subject. The knowledge is represented in terms of rules. A designer may use hundreds or thousands of such rules during the design of a device. Efforts have been made to capture such knowledge from designers to make automatic design programs.

There are limitations to such programs. The reasons are: knowledge used in design is too complex to be reduced to rules, and second, experts often cannot or will not explain their knowledge.

c) Natural language processing -> To many AI researchers, this is the most crucial goal to achieve because it enables the computer to understand human language directly. The worst obstacle to achieving this is goal is the size and complexity of human languages. In addition, there is the problem of making the computer aware of the contextual information that is present in all but simplest situations.

d) Pattern matching and recognition -> These concepts are important to several applications, which includes robotics, and image processing. For example, when given a digitized television picture, how can computer determine where one object end and another begin, or one object is on top of another? How to match various parts of assembly in the solid model with the parts existing in data bases and understand the function of various parts? Like natural language processing, pattern matching and pattern recognition is necessary capabilities that allow the computer to interface directly with the human world.

e) Robotics -> AI can use spatial reasoning to build computer controlled motion for robots. For such industrial robots as the ones that assemble automobiles, the problems of AI are primarily concerned with providing smooth, natural motions within a set of discrete locations. For autonomous robots, there is the more difficult problem of interfacing to a human world, with its obstacles, unexpected events, and changing environment.

f) Machine learning -> This area deals with making programs learn from their mistakes, from observations, or by request. Machine learning simply means making the computer capable of benefiting from experience.

g) Logic -> AI products of current practical importance are those programs that use can use to study the logical correctness of an argument by applying the standard rules of logic. In this context, the word argument refers to any logically connected statements that yield a goal. This includes mathematical proofs, formal logic, and syllogistic or philosophical logic.

h) Uncertainty and "fuzzy logic" -> Most decisions are made on incomplete knowledge. For example, while buying a car, we do not know how it will perform in harsh weather. How long the engine will run before tuning is required? Our decision to buy is based upon several assumptions that have a certain probability or likelihood of being true. For a computer to be able to think in the same way implies the use of fuzzy logic; that is, decision making based on incomplete or probabilistic information.

2.7.1 Expert Systems in the Management of the Engineering Design Process

The impact of expert systems on all aspects of industrial productivity is well documented by Feigenbaum et al. (1988) in their recent book. Expert systems technology is being successfully applied daily within Fortune 500 companies to manufacturing processes, product configuration, quality control, customer service, preserving corporate expertise, and a host of other areas where increased human productivity is needed. The specific applications of expert systems to engineering design processes are also common (Dixon, et. Al., (1985); Dym, (1985); Garrett & Jain, (1988); Sriram, et. al., (1993)). A recent book from Carnegie-Mellon summarizes a group of expert systems projects in engineering design (Rychener, (1988)).

In spite of the extensive use of expert systems in engineering design and in other functional areas of corporate activity, no research has examined the feasibility and potential of establishing an integrated network of expert systems for the management of engineering design within a company. The reason may be that the knowledge used in a design is too complex and all knowledge is not available prior to the start of a design process to form the rules and use in an expert system.

2.8 Groupware Technology and Its Scope

The organization that is most likely to gain competitive advantage from improvements in engineering design is characterized by strong communication and information flows among the different functional areas of the organization. The proposed information interchange support system based on groupware technology will form the basis for strong communication and information flows among the different functional areas of the organization. The objective of groupware is to share useful information on the network that would otherwise stay locked in individual PCs or in peoples' heads (Stevenson 1993). Kaplan et al. (1992) define groupware as any software that allows two are more people to collaborate over a network. There is a considerable diversity of features between the packages. However, there are some common issues on the basis of which groupware packages can be compared.

1) Quality of E-Mail Facility --> The software foundation of groupware is electronic mail. According to Kaplan et al. (1992), a groupware should at least let one forward and reply messages, send a carbon copy, and distribute to a list. It should also provide some kind of built-in text editor, import and export text files, and attach formatted files to messages. Look for extras like notification that your message has been read, electronic "while you were out forms", and a file management feature.
2) "Chat" capability --> Products such as Futurus Team Dos/Windows Combo allow small groups to participate in simultaneous real-time keyboard conversations.
3) Scheduling --> Meetings are vital for most organizations. If everybody's personal schedule is accessible over the Local Area Network, the computer can handle the

donkey work of arranging meetings. If the group scheduler is integrated with E-Mail then one need not have to update one's personal schedule manually when accepting an invitation or confirming a meeting. Products such as WordPerfect Office 4.0 and Futurus Team build scheduling into the fabric of their e-mail-centered systems.

4) "Virtual meeting" products --> The idea here is that face-to-face meetings tend to be dominated by personalities, not ideas. Since the ideas are what meeting organizers are interested in, filtering out personalities, via structured interactions over a computer network, should promote a speedier and more productive result. Ventana Corporation's GroupSystems 5.0 and Collaborative Technologies Vision Quest is another respected "meeting support" product.

5) Group Decision tools--> Products such as CM/1 and Expert Choice offer both methodology and structure to facilitate the group decision-making process. Operating in virtual time, they allow discussions to be carried out on as-available basis by anyone on the network.

6) Information Managing GROUPWARE --> This groupware focuses on managing information; that is, accessing, collecting, parsing, sorting, storing, and distributing information.

2.8.1 Lotus Notes: To Build Information Interchange Support System (IISS)

Lotus Notes is a distributed database with built-in wide area connectivity, automated document routing, and personal e-mail. Stevenson (1993) writes that with these tools, the users can easily build data-storage, data-tracking, and open discussion applications that can be connected via phone lines. Ulanoff (1993) suggests that with offices all over the world, a company can have a hard time keeping track of all its wide-reaching information. Groupwares such as Lotus Notes can help by making available up-to-date customer and account histories at all locations. With a sales-order tracking tool built into the application development environment, all invoices are automatically filled and copied to the product distribution center. Kaplan et al. (1992) state that without any programming, Notes users can design their own data bases, assuring themselves and team members of access to up-to-date information and a forum for debate and collaboration. The creator of the data base controls who has access to it.

2.9 A Summary of the Literature Review and New Needs

The sequential engineering design process given by various authors is examined. Then a model of an information exchange in sequential product development is presented. The review of sequential design process and the model of information exchange in sequential product development stress the urgent need for the development of a comprehensive model of engineering design communication in the concurrent engineering environment. This need gives rise to the first phase of this research.

The concept of concurrent engineering product development is reviewed next. Most companies have a sequential product development process; that is, product concept, product design, product testing, process planning, production, and product marketing functions, are carried out serially in separate departments. Without having the proper input from different departments, the design team makes certain decisions that may prove costly to reverse.

The last few years have witnessed the growth of a new concept, concurrent engineering, to reduce the drawbacks of the conventional method of product development. Concurrent engineering is a design approach where experts from different departments of the company interact together and work together in every phase of the product development. Hall (1991) has discussed some classic methods that should be part of the concurrent engineering lexicon. Quality Function Deployment, Design for Manufacture and Assembly and Robust Design, these methods are briefly reviewed. Why do many manufacturing companies not achieve "superior" design systems and what should be done to change design systems to adapt to the concurrent engineering environment? The next section tries to find the answers to these questions by summarizing the thoughts of LaMantia and Shapiro (1989), Pahl & Beitz (1984) and Dr. Roland Schmitt (1989).

Since the aim of the research is to develop a computer-based information interchange support system, ongoing research on the topic of computer support for concurrent engineering is reviewed next. Finger et al. (1992) have developed "Design Fusion", a computer-based design system that will help designers to consider concurrently the interactions and tradeoffs among different and conflicting requirements. Reddy et al. (1993) have stated a layered architecture of different types of computer technology that must come together to support concurrent engineering. Chung et al. (1993) have developed and placed in the public domain a shared window system, called 'X Teleconferencing and Viewing' (XTV). XTV is based on the X window system and lets user create a conference around one or more arbitrary X applications. Cutkosky et al. (10) and several other research group are jointly developing the Palo Alto Collaborative Testbed (PACT), a concurrent engineering infrastructure that encompasses multiple sites, subsystems, and disciplines. Their approach has been to integrate existing multitool systems. Bowen et al. (1992) have stressed the need to develop an Intelligent Networked Collocation Advisor that relieves the logistic and scheduling difficulties of the product development team. Malony (1991) has given outlines of computing objectives to support concurrent engineering. The author has developed an integrated computing environment, called Access Manager, to facilitate concurrent engineering. The developed system improves the users' access to all the resources required to do their job effectively.

The review of computer-aids in concurrent engineering stressed the following needs:

1) A computing environment which can effectively deal with distributed and heterogeneous computing hardwares and softwares,
2) Transparent access to all computing resources, including hardware, software and databases,
3) An environment to support the management and sharing of information with the appropriate levels of configuration controls and notification changes,
4) Design-build team data and documents and responses to these documents in a central repository,
5) Support to the integration of various designs and analysis processes.

The proposed research involves developing a communication model of the design process in a concurrent engineering environment and then developing an information interchange support system. Hence the following components are also vital to this research: identifying which functions have a role to play at each stage of the design, who communicates with whom and what information is interchanged, and what is the ideal against what is practiced. Hence the published work communication patterns and information transfer among functions during product development are reviewed next. Griffin et al. (1992) have concluded that the likelihood of product success is enhanced if marketing, research & development, design and manufacturing share information on various things during the product development process. Souder (1988) demonstrates through a ten-year study that interfunctional harmony, communication and cooperation are directly related to the degree of success of the new product. Cooper et al. (1984b) and DeBrentani (1989), in separate research, have confirmed the findings of Souder. Gupta et al. (1985) have found that the perceptions of marketing and research and development differ both on their levels of involvement and on the value of information each provides. Moenaert and Souder (1990a) have developed two formal models and a number of propositions about communication effectiveness. Both models conclude that the quantity and quality of marketing-research & development interactions are linked causally to new product success.

Thus everyone agrees that there is a need for inter-function communication for the success of new product. However, there is no specific research done to find out communication at each stage of the design process. Most of the researchers, in the product development area, are considering product design as one step in the whole development process. There has been no study found in the literature in which the product design is further divided into four or six substeps to research communication pattern. There is no research to find out which functions are involved and up to what degree at every stage of the product design. There is no research to determine who should interact with whom, up to what degree and at what stage for a successful product design. At each stage of the product design, what are the information categories important to every function? In other words, which function needs any given information and which function can supply that information? At what stage of the product design does this information exchange take place? If anyone tries to find answers to these questions through research papers then he may draw a blank. There is a need recognized here to do detailed research on the information exchange during the product design process in the concurrent engineering environment.

The roles played by different departments in an organization are reviewed in the next section. The departments whose functions in a design and manufacturing company examined are: marketing, design, top management, research and development, finance, purchasing, manufacturing, quality assurance, sales, and project management.

The developed model is validated by collecting data on the new product design communication process in the CE environment. The method of collecting data by using mail questionnaires is reviewed in the next section.

Nam Suh's (1990) design axioms are reviewed next. He recommends a firm scientific basis for design. He proposes that the axiomatic approach may be one of many possible avenues to give scientific basis for design. He explains, "The basic assumption of an axiomatic approach to design is that there exists a fundamental set of principles that determines good design practice." He gives fundamental principles that can be applied in all design situations. These axioms apply in designing structures, products, software, manufacturing processes, systems and even organizations. The research proposes to design an information interchange support system for concurrent engineering design. The second design axiom itself is called "The Information Axiom" and states that the best design always has a minimum information content. This is going to be a key axiom in designing the information interchange support system. The cross-functional design team would not like to be overwhelmed by the massive amount of information that all functions are capable of bringing. On the other hand, they will need important information on a timely basis as the product moves through various stages of development. The proposed information interchange support system (IISS) will give necessary control over the design system. It will tell functions what information is required at various stages and when to give that information or from where to obtain that information. Then the design team can design the product to the specifications acceptable to most of the systems or functions. Then the probability of meeting design specifications will increase, information content will decrease and the design system will be based on the second axiom of minimum information. Thus the review of Nam Suh's book and design axioms stress the need for proper control over the design system to maximize the probability of the system meeting the design team's specifications. However, he does not mention any methods to properly control the design system. This need to control the design system through an information interchange support system forms the basis for this research.

Computer aids for design process are briefly reviewed next. Four categories of tools discussed are: general purpose analysis tools, special-purpose analysis tools, drafting/visualization tools, and expert systems. The fourth category of expert systems is reviewed in a separate section under the title of "Artificial Intelligence and Its scope."

Computer tools can be a significant aid to product evaluation. However, they are difficult to use in generating concepts or products. Kinematics is one of the few areas in which concepts can be generated according to given requirements. In most other areas, the designers rely exclusively on pencil, paper and imagination at the conceptual design stage. There has been an increasing use of computers during the product development process. Apart from the evaluation of design, design teams seek information stored in computer databases, send messages and seek the opinions of an expert through electronic mail. Although the computer aids have limitations in generating conceptual designs, the design team can make use of computer aids for analysis, information storage and retrieval and quick message passing. As discussed above, there are various packages available for analysis and they will generate information in various formats. There is a need for an information interchange support system to determine which function will need what information, at what stage of the development process and where they can find that information. The review of computer aids and expert systems in the design/development process has given a general overview of various packages available for analysis purposes and the types of information they can generate. The proposed research will determine an effective way of using this information.

Groupware technology, its use in the product development process, and the features of Lotus Notes are reviewed next. Groupware's objective is to share useful information on the network that would otherwise stay locked in an individual PC or in peoples' heads, and to automate group tasks that would usually require meetings or circulating hard copy. There is considerable diversity of features between packages. Some common features are: 1) quality of the E-Mail Facility, 2) the "chat" capability,

3) scheduling, 4) the "virtual meeting" product, 5) group decision tools and 6) Information Managing groupware. Each of these features is explained briefly. It was proposed in the Marketing Science Institute's proposal to develop an integrated network of expert systems to help engineering design process. However after realizing the complexity of the task, it is proposed to use Lotus Notes based Groupware Technology to develop a prototype information interchange support system to help engineering design process.

CHAPTER 3

RESEARCH METHODOLOGY

The research was executed in several phases. The following tasks were planned:

Phase 1: Development of a Communication Model for Concurrent Engineering Design

Phase 2: Validation of the Proposed Model

a) Validation by a mail questionnaire survey on product design

b) Validation by case study

Phase 3: Formulation of Hypotheses Based on the Conceptual Model

Phase 4: Evaluation of Results

Phase 5: Building a Prototype Information Interchange Support System

Phase 6: Testing and Evaluation of the Support System

3.1. Development of a Communication Model for Concurrent Engineering Design

The first task was to develop a comprehensive model of concurrent engineering design communication. This concurrent engineering design communication model emerged from a synthesis of traditional sequential design models (Shigley, 1989), (Nam Suh, 1990), (Pahl and Beitz, 1984), management models (Crawford, 1991), and insight from recent literature examining concurrent engineering by Foundyller (1992), Bowonder (1992), Siegel (1991), Albin and Crefeld (1994), Mackey and Carter (1994), Dominach (1994), Kempfer (1993), Rasmus (1993), Dowlatshahi (1992 and 1993). The typical new product development model consists of the following major phases: idea generation, idea screening/evaluation, product development/design, the product verification stage, the introduction stage, and the production stage. Though improving the entire New Product Development (NPD) process should be the ultimate objective of research in this area, this research concentrated on a single phase (design) in the NPD process. The research followed Crawford's (1994) suggestion to break the process into smaller modules. Thus the product design phase in the NPD process was further divided into four stages and the developed model identifies the four stages of the engineering design process (Figure 3.1.).

Stage one involves the formulation of detailed product specifications. Stage two combines the two related processes of conceptual design development and review. Preliminary examination of the model from executives suggested that these two processes involve real-time micro iterations with input and continuous evaluation from several of the participating departments. Stage three, another compound stage, includes both detail design and evaluation of the detail design in a tightly coupled iterative process. The design phase of the NPD process concludes with the successful building and testing of a product prototype. Failure in the prototype build and test stage requires returning to the detail design stage.

At each stage, the model shows involvement of the departments that can provide vital information and be party in the design decision making process. The amount of interaction can vary. The predicted degree of interaction is shown by varying the thickness of the arrows with a thick arrow indicating much interaction and a thin arrow indicating less interaction. The involvement depends upon the role that each department plays during different stages of the design process.. The involvement depends on what information that each department can provide to help the design group make the right decisions early. These roles can change. At one stage of the design, the role may be to provide information. At other stages the role may be to evaluate the design, to decide certain issues, and to settle trade-offs. For example, manufacturing will provide information about manufacturing capabilities at the product specification stage. They will evaluate both conceptual and detail designs based on the manufacturing knowledge-base. They will make certain decisions about planning the manufacturing process based on the design and will also participate in settling trade-offs.

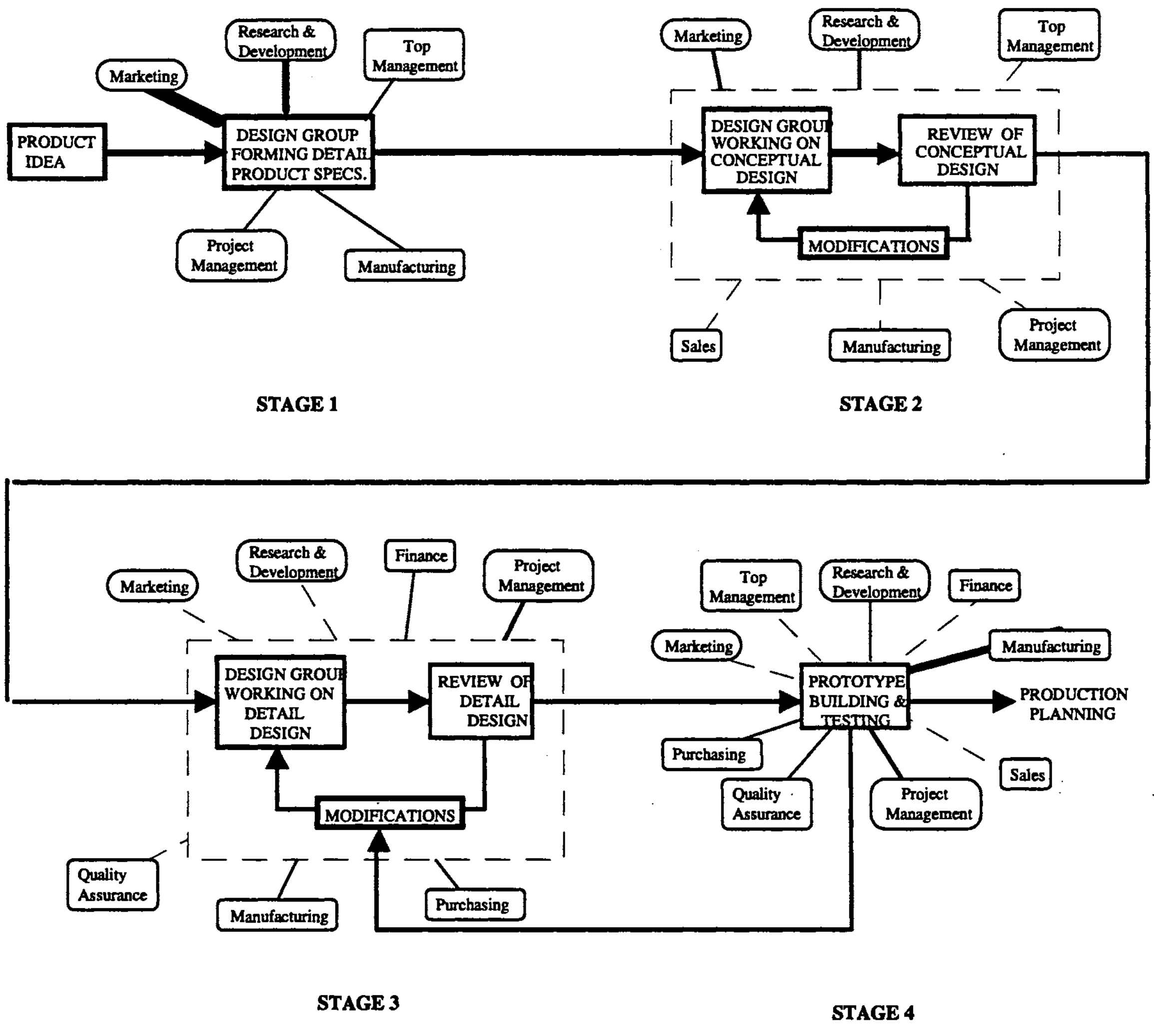


Figure 3.1. A proposed Communication Model for Concurrent Engineering Design

3.2 Validation of the Proposed Model

This phase of the research validates the communication model for concurrent engineering design developed in the first phase using two tools:

i) a questionnaire based on the proposed model, which was mailed to the Fortune 1000 firms, and

ii) a case study of the participating firm as their NPD moved through the design stages.

3.2.1 Validation by Mail Questionnaire

First, a three-page questionnaire was developed based on the model in Figure 3.1. The questionnaire and a statistical analysis of its responses attempted to determine answers to the following questions:

For a successful product design in the concurrent engineering environment,

- What role does each department play during each stage of the product design process?
- How much interaction takes place among the various departments during each stage of the design process?
- What information is exchanged among the various departments during each stage of the design process?

In the questionnaire, representatives from industry who are involved in the development of new products were asked to think of a successful NPD project that they could use as a reference to complete the questionnaire. While the complete NPD process involves many steps, from idea generation through product roll out, this research has concentrated on only four stages of the product design process: 1) product specification, 2) conceptual design and review, 3) detail design and review, and 4) prototype build and test.

These four stages were defined further on the first page of the questionnaire. For this study, representatives from industry were asked to assume that the sales and/or marketing should represent customer inputs, the purchasing department should represent supplier inputs, and the manufacturing department should include manufacturing engineering, testing and actual production.

The first page of the questionnaire determined the level of involvement for each department at each of the four stages of the design process. The first column on the left listed possible departments in the firm. The first row listed the four stages in the product design and their definitions. Respondents were requested to use a scale of "1" to "9" where "1" would mean no involvement, "3" would mean low involvement, "5" would mean moderate involvement, "7" would mean high involvement and "9" would mean maximum involvement. Hence completing the first page involved putting the appropriate number in each cell depending upon the involvement of each department at each stage.

The second page of the questionnaire determined the level of interaction between each pair of departments at each of the four stages of the design process. Again respondents were requested to use a scale of "1" to "9" where "1" would mean no interaction, "3" would mean low interaction, "5" would mean moderate interaction, "7" would mean high interaction and "9" would mean maximum interaction. Hence completing the second page involved putting the appropriate number in each cell depending upon the interaction of each department with every other department at each stage.

The third page of the questionnaire determined the stage at which the departments needed to send or receive product-related information. The departments were listed in the first row and the information categories were listed in the first column. The representatives from industry were asked to circle stage numbers listed in each cell of the table. They were free to consult with team participants throughout the firm to complete this page. If they circled only one number in the cell, they implied that the information was either sent or received by the department at only one stage. A sample of the questionnaire, cover letter, and follow up letter is included in Appendix A.

3.2.2 Validation by Case Study

A case study approach was used to understand the NPD process at the plant of an industrial partner. This approach involved attending concurrent engineering group meetings, interviewing key people involved in the product development process, and studying standard operating procedures (SOPs). Their NPD activities are carried out in the concurrent engineering environment through group meetings with marketing, design, research and development, quality assurance, program management, manufacturing engineering, and production from the beginning of the development phase. Interviewing key people involved in the product development process helped to understand the communication and information flow during this process. The case study approach helped in gathering important information for developing a prototype information interchange support system (IISS) in Lotus Notes to assist the product development process. The reasons for choosing Lotus Notes to develop IISS are explained in section 3.5 of this chapter.

3.3 Hypotheses Formulation Based on the Conceptual Model

At this stage, some potential hypotheses of interest were formulated based on the model developed in the first phase. This study was exploratory in the sense that little empirical research had been conducted previously to determine which departments play which roles at different stages of the concurrent engineering design process. The first page of the questionnaire determined the departments involved and their degree of involvement at each of the four defined stages of the product design process. Despite the lack of research examining the role of various departments during the design phase of the NPD process, studies examining the involvement of individual departments in the broader new product development process do exist. For example Hutt, et al. (1988) found that both the involvement of individual managers and departments changed as a NPD project advanced through the strategy decision making process. Specifically, marketing displayed higher involvement in the earlier phases of the process than they did in the later phases. In contrast, manufacturing was more involved in the final phase than in the initial phases. This discussion suggested the following hypotheses.

HYP # 1: Within each stage of the Concurrent Engineering (CE) product design process, the levels of involvement will vary significantly across departments.

HYP # 2: Each department's involvement in the CE product design process will vary significantly across the four stages of the product design process.

Examining the communication patterns among members of an informal new product strategy decision making team, Hutt et al. (1988) found that communication interaction between pairs of members changed significantly as the process evolved. This discussion suggested hypothesis three.

HYP # 3: Within each stage of the CE product design process, the levels of interaction will vary significantly across different pairs of departments.

The second page of the questionnaire determined the levels of interaction between each pair of departments at each of the four stages of the design process. Griffin et al.

(1992) have concluded that the likelihood of product success is enhanced if marketing, research and development, and design and manufacturing share information on various things during the product development process. Souder (1988) demonstrated through a ten-year study that interfunctional harmony, communication and cooperation are directly related to the degree of success of the new product. Cooper et al. (1987) and DeBrentani (1989), in separate studies, have confirmed Souder's findings. Moenaert and Souder (1990a) have developed two formal models and a number of propositions about communication effectiveness. Both models conclude that the quantity and quality of marketing and research and development interactions are linked causally to new product success. Examining the communication patterns of two different types of NPD teams, Griffin and Hauser (1992) found different patterns of communication interaction for each of the two groups, and that interaction levels varied between functional units during the NPD process. This discussion suggested hypothesis four.

HYP # 4: The levels of the interaction between different pairs of departments will vary significantly across the four stages of the CE product design process.

In addition to the changing levels of communication between pairs of departments within and across the new product design stages, the absolute level of communication will increase as the design moves from inception to completion. Studying communication patterns in the broader new product development process, Hutt et al. (1988) found that communication density throughout the network of team members increases across the various milestones encountered in the process. Network communication density is defined as the number of all communication links divided by the number of all possible links (Knoke and Kuklinski, 1982). Consistent with the broader view of new product development, this research also expected the communication network density of the entire design team to increase across the four stages of the design phase of the NPD process. This discussion suggested hypothesis five.

HYP # 5: Network density will increase from stage one (product specification stage) through stage four (prototypes build and test) of the CE product design process.

Dr. Roland W. Schmitt (1989), in his keynote address to the Design Theory '88 Workshop sponsored by NSF suggested a "design-centered innovation" where a gifted designer is put in charge of the process and invention and where marketing and manufacturing are integrated in a supportive manner, providing appropriate guidance to the designer as required. The proposed model followed his suggestion (Figure 3.1.); that is, design department occupies a central position in each stage of the design process. This discussion suggested the next hypothesis.

HYP # 6: The design department will have the highest level of centrality at each stage in the concurrent engineering design process.

Centrality is measured by counting the number of direct links one department has with other departments (Freeman, 1979). The department with the greatest number of direct links occupies the most central position in the communication network. The next section presents the methodology, including data collection, sample description, and data analysis, employed in the study.

The third page of the questionnaire determined which departments sent or received information from the listed categories at each stage of the product design. Dowlatshahi (1993) explains why the marketing department has higher involvement in the early development cycle. He argues that the higher the degree of dialogue, cooperation, and exchange of usable information between design and marketing, the higher the probability of product success. Moenaert and Souder (1990) explain the involvement of marketing and research and development through their roles in the product development. It is expected that the marketing department will be a key actor in the acquisition and utilization of information regarding user needs, competition, and resources. On the other hand research and department will be a key actor in the acquisition, processing, dissemination, and application of information concerning technologies, competition and resources. Both marketing and research and development need information from each other to accomplish their specific tasks. It is intuitively obvious that if departments have more involvement in the product design process, they will have higher need for the information exchange. This suggested the following hypothesis.

HYP # 7: For each stage of the concurrent engineering design process, departments having high involvement in the design process will exchange more information than departments having moderate and low involvement.

Sharda et al. (1994) argue that a CE team should be viewed as a biological entity that takes different shapes during its life time. With this organic entity, some particular organs (departments) play a key role during certain stages, and thus are more central to the body (CE team). As the entity (product design) moves to another stage, some other organs (departments) have to play key roles while other organs move to the periphery. Thus, when a department is at the core during certain stage, its need for information exchange is higher. When the same department moves to the periphery at some other stage, its need for information exchange is less. This suggested hypothesis eight.

HYP # 8: For each department, the information content exchanged is different for each stage of the concurrent engineering design process.

3.4 Evaluation of Survey Responses

A 10% response rate was expected from the questionnaires. This number would provide a sample of 70, which was considered adequate for analysis. SPSS, a window based statistical package, was used for a detailed examination of the data and subsequent statistical analysis. An examination of the data revealed some extreme responses. The two techniques that were used to do the exploratory data analysis were i) the Stem-and-Leaf Plot and ii) the Box Plot.

After removing extreme outliers, SPSS was used to provide a numerical descriptive statistic. The use of a numerical descriptive statistic condensed large data sets into a coherent format. The most useful numerical descriptive statistics were mean and standard deviations for each cell on the first and second page of the questionnaire. Then SPSS was used to do an analysis of variance (ANOVA), a statistical technique to test the null hypothesis that several population means were equal. This technique examined the variability of observations within each group as well as the variability between the group means. On the basis of these two estimates of variability, conclusions were drawn about the population means. In the cases when the null hypothesis was rejected, additional analysis, such as Tukey's Multiple Pairwise Comparison Test, was carried out to identify which effects were statistically different. In the single-factor ANOVA, two estimates of the variance were made using the between-group variance and the within-group variance. The between group variance gave the variance across four defined stages and the within group variance gave the variance within each stage across various departments.

In this study, one variable was used at a time for one-way analysis of the variance. One-way analysis of the variance was applied for the following cases:

1) to analyze the variance for involvement of each department across four stages of the product design,
2) to analyze the variance for involvement at each stage of the product design among ten departments of a company,
3) to analyze the variance for interaction of each pair of departments across four stages of the product design, and
4) to analyze the variance for interaction at each stage of the product design for each pair of departments.

The statistical test for the null hypothesis that all groups have the same mean in the population is based on a ratio called an F statistic. The ratio of the between-groups mean square and the within-groups mean square is called the F statistic. The observed significance level is obtained by comparing the calculated F value to the F distribution (the distribution of the F statistic when the null hypothesis is true). The significance level is based on both the actual F values and on the degrees of freedom for the two mean squares. If the observed significance level was less than 0.05, the null hypothesis was rejected that the involvement of departments at different stages is same.

A significant F value tells only that the population means are probably not all equal. It does not tell which pairs of groups appear to have different means. The null hypothesis is rejected even if any two means are unequal. To find out which pairs of groups have different means, a special test called the multiple comparison test was used. This test determined which means were significantly different from each other. "Tukey's Honestly Significant Test" was used in this analysis. In the results of this test, an asterisk showed a pair of means that were different at the 0.05 level.

On page three of the questionnaire, each cell of the table had four numbers which were either circle or not circled. If the number was circled, then it was assigned value of

'1' and if it was not circled then it was assigned value of '0'. The percentage of responses with circled numbers was determined along with an upper critical cut-off point. If the percentage of responses with circled numbers was found to be above this upper critical value, then the corresponding department either received or delivered detailed information about the corresponding category at a given stage. Similarly, on the lower side, another cut-off point was determined. This lower cut-off point helped to determine whether the percentage of responses was significantly different from the '0' value. If the percentage was found to be within the bounds of the lower and upper critical values, then it indicated that the corresponding department either received or delivered summary information about the related category at a given stage. If the percentage was found to be below the lower critical value, then it indicated that no information was exchanged by the corresponding department at a given stage.

The information network was determined using the mean values of involvement and mean values of interaction between different departments. Each department was shown by a circle. The size of the circle indicated the mean level of involvement of the department at that stage. The thickness of the line between two departments indicated the mean level of interaction for the pair at that stage.

Chapter 4 illustrates the results of the statistical analysis. A detailed discussion follows these results.

3.5 Building a Prototype Information Interchange Support System

Lotus Notes, a group communication software, was used to build a prototype information interchange support system. This system is assisting the new product design process in the concurrent engineering environment. Lotus Notes is a distributed database with built-in wide area connectivity, automated document routing, and personal e-mail.

Stevenson (1993) writes that with these tools, users can easily build data-storage, data-tracking, and open discussion applications that can be connected via phone lines. Kaplan et al. (1992) state that without any programming, Notes users can design their own data bases, assuring themselves and team members of access to up-to-date information and a forum for debate and collaboration. The creator of the database controls who has access to it.

A case study approach was used to understand the NPD process at the plant of an industrial partner. At the beginning of this research, the use of Lotus Notes was mainly limited to their Advanced Technology department. The Advanced Technology department used Lotus Notes to store its departmental databases and to communicate through an electronic mail facility. Company executives were aware of the potential use of Lotus Notes in developing new products. However, apart from a few people both in Engineering and in Advanced Technology, most people in other departments simply did not have access to Lotus Notes to learn its various capabilities.

As explained in chapter 2, Lotus Notes is an information manager for work groups. Using Notes, a group of people can share information across a computer network even if those people are in a different part of the world. The superior electronic mail capabilities of Lotus Notes make the software ideal to use for product development purposes. Within Notes, the user can easily send a message, and attach documents, pictures, CAD drawings or other forms of data to it. Notes lets users electronically sign all the documents that they send -- even if they did not compose the documents within Notes Mail. Individual documents may be encrypted and the encryption key mailed to select recipients. These security features enable users to communicate about confidential topics. Notes also provides database functions. In Notes, forms may be designed to build information bases. Users then access these databases to communicate with each other. Databases can be discussions about a given project, status reports, individual personnel assessments, request forms, or just a collection of messages kept for future references. If properly used and maintained, this type of system can reduce paper load and increase each user's ability to communicate with others in the group. The superior E-mail, electronic signature, other security measures, and ease of database operations make Lotus Notes an ideal group communication software to use in the product development process in a concurrent engineering environment. More information about the building blocks of Lotus Notes is given in Appendix B.

3.6 Testing and Evaluation of the Support System

A prototype Information Interchange Support System (IISS) was installed at the site of the company participating in this research for use by two CE teams working on two different NPD projects. The performance, use and user satisfaction of this system were determined by following three methods:

i) Attending CE meetings and judging the effect system had on CE team's working,

ii) Informal talks with users of the system and program managers, and

iii) Formal questionnaire to measure the user satisfaction.

Users were asked to complete the questionnaire given in the Appendix C. A simple statistical analysis of the responses was performed, and the results are presented in chapter 5, section 5.4.3.

CHAPTER 4

STATISTICAL ANALYSIS OF SURVEY RESPONSES

The first step of the data analysis is an examination of the sample background. Seven hundred questionnaires were mailed to Fortune 1000 companies. Seventy-two questionnaires were returned yielding a 10.29 percent response rate. Table 4.1 provides the respondent's break up by industry, functional area, and experience.

Table 4.1 Break up of Respondents

Break up based on Product	No. of Respondents
Mechanical Components and system manufacturers	21
Electronics manufacturers	18
Automobile manufacturers	12
Industrial equipment manufacturers	11
Consumer goods manufacturers	5

Break up by functional area		Break up by functional area	
Marketing and Sales	4	Purchasing	4
Design	16	Manufacturing	5
Top Management	10	Quality Assurance	10
Research and Development	10	Project Management	15
Finance	4		

Break up by experience

Eighty percent of the respondents had more than 10 years of experience in their field.

4.1 Preliminary Analysis of Data

A preliminary data analysis was performed by exploratory data analysis techniques and numerical descriptive statistics. This examination revealed some extreme or outlying observations. The extreme outliers cause the skewed distribution and also weaken the ability of the mean and standard deviation to describe the characteristics of a distribution. The two techniques that were used to do the exploratory data analysis are: i) The Stem-and-Leaf Plot and ii) The Box Plot. After removing extreme outliers in the data, numeric descriptive statistics were determined. The numerical measures provided descriptions of the characteristics of the distributions, that was used to provide more readily interpretable information. The use of numerical descriptive statistics condensed large data sets into a coherent format. Table 4.2 shows the mean level of involvement and a 95% confidence interval on the mean for different departments. Then Table 4.2 shows the department involvement means excluding responses from that department. The mean is determined this way to test against the bias. It is natural for people to rank their department's involvement a little higher than what actually is. To remove this bias in calculating the mean involvement of a particular department, responses from that department are omitted. Observe in Table 4.2 that all such totally unbiased means still fall within a 95% confidence interval on the overall means. Thus little bias by the people for their department's involvement does not make a significant difference in the overall mean determined by considering all responses.

The Table 4.3 shows overall, individual, and average interaction means for different pair of departments. The second line in each cell of Table 4.3 shows the mean interaction level for a given pair of departments considering all responses. The numbers of responses are shown in parentheses. It is difficult to determine how much interaction occurs between any two given departments for a third department person.

Table 4.2

Descriptive Statistic of Department Involvement

Department	Stage 1	Stage 2	Stage 3	Stage 4
Marketing				
Involvement Mean	7.7778 (N = 70)	6.4722 (N = 72)	5.0556 (N = 72)	4.8333 (N = 72)
95% Conf. Interval	(7.3312, 8.2244)	(6.0039, 6.9405)	(4.5325, 5.5786)	(4.2632, 5.4035)
Mean (Excluding 4 Marketing People Responses)	7.7206 (N = 66)	6.4118 (N = 68)	5.0441 (N = 68)	4.8529 (N = 68)
Design				
Involvement Mean	7.3478 (N = 69)	8.6957 (N = 69)	8.5507 (N = 69)	7.8261 (N = 69)
95% Conf. Interval	(6.9102, 7.7854)	(8.5243, 8.8670)	(8.3017, 8.7997)	(7.4267, 8.2254)
Mean (Excluding 16 Design People Responses)	7.4340 (N = 53)	8.7547 (N = 53)	8.4528 (N = 53)	7.7170 (N = 53)
Top Management				
Involvement Mean	5.4366 (N = 71)	4.9296 (N = 71)	4.3944 (N = 71)	4.8169 (N = 71)
95% Conf. Interval	(4.9017, 5.9715)	(4.3805, 5.4786)	(3.8828, 4.9059)	(4.2737, 5.3601)
Mean (Excluding 10 Top Mgt. People Responses)	5.4262 (N = 61)	4.9016 (N = 61)	4.3443 (N = 61)	4.6885 (N = 61)
Research & Development				
Involvement Mean	6.5429 (N = 70)	6.9857 (N = 70)	6.2714 (N = 70)	5.7000 (N = 70)
95% Conf. Interval	(5.9972, 7.0885)	(6.3870, 7.5844)	(5.6020, 6.9408)	(5.0412, 6.3588)
Mean (Excluding 10 R. & D. People Responses)	6.4000 (N = 60)	6.8167 (N = 60)	6.0500 (N = 60)	5.5667 (N = 60)
Finance				
Involvement Mean	2.9155 (N = 70)	3.3521 (N = 71)	4.3521 (N = 71)	4.3286 (N = 70)
95% Conf. Interval	(2.4759, 3.3551)	(2.9210, 3.7832)	(3.7933, 4.9109)	(3.7173, 4.9398)
Mean (Excluding 4 Finance People Responses)	2.8209 (N = 67)	3.2836 (N = 67)	4.3284 (N = 67)	4.2273 (N = 66)

Table 4.2 (continued)

Descriptive Statistic of Department Involvement

Department	Stage 1	Stage 2	Stage 3	Stage 4
Purchasing				
Involvement Mean	2.9155 (N = 71)	4.0141 (N = 71)	6.0845 (N = 71)	6.3380 (N = 71)
95% Conf. Interval	(2.5344, 3.2966)	(3.6012, 4.4270)	(5.6032, 6.5659)	(5.7939, 6.8821)
Mean (Excluding 4 Purchasing People Responses)	2.8358 (N = 67)	3.8955 (N = 67)	5.9254 (N = 67)	6.1791 (N = 67)
Manufacturing				
Involvement Mean	3.9155 (N = 71)	5.2535 (N = 71)	6.6338 (N = 71)	8.1549 (N = 71)
95% Conf. Interval	(3.4067, 4.4243)	(4.8158, 5.6913)	(6.1897, 7.0780)	(7.7496, 8.5603)
Mean (Excluding 5 Mfg. People Responses)	3.9394 (N = 66)	5.2879 (N = 66)	6.6515 (N = 66)	8.1818 (N = 66)
Quality Assurance				
Involvement Mean	3.4143 (N = 70)	4.0857 (N = 70)	5.3714 (N = 70)	6.9429 (N = 70)
95% Conf. Interval	(2.8780, 3.9505)	(3.5791, 4.5923)	(4.7704, 5.9724)	(6.3924, 7.4933)
Mean (Excluding 4 Qua. Assur. People Responses)	3.2576 (N = 66)	3.9242 (N = 66)	5.1818 (N = 66)	6.8182
Sales				
Involvement Mean	5.2113 (N = 71)	4.3521 (N = 71)	3.6901 (N = 71)	4.4789 (N = 71)
95% Conf. Interval	(4.5954, 5.8271)	(3.7876, 4.9166)	(3.1645, 4.2158)	(3.8816, 5.0761)
Mean (Excluding 1 Sales People Responses)	5.2537	4.3284	3.5821	4.4030
Project Management				
Involvement Mean	6.3333 (N = 66)	6.8788 (N = 66)	7.1667 (N = 65)	7.7273 (N = 65)
95% Conf. Interval	(5.7245, 6.9421)	(6.3480, 7.4096)	(6.6815, 7.6518)	(7.3080, 8.1466)
Mean (Excluding 15 Pro. Mgt. People Responses)	6.1765 (N = 51)	6.8039 (N = 51)	7.1373 (N = 51)	7.6667 (N = 51)

The level of interaction that occurs between two departments will best be judged by the responses of people from those two departments. The third and the fourth line in each cell of Table 4.3 show the mean interaction level for a given pair of departments considering responses from the individual departments. Thus if it is interaction between marketing and design, then the third line in the cell displays the mean of marketing responses; whereas, the fourth line displays the mean of design responses.

The fifth line in each cell of Table 4.3 displays the average. There are two reasons for determining the average in this case. The first reason is that the number of responses received from each functional area are not the same. There are sixteen responses from the design people, ten responses each from the research and development and top management, fifteen responses from project management, four responses each from marketing, finance, purchasing and quality assurance, five responses from manufacturing, and no responses from sales department. The second reason is that there are always bound to be differences of opinion on what each group says about their interaction level with the other group. For example, if the mean interaction value is determined for the first group with four responses, it may be 8.00; whereas, the mean interaction value for the second group with ten responses may be 6.00. The literature on the network analysis determines the strength of the tie in different ways (Richards, 1986). The three ways that are considered here are as follows: i) If X and Y are the mean interaction values for groups 'A' and 'B' respectively, then the weighted mean for the interaction between 'A' and 'B' is simply (X+Y)/2. ii) If group 'A' consists of N_A responses and group 'B' consists of N_B responses, then the weighed mean is $(X (N_A) + Y (N_B))/2$. iii) The third is reverse multiplication; that is, the weighted mean is equal to $(X (N_B) + Y (N_A))/2$. In this analysis, first method is used to determine weighted mean. This method gives the exact midpoint of two means and the weighted mean is not biased by the number of responses in a single group.

Table 4.3

Overall, Individuals, and Average Interaction Means

	Stage Numbers			
	Stage 1	Stage 2	Stage 3	Stage 4
Mktg.-Design Interaction				
Overall Mean	7.58 (N = 67)	7.27 (N = 70)	5.97 (N = 70)	5.74 (N = 70)
Mktg. resp. mean	8.50 (N = 4)	7.75 (N = 4)	7.00 (N = 4)	5.25 (N = 4)
Design resp. mean	6.87 (N = 15)	6.56 (N = 16)	5.00 (N = 16)	5.06 (N = 16)
Average	7.69	7.16	6.00	5.16
Mktg.-T. M. Interaction				
Overall Mean	5.73 (N = 70)	5.84 (N = 70)	4.90 (N =70)	5.13 (N = 70)
Mktg. resp. mean	6.50 (N = 4)	6.25 (N = 4)	5.50 (N = 4)	4.75 (N = 4)
Top Mgt. resp. mean	6.00 (N = 10)	6.00 (N = 10)	6.10 (N = 10)	6.70 (N = 10)
Average	6.25	6.13	5.80	5.73
Mktg.-R & D Interaction				
Overall Mean	6.17 (N = 69)	5.87 (N = 69)	4.84 (N = 69)	4.38 (N = 69)
Mktg. resp. mean	5.50 (N = 4)	5.25 (N = 4)	4.50 (N = 4)	2.50 (N = 4)
R & D resp. mean	7.40 (N = 10)	7.30 (N = 10)	5.70 (N = 10)	6.10 (N = 10)
Average	6.45	6.28	5.10	4.30
Mktg.-Finan. Interaction				
Overall Mean	3.53 (N = 70)	3.46 (N = 70)	3.73 (N = 70)	3.86 (N =70)
Mktg. resp. mean	5.00 (N = 4)	4.25 (N = 4)	5.00 (N = 4)	3.25 (N = 4)
Finance resp. mean	4.33 (N = 3)	3.67 (N = 3)	5.00 (N = 3)	6.00 (N = 3)
Average	4.67	3.96	5.00	4.63
Mktg.-Purc'g Interaction				
Overall Mean	2.14 (N = 70)	2.51 (N = 70)	2.54 (N = 70)	2.96 (N = 69)
Mktg. resp. mean	2.00 (N = 4)	2.25 (N = 4)	3.25 (N = 4)	2.25 (N = 4)
Purchasing resp. mean	3.50 (N = 4)	3.50 (N = 4)	2.75 (N = 4)	3.75 (N = 4)
Average	2.75	2.88	3.00	3.00
Mktg-Mfg. Interaction				
Overall Mean	2.66 (N = 68)	2.81 (N = 70)	3.11 (N = 70)	4.20 (N = 70)
Mktg. resp. mean	2.00 (N = 4)	2.50 (N = 4)	2.25 (N = 4)	2.75 (N = 4)
Mfg. resp. mean	3.00 (N = 5)	4.60 (N = 5)	4.60 (N = 5)	5.60 (N = 5)
Average	2.50	3.55	3.43	4.18
Mktg.-Q. A. Interaction				
Overall Mean	2.62 (N = 69)	2.54 (N = 69)	2.87 (N = 69)	3.64 (N = 69)
Mktg. resp. mean	2.00 (N = 4)	2.50 (N = 4)	3.00 (N = 4)	3.25 (N = 4)
Q. A. resp. mean	5.25 (N = 4)	5.75 (N = 4)	5.25 (N = 4)	6.25 (N = 4)
Average	3.63	4.13	4.13	4.75
Mktg.-Sales Interaction				
Overall Mean	6.40 (N = 68)	5.75 (N = 68)	5.38 (N = 68)	5.93 (N = 68)
Mktg. resp. mean	7.25 (N = 4)	7.50 (N = 4)	7.25 (N = 4)	6.25 (N =4)

Table 4.3 (continued)

Overall, Individuals, and Average Interaction Means

	Stage Numbers			
	Stage 1	Stage 2	Stage 3	Stage 4
Mktg.-P. Mgt. Interaction				
Overall Mean	5.56 (N = 64)	5.83 (N = 64)	6.00 (N = 64)	6.47 (N = 64)
Mktg. resp. mean	6.00 (N = 4)	5.50 (N = 4)	6.50 (N = 4)	7.00 (N = 4)
Project Mgt. resp. mean	4.57 (N = 14)	5.43 (N = 14)	5.57 (N = 14)	6.14 (N = 14)
Average	5.29	5.47	6.03	6.57
Design-T. M. Interaction				
Overall Mean	5.22 (N = 69)	5.36 (N = 69)	4.68 (N = 69)	5.00 (N = 69)
Design resp. mean	4.81 (N = 16)	5.63 (N = 16)	4.19 (N = 16)	4.81 (N = 16)
Top Mgt. resp. mean	5.22 (N = 9)	6.00 (N = 9)	6.22 (N = 9)	6.44 (N = 9)
Average	5.02	5.82	5.21	5.63
Design-R&D Interaction				
Overall Mean	7.81 (N = 66)	6.97 (N = 66)	6.42 (N = 66)	5.98 (N = 66)
Design resp. mean	6.40 (N = 15)	6.93 (N = 15)	6.07 (N = 15)	5.47 (N = 15)
R & D resp. mean	8.00 (N = 10)	7.80 (N = 10)	7.60 (N = 10)	8.00 (N = 10)
Average	7.20	7.37	6.84	6.74
Design-Fina. Interaction				
Overall Mean	3.46 (N = 67)	3.78 (N = 67)	4.36 (N = 67)	4.25 (N = 67)
Design resp. mean	2.88 (N = 16)	3.50 (N = 16)	3.69 (N = 16)	3.69 (N = 16)
Finance resp. mean	4.33 (N = 3)	4.33 (N = 3)	3.67 (N = 3)	4.33 (N = 3)
Average	3.61	3.92	3.68	4.01
Design-Purc'g Interaction				
Overall Mean	4.27 (N = 67)	5.01 (N = 67)	6.09 (N = 67)	6.04 (N = 67)
Design resp. mean	3.31 (N = 16)	5.13 (N = 16)	6.06 (N = 16)	6.00 (N = 16)
Purchasing resp. mean	5.75 (N = 4)	6.25 (N = 4)	8.25 (N = 4)	7.50 (N = 4)
Average	4.53	5.69	7.16	6.75
Design-Mfg. Interaction				
Overall Mean	4.78 (N = 67)	5.45 (N = 67)	6.69 (N = 67)	7.52 (N = 66)
Design. resp. mean	4.50 (N = 16)	5.56 (N = 16)	6.88 (N = 16)	7.69 (N = 16)
Mfg. resp. mean	5.25 (N = 4)	6.25 (N = 4)	6.75 (N = 4)	8.25 (N = 4)
Average	4.88	5.91	6.82	7.97
Design-Q. A. Interaction				
Overall Mean	4.08 (N = 66)	4.30 (N = 66)	5.53 (N = 66)	6.26 (N = 66)
Design resp. mean	3.00 (N = 16)	3.75 (N = 16)	4.63 (N = 16)	6.06 (N = 16)
Q. A. resp. mean	7.00 (N = 4)	6.25 (N = 4)	7.75 (N = 4)	8.75 (N = 4)
Average	5.00	5.00	6.19	7.41
Design-Sales Interaction				
Overall Mean	4.26 (N = 66)	4.39 (N = 66)	3.97 (N = 66)	4.11 (N = 65)
Design resp. mean	3.60 (N = 15)	4.53 (N = 15)	3.47 (N = 15)	4.07 (N = 15)

Table 4.3 (continued)

Overall, Individuals, and Average Interaction Means

	Stage Numbers			
	Stage 1	Stage 2	Stage 3	Stage 4
Design-P. M. Interaction				
Overall Mean	6.16 (N = 62)	7.08 (N = 62)	7.35 (N = 62)	7.32 (N = 62)
Design resp. mean	5.67 (N = 15)	7.00 (N = 15)	6.87 (N = 15)	6.93 (N = 15)
Project Mgt. resp. mean	6.00 (N = 14)	6.71 (N = 14)	7.00 (N = 14)	6.86 (N = 14)
Average	5.84	6.86	6.94	6.90
T. Mgt.-R&D Interaction				
Overall Mean	4.33 (N = 70)	4.44 (N = 70)	3.63 (N =70)	3.50 (N = 70)
Top Mgt. resp. mean	4.60 (N = 10)	4.60 (N = 10)	3.70 (N = 10)	4.00 (N = 10)
R&D resp. mean	4.70 (N = 10)	4.80 (N = 10)	3.80 (N = 10)	4.10 (N = 10)
Average	4.65	4.70	3.75	4.05
T. Mgt.-Fina. Interaction				
Overall Mean	3.90 (N = 69)	4.07 (N = 69)	4.33 (N = 69)	4.74 (N = 69)
Top Mgt. resp. mean	4.90 (N = 10)	4.80 (N = 10)	5.50 (N = 10)	5.70 (N = 10)
Finance resp. mean	3.33 (N = 3)	3.33 (N = 3)	3.33 (N = 3)	4.00 (N = 3)
Average	4.12	4.07	4.42.	4.85
T. M.-Purch'g Interaction				
Overall Mean	2.33 (N = 69)	2.72 (N = 68)	3.03 (N = 69)	3.51 (N = 69)
Top Mgt. resp. mean	2.80 (N = 10)	2.89 (N = 9)	3.20 (N = 10)	4.20 (N = 10)
Purchasing resp. mean	4.50 (N = 4)	5.00 (N = 4)	5.00 (N = 4)	6.25 (N = 4)
Average	3.65	3.95	4.10	5.23
T. Mgt.-Mfg. Interaction				
Overall Mean	3.06 (N = 69)	3.49 (N = 69)	3.70 (N = 69)	4.57 (N = 69)
Top Mgt. resp. mean	3.60 (N = 10)	4.50 (N = 10)	5.20 (N = 10)	5.40 (N = 10)
Mfg. resp. mean	3.00 (N = 5)	4.00 (N = 5)	5.60 (N = 5)	6.40 (N = 5)
Average	3.30	4.25	5.40	5.90
T. Mgt.-Q. A. Interaction				
Overall Mean	2.84 (N = 68)	3.01 (N = 68)	3.37 (N = 68)	4.28 (N = 68)
Top Mgt. resp. mean	3.30 (N = 10)	4.00 (N = 10)	4.20 (N = 10)	5.00 (N = 10)
Q. A. resp. mean	6.25 (N = 4)	7.25 (N = 4)	7.25 (N = 4)	7.75 (N = 4)
Average	4.78	5.63	5.73	6.38
T. Mgt.-Sales Interaction				
Overall Mean	3.91 (N = 68)	3.82 (N = 68)	3.57 (N = 68)	4.66 (N = 67)
Top Mgt. resp. mean	5.20 (N = 10)	4.40 (N = 10)	4.70 (N = 10)	5.40 (N = 10)
T. Mgt.-P. M. Interaction				
Overall Mean	5.32 (N = 63)	5.63 (N = 63)	5.41 (N = 63)	6.13 (N = 63)
Top Mgt. resp. mean	5.78 (N = 9)	7.00 (N = 9)	7.00 (N = 9)	7.56 (N = 9)
Project Mgt. resp. mean	5.14 (N = 14)	5.14 (N = 14)	4.71 (N = 14)	5.14 (N = 14)
Average	5.46	6.07	5.86	6.35

Table 4.3 (continued)

Overall, Individuals, and Average Interaction Means

	Stage Numbers			
	Stage 1	Stage 2	Stage 3	Stage 4
R&D-Finance Interaction				
Overall Mean	2.64 (N = 70)	3.17 (N = 70)	3.06 (N = 70)	2.81 (N = 70)
R&D resp. mean	2.60 (N = 10)	3.40 (N = 10)	3.40 (N = 10)	2.90 (N = 10)
Finance resp. mean	4.50 (N = 4)	4.00 (N = 4)	2.00 (N = 4)	3.00 (N = 4)
Average	3.55	3.70	2.70	2.95
R&D-Purch'g Interaction				
Overall Mean	3.47 (N = 68)	4.06 (N = 68)	4.12 (N = 68)	3.74 (N = 68)
R&D resp. mean	3.70 (N = 10)	4.90 (N = 10)	4.60 (N = 10)	4.20 (N = 10)
Purch'g resp. mean	5.25 (N = 4)	6.00 (N = 4)	6.50 (N = 4)	5.00 (N = 4)
Average	4.48	5.45	5.55	4.60
R&D-Mfg. Interaction				
Overall Mean	3.71 (N = 68)	4.25 (N = 68)	4.28 (N = 68)	4.68 (N = 68)
R&D resp. mean	4.20 (N = 10)	4.80 (N = 10)	5.10 (N = 10)	5.60 (N = 10)
Mfg. resp. mean	4.60 (N = 5)	4.80 (N = 5)	5.00 (N = 5)	5.40 (N = 5)
Average	4.40	4.80	5.05	5.50
R&D-Q. A. Interaction				
Overall Mean	3.37 (N = 67)	3.72 (N = 67)	3.90 (N = 67)	4.13 (N = 67)
R&D resp. mean	3.40 (N = 10)	3.40 (N = 10)	4.00 (N = 10)	3.90 (N = 10)
Q. A. resp. mean	7.00 (N = 4)	6.00 (N = 4)	6.75 (N = 4)	7.75 (N = 4)
Average	5.20	4.70	5.38	5.83
R&D-Sales Interaction				
Overall Mean	3.31 (N = 67)	3.25 (N = 67)	2.52 (N = 67)	2.94 (N = 66)
R&D resp. mean	5.00 (N = 10)	5.40 (N = 10)	3.10 (N = 10)	4.00 (N = 10)
R&D-P. Mgt. Interaction				
Overall Mean	5.24 (N = 62)	5.65 (N = 62)	5.27 (N = 62)	5.08 (N = 62)
R&D resp. mean	5.88 (N = 8)	6.13 (N = 8)	6.50 (N = 8)	5.88 (N = 8)
P. Mgt. resp. mean	4.00 (N = 14)	4.57 (N = 14)	4.14 (N = 14)	4.00 (N = 14)
Average	4.94	5.35	5.32	4.94
Fina.-Purch'g Interaction				
Overall Mean	2.59 (N = 68)	3.37 (N = 70)	4.15 (N = 71)	4.93 (N = 71)
Finance resp. mean	2.50 (N = 4)	3.50 (N = 4)	3.75 (N = 4)	4.50 (N = 4)
Purchasing resp. mean	3.00 (N = 2)	5.25 (N = 4)	7.00 (N = 4)	8.00 (N = 4)
Average	2.75	4.34	5.38	6.25
Finance-Mfg. Interaction				
Overall Mean	2.81 (N = 69)	3.24 (N = 68)	4.33 (N = 69)	5.06 (N = 69)
Finance resp. mean	2.33 (N = 3)	4.00 (N = 3)	3.67 (N = 3)	5.67 (N = 3)
Mfg. resp. mean	3.40 (N = 5)	4.20 (N = 5)	5.60 (N = 5)	6.40 (N = 5)
Average	2.87	4.10	4.64	6.04

Table 4.3 (continued)

Overall, Individuals, and Average Interaction Means

	Stage Numbers			
	Stage 1	Stage 2	Stage 3	Stage 4
Finan.-Q. A. Interaction				
Overall Mean	1.90 (N = 68)	2.36 (N = 67)	2.72 (N = 68)	3.21 (N = 68)
Finance resp. mean	3.33 (N = 3)	3.33 (N = 3)	3.67 (N = 3)	5.00 (N = 3)
Q. A. resp. mean	2.75 (N = 4)	2.75 (N = 4)	2.75 (N = 4)	2.75 (N = 4)
Average	3.04	3.04	3.21	3.88
Finan.-Sales Interaction				
Overall Mean	2.59 (N = 68)	2.27 (N = 67)	2.72 (N = 68)	3.40 (N = 67)
Finance resp. mean	3.33 (N = 3)	3.33 (N = 3)	3.33 (N = 3)	5.00 (N = 3)
Fina.-P. Mgt. Interaction				
Overall Mean	3.78 (N = 63)	4.48 (N = 62)	5.29 (N = 63)	5.81 (N = 63)
Finance resp. mean	6.00 (N = 3)	6.67 (N = 3)	6.67 (N = 3)	7.00 (N = 3)
Project Mgt. resp. mean	2.86 (N = 14)	3.43 (N = 14)	4.86 (N = 14)	5.14 (N = 14)
Average	4.43	5.05	5.77	6.07
Purch'g-Mfg. Interaction				
Overall Mean	3.42 (N = 71)	4.49 (N = 69)	5.79 (N = 71)	6.45 (N =71)
Purchasing resp. mean	6.00 (N = 4)	5.50 (N = 4)	7.50 (N = 4)	8.00 (N = 4)
Mfg. resp. mean	4.60 (N = 5)	5.60 (N = 5)	6.40 (N = 5)	6.40 (N = 5)
Average	5.30	5.55	6.95	7.20
Purch'g-Q. A. Interaction				
Overall Mean	2.96 (N = 68)	3.74 (N = 66)	5.10 (N = 68)	5.65 (N = 68)
Purchasing resp. mean	6.00 (N = 4)	5.50 (N = 4)	7.50 (N = 4)	8.00 (N = 4)
Q. A. resp. mean	3.75 (N = 4)	4.75 (N = 4)	6.75 (N = 4)	7.25 (N = 4)
Average	4.88	5.13	7.13	7.63
Purch'g-Sales Interaction				
Overall Mean	1.82 (N = 68)	2.03 (N = 66)	2.19 (N = 67)	2.62 (N = 65)
Purchasing resp. mean	2.75 (N = 4)\	3.00 (N = 4)	3.00 (N = 4)	3.67 (N = 3)
Purch'g-P. M. Interaction				
Overall Mean	3.54 (N = 63)	5.02 (N = 61)	5.78 (N = 63)	6.30 (N = 63)
Purchasing resp. mean	6.25 (N = 4)	7.00 (N = 4)	7.75 (N = 4)	7.75 (N = 4)
Sales resp. mean	3.14 (N = 14)	4.08 (N = 13)	5.43 (N = 14)	6.00 (N = 14)
Average	4.70	5.54	6.59	6.88
Mfg.-Q. A. Interaction				
Overall Mean	3.76 (N = 70)	4.49 (N = 68)	5.71 (N = 70)	6.87 (N = 70)
Mfg. resp. mean	4.60 (N = 5)	5.40 (N = 5)	6.00 (N = 5)	7.00 (N = 5)
Q. A. resp. mean	5.00 (N = 4)	6.00 (N = 4)	8.50 (N = 4)	9.00 (N = 4)
Average	4.80	5.70	7.25	8.00

Table 4.3 (continued)

Overall, Individuals, and Average Interaction Means

	Stage Numbers			
	Stage 1	Stage 2	Stage 3	Stage 4
Mfg.-Sales Interaction				
Overall Mean	1.99 (N = 68)	2.12 (N = 66)	2.53 (N = 68)	3.49 (N = 67)
Mfg. resp. mean	1.80 (N = 5)	2.00 (N = 5)	2.20 (N = 5)	4.00 (N = 5)
Mfg.-P. Mgt. Interaction				
Overall Mean	4.00 (N = 63)	5.18 (N = 61)	6.17 (N = 63)	6.89 (N = 63)
Mfg. resp. mean	2.67 (N = 3)	3.67 (N = 3)	5.67 (N = 3)	5.67 (N = 3)
Proj. Mgt. resp. mean	3.57 (N = 14)	4.85 (N = 13)	5.71 (N = 14)	6.43 (N = 14)
Average	3.12	4.26	5.69	6.05
Q. A.-Sales Interaction				
Overall Mean	1.88 (N = 69)	2.00 (N = 66)	2.26 (N = 68)	3.32 (N = 68)
Q. A. resp. mean	2.25 (N = 4)	1.75 (N = 4)	1.75 (N = 4)	3.25 (N = 4)
Q. A.-P. Mgt. Interaction				
Overall Mean	3.89 (N = 62)	4.44 (N = 59)	5.06 (N = 62)	6.16 (N = 62)
Q. A. resp. mean	7.00 (N = 4)	8.50 (N = 4)	8.50 (N = 4)	9.00 (N = 4)
Project Mgt. resp. mean	3.31 (N = 13)	3.73 (N = 11)	3.92 (N = 13)	5.15 (N = 13)
Average	5.16	6.12	6.21	7.08
Sales-P. Mgt. Interaction				
Overall Mean	3.77 (N = 64)	4.39 (N = 59)	4.31 (N = 64)	5.22 (N = 63)
Project Mgt. resp. mean	3.79 (N = 14)	4.27 (N = 11)	3.29 (N = 14)	4.23 (N = 13)

4.2 One-Way Analysis of Variance

The statistical technique to test the null hypothesis that several population means are equal is called analysis of variance (ANOVA). This technique examines the variability of the observations within each group as well as the variability between the group means. On the basis of these two estimates of variability, a conclusion is drawn about the population means. SPSS for Windows contains two different analysis-of-variance procedures (Norusis, 1992): One-Way ANOVA and Simple Factorial ANOVA. A one-way analysis of variance is needed when only one variable is used to classify the cases into the different groups. In this study, one variable is used at a time to use a one-way analysis of variance procedure. A one-way analysis of variance procedure is applied for the following cases:

1) to analyze the variance for involvement of each department across four stages of the product design,
2) to analyze the variance for involvement at each stage of the product design among ten departments of a company,
3) to analyze the variance for interaction of each pair of departments across four stages of the product design, and
4) to analyze the variance for interaction at each stage of the product design for each pair of departments.

4.2.1 Assumptions Needed for Analysis of Variance

Analysis of variance procedure requires the following assumptions:

1) Each of the groups is an independent random sample from a normal population,
2) in the population, the variances of the groups are equal, and

3) the observations are all independent of one another.

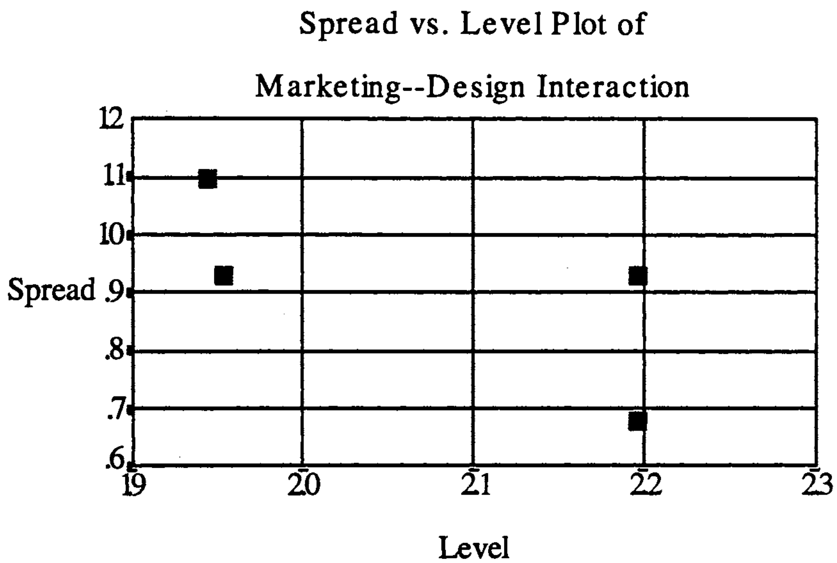
To test the null hypothesis that the groups come from a population with the same variance, a Levene test can be used. If the observed significance level is small (usually < 0.05), one can reject the null hypothesis that all variances are equal. If the observed significance is large (> 0.05), one cannot reject the null hypothesis. This means there is no sufficient evidence to suspect that the variances are unequal.

4.2.2 Determining the Transformation

A power of transformation is frequently used to stabilize variances. A power of transformation raises each data value to a specified power. For example, a power transformation of 2 squares all of the data values. A transformation of 1/2 calculates the square root of all the values. To determine an appropriate power for transforming data, the log of the median for each group is plotted against the log of the inter quartile range. Figure 4.1. shows such a plot for the marketing -- design interaction by stages.

From the slope of the line, the power value is estimated. The power is obtained by subtracting the slope from 1. That is, Power = 1 - slope.

Although this formula can result in all sorts of powers, for simplicity and clarity the closest powers that are multiples of 0.5 should be chosen.



*Plot of Natural Log of Spread vs Natural Log of Level
Slope = -.807 Power for transformation = 1.807

Figure 4.1. Spread vs. Level Plot of Marketing--Design Interaction

4.2.3 Violations of Assumptions, The Welch Procedure

There are alternative ways if one wants to avoid the transformation of the data to deal with the heterogeneity of variance. Wilcox (1987b) recommends the Welch procedure (Welch 1951) with samples having different variances, especially when the sample sizes are equal. Tomarken and Serlin (1986) have investigated the robustness and power of Welch's procedure and have shown Welch's procedure to perform well under several conditions. This research has used Welch's procedure to adjust F values. This procedure calculates adjusted F statistics by using the following formulae:

$$w_i = \frac{n_k}{s_k^2} \quad \text{......................................(4.1)}$$

$$\overline{X}' = \frac{\sum w_i * \overline{X}_i}{\sum w_i} \quad \text{................................(4.2)}$$

$$F'' = \frac{\dfrac{\sum w_i * (\overline{X}_i - \overline{X}')^2}{i-1}}{1 + \dfrac{2(k-2)}{k^2-1} \sum (\dfrac{1}{n_i - 1})(1 - \dfrac{w_i}{\sum w_i})^2} \quad \text{......(4.3)}$$

The statistic (F") is approximately distributed as F on k-1 and df' degrees of freedom, where

$$df' = \frac{k^2 - 1}{3 \sum (\dfrac{1}{n_i - 1})(1 - \dfrac{w_i}{\sum w_i})^2} \quad \text{.................(4.4)}$$

4.2.4 Multiple Comparison Procedures

A significant F value tells only that the population means are probably not all equal. It does not tell which pairs of groups appear to have different means. The null hypothesis is rejected even if any two means are unequal. There is the need to use special tests called multiple comparison procedures to determine which means are significantly different from each other. Many multiple comparison procedures are available. They differ in how they adjust the observed significance level. "Tukey's Honestly Significant Test" is shown below. An asterisk marks a pair of means that are different at the 0.05 level. The differences are marked only once, in the lower diagonal of the table. If the significance level is greater than 0.05, the space is left blank.

Multiple Comparison Test for marketing Involvement by Stages

Multiple Range Tests: Tukey-HSD test with significance level .050

The difference between two means is significant if

MEAN(J)-MEAN(I) >= 1.5186 * RANGE * SQRT(1/N(I) 1/N(J))

with the following value(s) for RANGE: 3.67

(*) Indicates significant differences which are shown in the lower triangle

Mean	STAGENO	Stg 3	Stg 4	Stg 2	Stg 1
4.8545	Stage 3				
4.9455	Stage 4				
6.5741	Stage 2	*	*		
7.9808	Stage 1	*	*	*	

4.3 Results of Department Involvement

The results of a one-way analysis of variance are displayed in Table 4.4 and Table 4.5. Table 4.4 displays mean involvement values for different departments across four stages of the product design. Table 4.4 also displays F statistics and p values given by the one-way analysis of variance procedure. Wherever Levene test indicated violation of assumption of equal variance, the Welch procedure is adopted to adjust F statistics and p values. Figure 4.2 shows the same results graphically.

Table 4.4

Results of One-Way Analysis of Variance for Department Involvement

Departments	Stage 1	Stage 2	Stage 3	Stage 4	F Stat	p Value
Marketing	7.971	6.472	5.056	4.833	*42.497	0.000
Design	7.348	8.696	8.754	7.826	*17.182	0.000
Top Mgt.	5.437	4.930	4.394	4.817	2.555	0.055
R. & D.	6.543	6.986	6.271	5.700	*2.894	0.102
Finance	2.829	3.352	4.329	4.352	*9.134	0.000
Purchasing	2.916	4.014	6.085	6.338	*53.629	0.000
Manufacturing	3.916	5.254	6.634	8.362	*96.382	0.000
Qua. Assur.	3.414	4.086	5.371	6.943	*32.368	0.000
Sales	5.211	4.352	3.690	4.479	4.647	0.003
Pro. Mgt.	6.333	6.879	7.262	7.831	*6.857	0.002
F Statistic	*77.193	*132.058	*100.133	*44.732	'*' indicates the	
p Value	0.000	0.000	0.000	0.000	adjusted F value.	

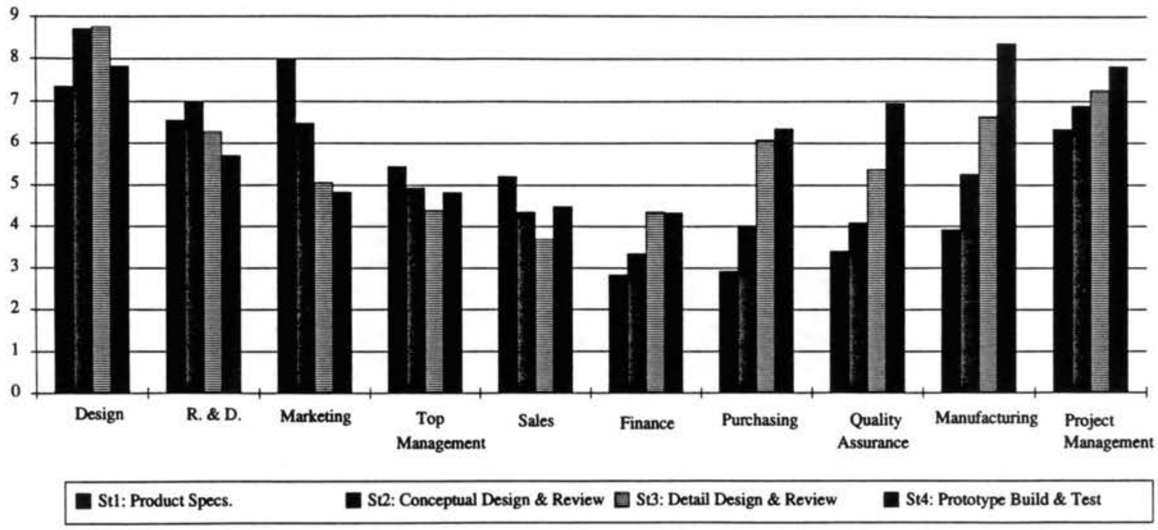


Figure 4.2. Comparison of Different Departments' Involvement Across Four Stages

4.3.1 Discussion of Results on Department Involvement

Hypothesis 1 states that within each stage of the CE product design process, the levels of involvement will vary significantly across departments. The ANOVA results in Table 4.4 show support for hypothesis one which states that for a given stage involvement in the concurrent engineering design process varies across departments. Observe in Table 4.4 that F = 77.19, 132.06, 100.13, and 44.73 in stages one through four respectively, and p=0.000 in each case. Further analysis, using Tukey's test, shows that design, marketing, research and development, top management, and Project Management are significantly more involved in stage one (product specification) than are the other five departments. At stage two (conceptual design & evaluation) Manufacturing increases its involvement to join the original five departments, while finance, Purchasing, Quality Assurance, and Sales remain on the periphery of the design team. The marketing and top management's involvement drop to their lowest levels in the third stage (detail design and evaluation), while Purchasing and Quality Assurance join the core group of significantly involved departments. Though the fourth stage (prototype build & test) finds finance and

Sales' involvement increasing, the level is not significant when compared to that of design, research and development, Purchasing, Manufacturing, Quality Assurance, and Project Management. In addition, marketing and top management are now only moderately involved in the process. Examining Table 4.4 and figure 4.2. at a glance show that design, research and development, and project management occupy core positions, while finance and Sales occupy periphery positions throughout the design process.

Hypothesis 2 states that each department's involvement in the CE product design process will vary significantly across the four stages of the product design process. The ANOVA results in Table 4.4 show support for hypothesis 2. Only two exceptions to this result exist. Observe in Table 4.4 that top management is consistently involved at the 4.39 to 5.44 range and research and development is consistently involved at the 5.70 to 6.99 level. This consistency indicates that top management always needs to know what is taking place in the new product design, though their involvement decreases relative to other departments in the later stages of the process. Other interesting results indicate that marketing's involvement, which was the highest of any departments at stage one, drops significantly by stage three. This suggests that market inputs may drive product specifications for successful new products, while only support input may be needed from marketing by the detail design and prototype build stages. Though the design department is one of three core team members throughout the design process, its involvement increases significantly from stage one to stage two where they dominate the design effort until stage four. The Manufacturing department dominates the design process in stage four (prototype build and test) after only minimal involvement in stage one and a steady increase throughout the process. Combining these results with those from the Purchasing department (involvement rising steadily from stage one at 2.92 to stage four at 6.34) and those from Quality Assurance (involvement rising steadily from 3.41 at stage one to 6.94 at stage four) suggests that supplier inputs, adherence to specifications, and manufacturing processes play major roles in the completion of a new product design. Project Management, the third core team member throughout the design process, also increases their involvement significantly, though gradually, from stage one through stage four. During the stages when the departments are highly involved in the design process, one would expect that their information needs and communication with other departments would also be high. This phenomenon is examined in the next sections.

4.4 Results of Department Interactions

Table 4.5 displays mean interaction values for different pairs of departments across the four stages of the product design. Table 4.5 also displays F statistics and p values given by the One-Way Analysis of Variance procedure. Wherever the Levene test indicated a violation of the assumption of equal variance, the Welch procedure is adopted to adjust F statistics and p value.

The results displayed in Table 4.4 and Table 4.5 can be shown graphically in network diagrams 4.3., 4.4., 4.5., and 4.6. Each department is shown by a circle. The size of the circle depends upon the mean level of involvement of the department at that stage. The thickness of the line between two departments depends upon the mean level of interaction for the pair at that stage. In addition figure 4.3 through figure 4.6 simultaneously capture the centrality of each department in the network and the overall density of the network at each of these stages.

Table 4.5

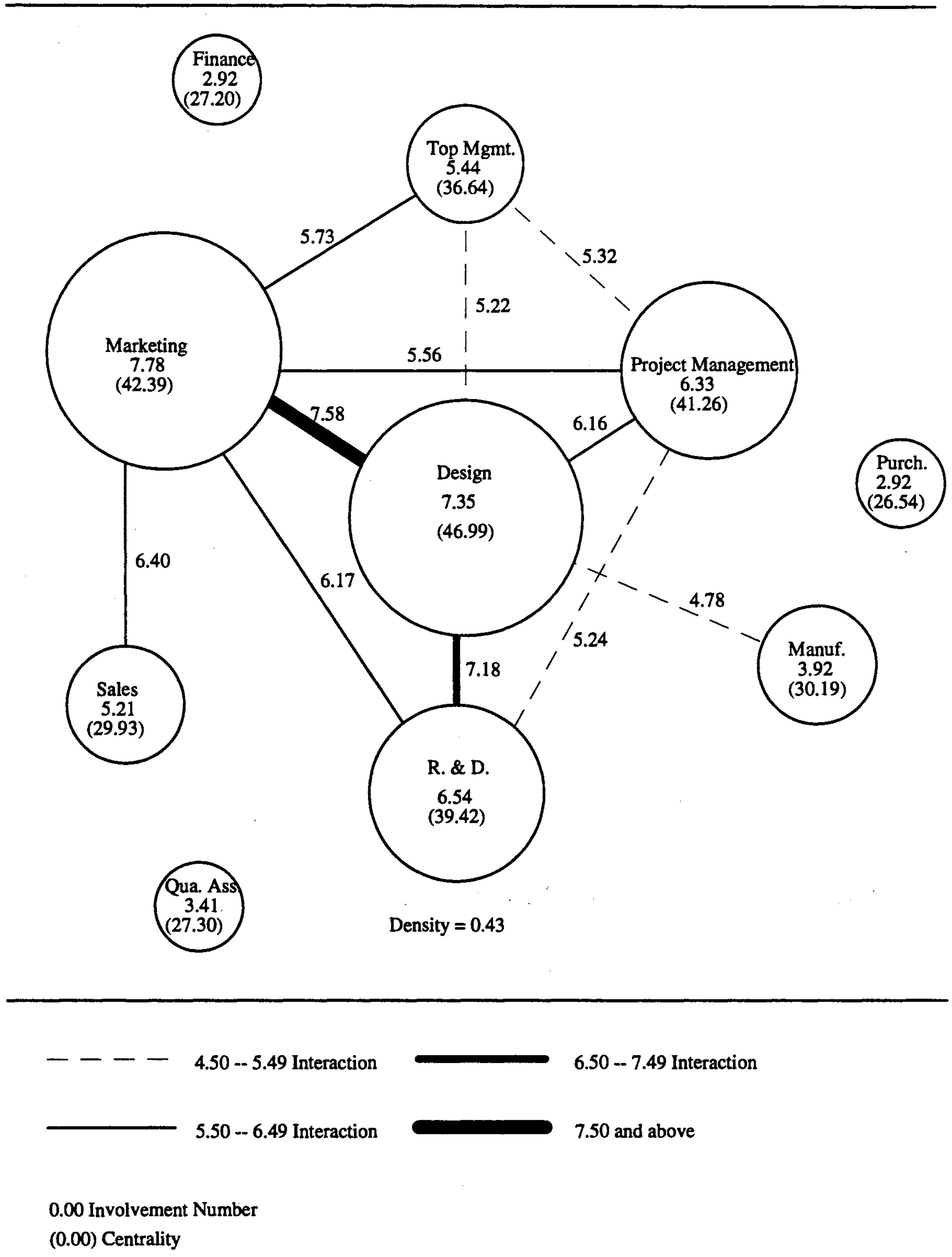
Results of One-Way Analysis of Variance for Department Interactions

Department Pair	Stage 1	Stage 2	Stage 3	Stage 4	F Stat	p value
Mktg.--Design	7.582	7.271	5.971	5.743	12.643	0.000
Mktg.--T. Mgt.	5.729	5.843	4.900	5.129	*2.666	0.050
Mktg.--R. & D.	6.174	5.870	4.841	4.377	7.291	0.000
Mktg.--Finance	3.529	3.457	3.729	3.857	0.496	0.685
Mktg.--Purch	2.143	2.514	2.543	2.957	2.577	0.054
Mktg.--Manuf.	2.662	2.814	3.114	4.200	*6.147	0.001
Mktg.--Qu. Ass.	2.623	2.536	2.870	3.638	4.142	0.006
Mktg.--Sales	6.397	5.750	5.382	5.927	1.639	0.180
Mktg.--Pr. Mgt.	5.563	5.828	6.000	6.469	1.318	0.268
Design--T. Mgt.	5.217	5.362	4.681	5.000	1.060	0.366
Design--R&D.	7.182	6.970	6.424	5.985	*2.743	0.045
Design--Finance	3.463	3.776	4.358	4.254	2.468	0.062
Design--Purch.	4.269	5.015	6.090	6.045	10.105	0.000
Design--Manuf.	4.776	5.448	6.687	7.515	24.286	0.000
Design--Q. Ass.	4.076	4.303	5.530	6.258	12.045	0.000
Design--Sales	4.260	4.390	3.970	4.110	0.362	0.780
Design--P. Mgt.	6.161	7.081	7.355	7.323	*3.316	0.022
T Mgt.--R&D.	4.329	4.443	3.629	3.500	3.012	0.030
T. Mgt.--Finance	3.899	4.073	4.333	4.739	1.548	0.202
T Mgt.--Purch.	2.333	2.721	3.029	3.507	4.564	0.003
T Mgt.--Manuf.	3.058	3.493	3.696	4.565	*5.642	0.001
T Mgt.-Q. Ass.	2.838	3.015	3.368	4.279	5.621	0.000
T Mgt.--Sales	3.912	3.824	3.574	4.657	2.605	0.052

Table 4.5 (continued)

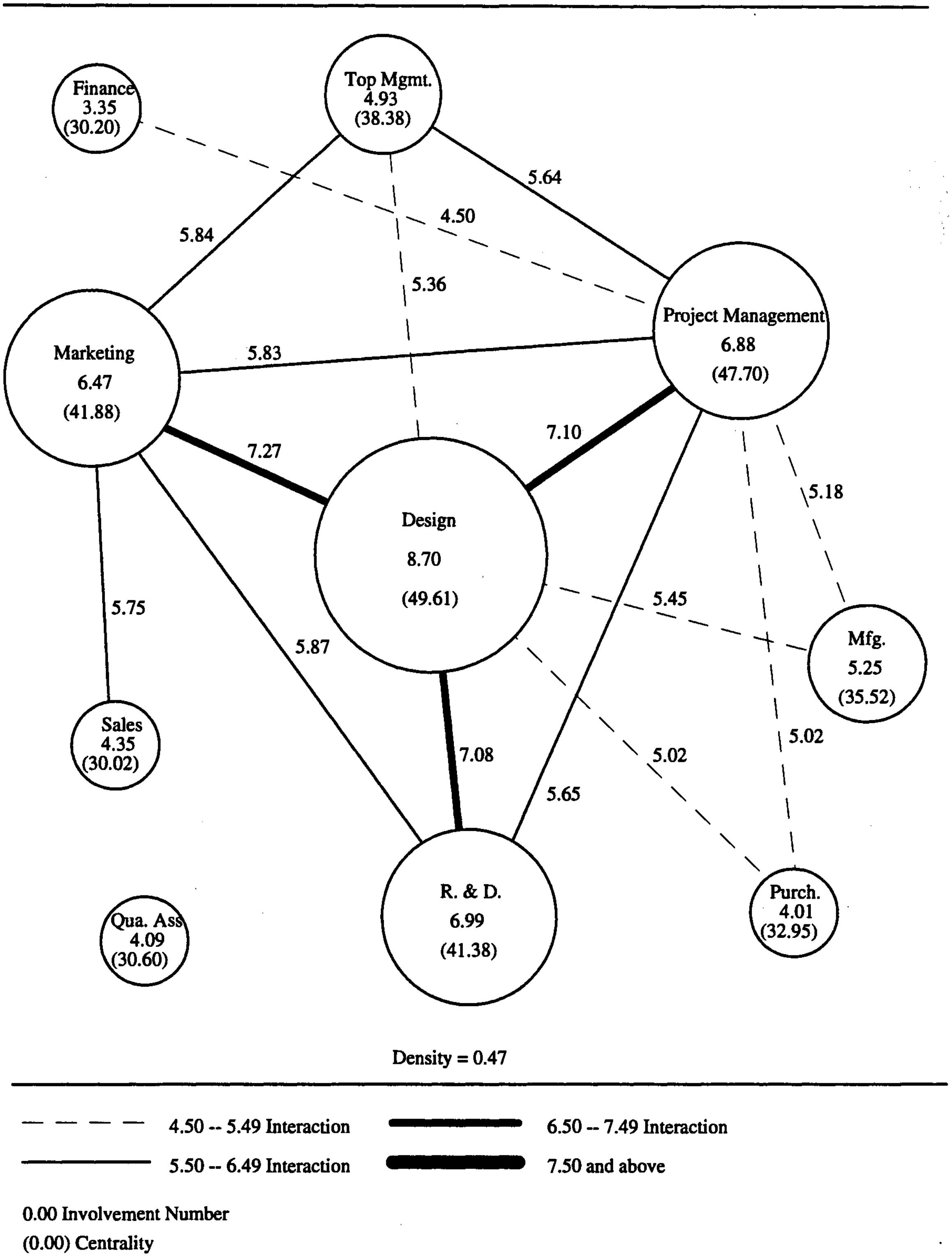
Results of One-Way Analysis of Variance for Department Interactions

T Mgt.--P. Mgt.	5.318	5.635	5.413	6.127	1.259	0.289
R&D--Finance	2.643	3.171	3.057	2.814	0.969	0.408
R&D--Purch'g	3.471	4.059	4.118	3.735	1.149	0.329
R&D--Mfg.	3.706	4.250	4.279	4.677	*1.793	0.151
R&D--Q. Assur.	3.373	3.716	3.896	4.134	1.072	0.361
R. & D.--Sales	3.310	3.250	2.520	2.940	1.877	0.133
R&D.--Pr. Mgt.	5.242	5.645	5.274	5.081	0.481	0.696
Finance--Purch'g	2.588	3.371	4.155	4.930	*16.030	0.000
Finance--Mfg.	2.812	3.235	4.333	5.058	*13.621	0.000
Finance--Q. A.	1.897	2.358	2.721	3.206	*7.030	0.000
Finance--Sales	2.558	2.269	2.721	3.403	*3.257	0.023
Finance--P. Mgt.	3.778	4.484	5.286	5.810	7.847	0.000
Purch'g--Mfg.	3.423	4.493	5.789	6.451	23.108	0.000
Purch'g--Q. A.	2.956	3.742	5.103	5.647	*16.084	0.000
Purch'g--Sales	1.824	2.030	2.194	2.615	3.092	0.027
Purch'g--P. Mgt.	3.540	5.016	5.778	6.302	*15.657	0.000
Mfg.--Q. A.	3.757	4.485	5.714	6.871	22.296	0.000
Mfg.--Sales	1.985	2.121	2.529	3.493	*6.279	0.000
Mfg.--P. Mgt.	4.000	5.180	6.175	6.889	17.992	0.000
Q. A.--Sales	1.884	2.000	2.362	3.324	*6.660	0.000
Q. A.--P. Mgt.	3.887	4.441	5.065	6.161	8.291	0.000
Sales--Pr. Mgt.	3.766	4.390	4.313	5.222	3.3000	0.021
F Statistic	*35.97	*31.06	*28.64	*23.29	'*' indicates the	
p Value	0.000	0.000	0.000	0.000	adjusted F value.	



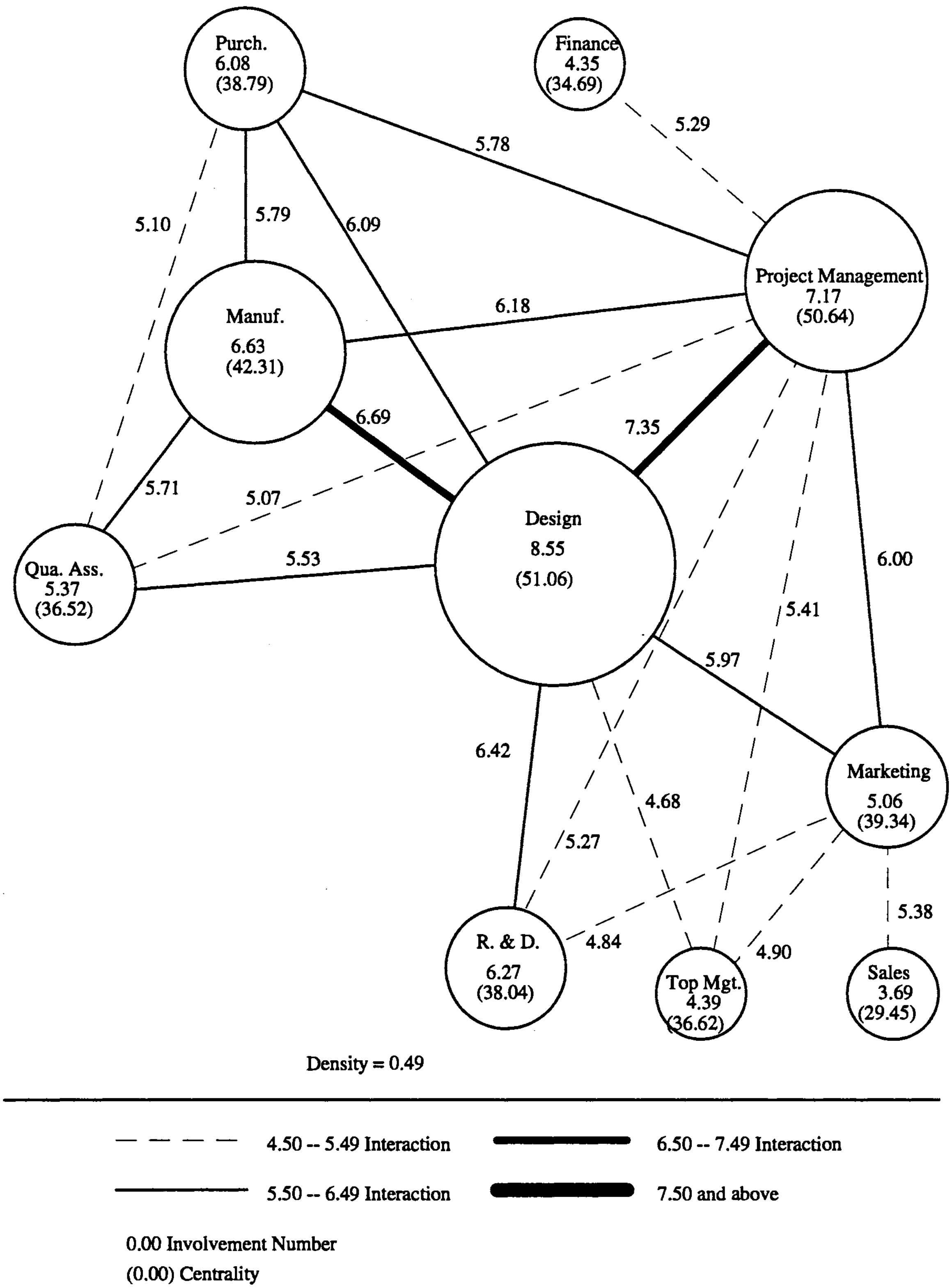
*Note: Interactions below moderate levels are not shown.

Figure 4.3. Stage 1 (Product Specification Stage) Interactions



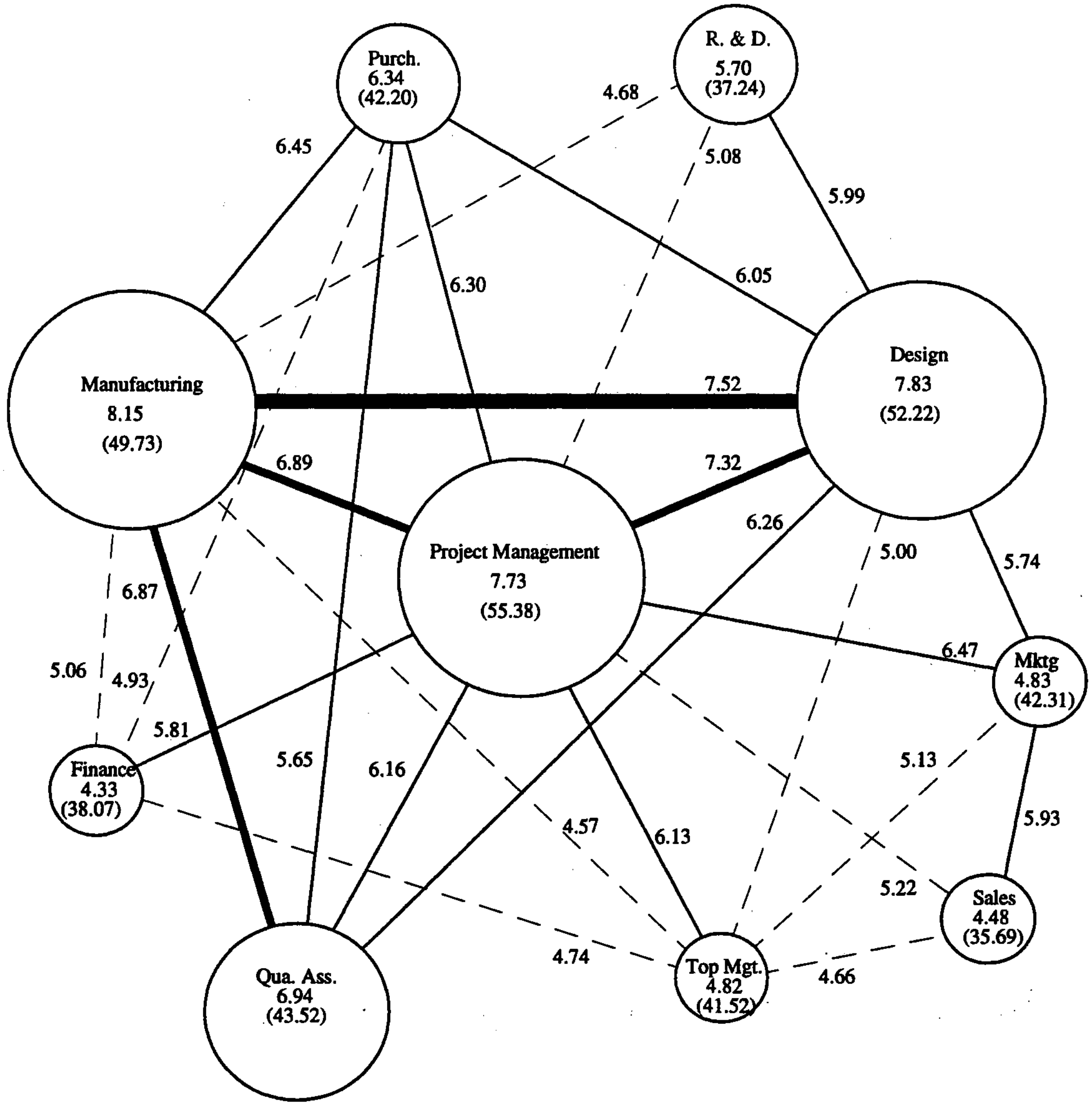
*Note: Interactions below moderate levels are not shown.

Figure 4.4. Stage 2 (Conceptual Design and Review Stage) Interactions



*Note: Interactions below moderate levels are not shown.

Figure 4.5. Stage 3 (Detail Design and Review Stage) Interactions



Density = 0.54

4.50 -- 5.49 Interaction

6.50 -- 7.49 Interaction

5.50 -- 6.49 Interaction

7.50 and above

0.00 Involvement Number
(0.00) Centrality

*Note: Interactions below moderate levels are not shown.

Figure 4.6. Stage 4 (Prototype Build and Test Stage) Interactions

4.4.1 Discussion of Results on Department Interactions

Hypothesis 3 states that within each stage of the CE product design process, the levels of interaction will vary significantly across different pairs of departments. The ANOVA results in Table 4.5 show support for hypothesis 3. Observe in Table 4.5 that F=35.97, 31.06, 28.64, and 23.29 in stages one through four respectively, and p=0.000 in each case. A further analysis, using Tukey's test, shows that design, marketing, research and development, top management, and Project Management have significantly more interaction with each other in stage one (product specification) than with other five departments. Sales has a noticeable interaction with marketing at this stage but not with any other departments. At stage two (conceptual design & evaluation) Purchasing and Manufacturing increase their interaction with design and Project Management. Sales interaction with marketing drops but is still at high level. Though still major players in the design process, marketing and top management's interactions drop to their lowest levels in the third stage (detail design and evaluation), while Manufacturing, Purchasing and Quality Assurance join design and Project Management to have significantly more interaction with each other. Though the fourth stage (prototype build & test) finds finance and Sales' interactions with other departments increasing, the level is not significant when compared to interactions among design, Purchasing, Manufacturing, Quality Assurance, and Project Management.

Hypothesis 4 states that the levels of the interaction between different pairs of departments will vary significantly across the four stages of the CE product design process. Examining the department dyadic communication interactions across the four product design stages in Table 4.5 shows support for hypothesis 4. Observe in Table 4.5 that the level of 28 of the 45 dyadic interactions between departments change significantly ($p < 0.05$) across the four design stages while only 17 of the dyadic interaction levels remain stable ($p > 0.05$). By examining those linkages which remain low, high, and change across the four stages, one can gain insight in to the information system requirements for each department. Observe in Table 4.5 that the design department and the project management department hold the highest levels of interaction throughout the design process, though the design department's interactions with marketing and research and development decrease over time while their interactions with Manufacturing, Purchasing, and Quality Assurance increase throughout the design process. On the basis of communication interaction, these departments require and extend the greatest amount of information regarding new product design. However, the timing of their communication needs varies with the progress of the design.

The research and development department has a particularly interesting communication pattern. Observe in Table 4.5 that the research and development department maintains a constant low level of communication with top management, finance, Purchasing, Manufacturing, Quality Assurance, and Sales throughout the design process. This phenomenon is noteworthy because research and development plays a major role in the design process. However, much of their information is filtered through the design, marketing, and Project Management departments, with whom they hold moderate to very high communication interactions.

Top Management maintains moderate to high levels of communication with design, Project Management, and marketing, three of the core team members. Observe in Table 4.5 that their interaction with other departments is low and rising very slowly throughout the design process. This suggests that top management may require more information from these peripheral departments in the very late phases of the overall new product development process.

Table 4.5 also shows that the finance department's interaction with all other departments rises gradually throughout the design process. However, with the exception of Purchasing, Manufacturing and Project Management, in the later stages of the design process, their interaction remains below the moderate level, suggesting that their primary need for information emerges in later phases of the overall new product development process.

Hypothesis 5 states that the network density will increase from stage one (product specification stage) through stage four (prototypes build and test) of the CE product design process. Observe the network diagrams in Figures 4.3. through 4.6. for network density values. Density is the measure of actual communication linkages in a network relative to the total possible linkages in the network (Knoke and Kuklinski 1982). Density values calculated by using this definition provide support for hypothesis five. The density level, listed in Figure 4.3. at 0.43, indicates that less than half of the possible linkages exist during stage one of the design process. Observe in Figure 4.4. through Figure 4.6. that density in the network gradually increases to 0.47 in stage two, 0.49 in stage three, and to 0.54 in stage four. Consistent with studies of the broader new product development process (for example, Hutt, et al., 1988), this result suggests that demands on the communication network increase gradually both within and across the phases of the new product development process.

Hypothesis 6 states that the design department will have the highest level of centrality at each stage in the concurrent engineering design process. Centrality is measured by a count of the direct communication links (interactions) between one department and all other departments (Freeman, 1979). The analysis was conducted using the mean interaction levels for each department reported by respondents. Centrality for a department is then determined by the sum of the mean interactions it has with all other departments. Centrality for each department is presented in parentheses in Figure 4.3. through Figure 4.6. The network diagrams have been drawn to show the most central departments in the center of the figure.

Hypothesis six predicts that the design department will occupy the central position in the network throughout the design phase of the new product development process. Centrality values provide support for this hypothesis through the first three stages of the design process. However, in stage four the Project Management department becomes the most central department, with the design department falling to second place.

4.5 Validated Model of CE Design Communication

Based on the results of statistical analysis displayed in Tables 4.3 and 4.4, the concurrent engineering design communication model shown in Figure 3.1 can be validated. This model identifies four stages in the engineering design process. Stage one involves the formulation of detailed product specifications. Stage two involves conceptual design and review. Stage three involves a detail design and an evaluation of the detail design in a tightly coupled iterative process. The design phase of the NPD process concludes with the successful building and testing of a product prototype. Failure in the prototype build and test stage requires recycling to the detail design stage.

Figure 3.1 shows the involvement of all departments that can provide vital information and be party in the design decision-making process at each stage. The involvement depends upon the role of each department at different stages of the engineering design and the information that each department can bring to help the design group make the right decisions very early. The model identifies involvement by just listing various departments at each stage of the product design process. There is no quantitative measure identifying an exact level of involvement for the departments shown at each stage. A statistical analysis of the first page of the questionnaire determines this mean involvement level. The model shows the interaction of possible departments with the design department at each stage. The design department is shown occupying central position at each stage. The amount of interaction by various departments with the design department can vary. The predicted degree of interaction is shown by the varying thicknesses of arrows with a thick arrow depicting much interaction and a thin arrow depicting less interaction. The model in Figure 3.1 shows only the interaction of different departments with the design department. In concurrent engineering product development, departments interact with each other in addition to interacting with the design department, measured by the second page of the questionnaire. The model in Figure 3.1 also does not show the centrality of each department at each stage nor the density of the network at each stage.

The validated model is shown in Figure 4.7. In this model, each department is shown by a circle. The size of the circle depends upon the mean level of involvement of the department at that stage. The thickness of the line between two departments depends upon the mean level of interaction for the pair at that stage. In order to have more clarity in the model, only interactions above a 4.5 value are shown. In addition, the model shows the centrality of each department and the overall density of the communication network at each of these stages. The validated model clearly identifies the most central department at each of these stages. Thus this validated model should answer two of the three research questions posed earlier in the section 3.1.2 of chapter 3: i) What role does each department play during each stage of the product design process? and ii) How much interaction takes place among the various departments during each stage of the design process? The third question, "What information is exchanged among various departments during each stage of the design process?" is difficult to answer using this model. However, it is intuitively obvious that the departments having higher levels of involvement and higher levels of interaction with other departments will either send or receive more information than departments having moderate and low levels of involvement and interaction.

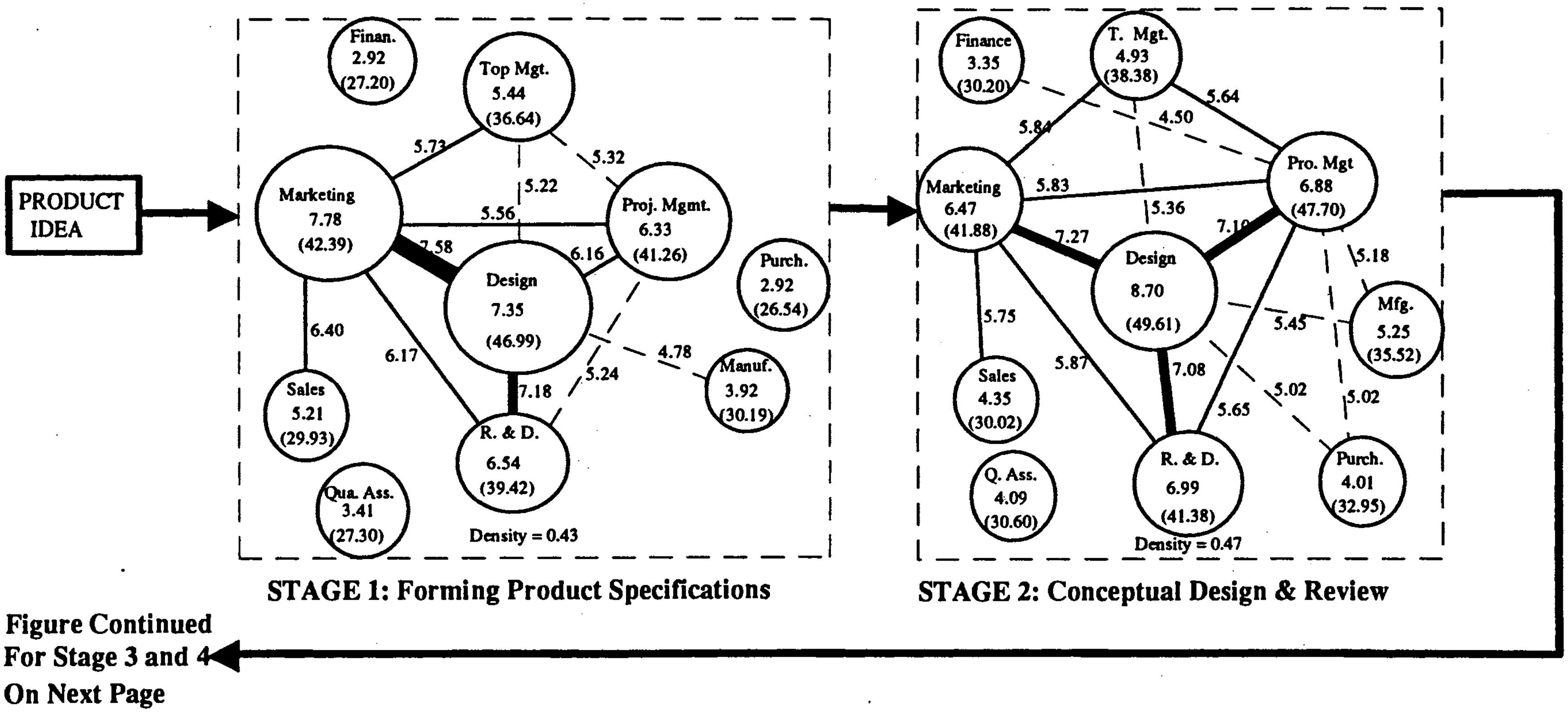


Figure 4.7. Validated Communication Model for Concurrent Engineering Design

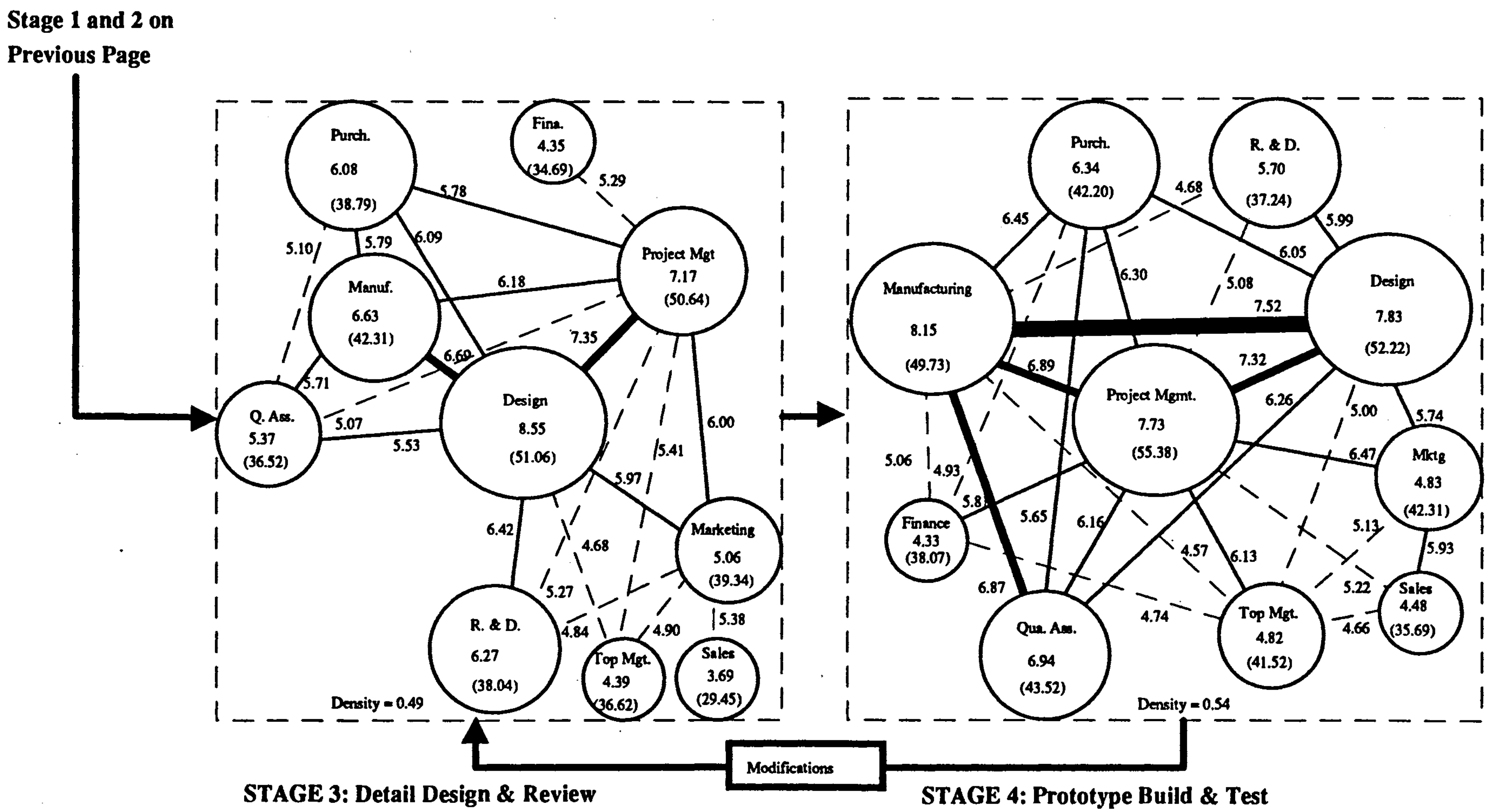


Figure 4.7. Validated Communication Model for Concurrent Engineering Design (Continued from previous page)

4.6 Results of Information Category Exchange

Table 4.6 displays analysis results of information exchange for different departments during each stage in the product design process. On page three of the questionnaire, each cell of the table had four numbers either circled or not circled. If the number was circled, then it was assigned value of '1' and if it was not circled then it was assigned value of '0'. The percentage of responses with circled numbers was determined. Then an upper critical cut-off point was determined (Tull and Hawkins, 1980). If the percentage of responses with circled numbers was found to be above this upper critical value, then the corresponding department either received or delivered detailed information about the corresponding category at a given stage. Similarly, on the lower side, another cut-off point was determined. This lower cut-off point helped to determine whether the percentage of responses was significantly different from a '0' value. If the percentage was found to be within the bounds of lower and upper critical values, then it indicated that the corresponding department either received or delivered summary information about the related category at a given stage. If the percentage was found below lower critical value, then it indicated that no information was exchanged by the corresponding department at a given stage.

4.6.1 A Discussion of the Results of an Information Category Exchange

Hypothesis 7 states that for each stage of the concurrent engineering design process, departments having high involvement in the design process will exchange more detailed information than departments having moderate and low involvement. The results displayed in Table 4.6 show support for hypothesis 7. Observe in Figure 4.2 that the design and Project Management departments have a high level of involvement through all

Table 4.6

Information Category Exchange Requirements for Different Departments at Four Stages in the Product Design

Information Categories	Marketing	Design	Top Mgt.	R. & D.	Finance/ Accounting	Purchasing	Manufa- cturing	Quality Assurance	Sales	Project Mgt.
Company goals & policies	1 2 3 4 D S S S	1 2 3 4 D D S S	1 2 3 4 D S S S	1 2 3 4 D S S S	1 2 3 4 D S S S	1 2 3 4 S S S S	1 2 3 4 S S S S	1 2 3 4 D S S S	1 2 3 4 D S S S	1 2 3 4 D S S S
Budget for new product	1 2 3 4 D S S S	1 2 3 4 D D S S	1 2 3 4 D D S S	1 2 3 4 D D S S	1 2 3 4 D S S S	1 2 3 4 S S S S	1 2 3 4 S S S S	1 2 3 4 S S S S	1 2 3 4 S S S S	1 2 3 4 D D D D
Capital investment in tools & technologies	1 2 3 4 S S S S	1 2 3 4 S D D S	1 2 3 4 D S S S	1 2 3 4 S S S S	1 2 3 4 D S D D	1 2 3 4 S S S S	1 2 3 4 S S D D	1 2 3 4 S S S S	1 2 3 4 S S N S	1 2 3 4 S S D D
Consumer preferences & needs	1 2 3 4 D D S S	1 2 3 4 D D S S	1 2 3 4 D S S S	1 2 3 4 D S S S	1 2 3 4 S S S S	1 2 3 4 S S S S	1 2 3 4 S S S S	1 2 3 4 S S S S	1 2 3 4 D S S D	1 2 3 4 D D S S
Product mix and synergy	1 2 3 4 D D S S	1 2 3 4 S D S S	1 2 3 4 D S S S	1 2 3 4 S S S S	1 2 3 4 S S S S	1 2 3 4 S S S S	1 2 3 4 S S S S	1 2 3 4 S S S S	1 2 3 4 D S S D	1 2 3 4 D S D S
Forecast of sales volume, revenue, gross margins	1 2 3 4 D D S S	1 2 3 4 S S S S	1 2 3 4 D S S D	1 2 3 4 S S S S	1 2 3 4 S S D D	1 2 3 4 S S S S	1 2 3 4 S S D D	1 2 3 4 S S S S	1 2 3 4 D D S D	1 2 3 4 D D S D
Dimensional, material, funct. & modularity	1 2 3 4 S S S S	1 2 3 4 D D D D	1 2 3 4 S S S S	1 2 3 4 D D S S	1 2 3 4 S S S S	1 2 3 4 S S S S	1 2 3 4 S D D D	1 2 3 4 S S D S	1 2 3 4 S S S S	1 2 3 4 S D D D
Product maintenance, repair ease of assemb\disassm	1 2 3 4 S S S S	1 2 3 4 S D D D	1 2 3 4 S S S S	1 2 3 4 S S S S	1 2 3 4 N N S S	1 2 3 4 N S S S	1 2 3 4 S D D D	1 2 3 4 S S D S	1 2 3 4 S S S S	1 2 3 4 S D D D
Mfg. process issues: layout, capacities, schedule	1 2 3 4 S S S S	1 2 3 4 S D D D	1 2 3 4 S S S S	1 2 3 4 S S S S	1 2 3 4 S S S S	1 2 3 4 S S S S	1 2 3 4 S D D D	1 2 3 4 S S D D	1 2 3 4 S S S S	1 2 3 4 S D D D

Table 4.6 (continued)

Information Category Exchange Requirements for Different Departments at Four Stages in the Product Design

Information Categories	Marketing	Design	Top Mgt.	R. & D.	Finance/ Accounting	Purchasing	Manufa-cturing	Quality Assurance	Sales	Project Mgt.
Quality & reliability issues:	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
quality of supplier's parts	S S S S	S D D D	S S S S	S S S S	S S S S	S S D D	S S D D	S D D D	S S S S	S D D D
Safety issues: e.g., safety of	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
product, processes & oper.	S S S S	S D D D	S S S D	S D S S	S S S S	S S S S	S S D D	S S D D	S S S S	S D D D
Environmental pollution,	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
disposal & recycl'ty issues	S S S S	S D S S	S S S S	S S S S	S S S S	S S S S	S S D D	S S S S	S S S S	S S S D
Labor issues	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
	S S N S	S S S S	S S S D	S S S S	S S S S	S S S S	S S D D	S S S S	S N N S	S S S D
Availability, quality and	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
cost of parts & materials	S S S S	S D D D	S S S S	S S S S	S S S S	S D D D	S S D D	S S D D	S S S S	S D D D
Product scheduling	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
& time to the market	D D D D	S D D D	D D S D	S S S S	S S S S	S S S D	S S D D	S S S S	S S S D	D D D D
Distribution issues	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
	S S S D	S S S S	S S S D	S S N S	S S S S	N N S S	S S S D	N N S S	S S S D	S S S D
Product retirement, legal	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
& liability Issues	S S S S	S S S S	S S S D	S S S S	S S S S	S S S S	S S S D	S S S S	S S S D	S S S D

four stages. The results in Table 4.6 show that information from eleven out of seventeen categories are exchanged in detail by the design department at two or more stages of design process; whereas, information from twelve out of the seventeen categories are exchanged in detail by the Project Management department at two or more stages of the design process. On the other hand, the finance department shows less than moderate involvement through all four stages in Figure 4.2. Table 4.6 shows that information from two out of the seventeen categories are exchanged in detail by the finance department at two or more stages of the design process. Top Management and the Sales department have more than moderate involvement in stage one but less than moderate involvement during the remaining stages. Table 4.6 shows that information from three out of the seventeen categories are exchanged in detail by these departments at two or more stages of design process. Manufacturing is more than moderately involved during the last three stages, and Table 4.6 shows that information from eleven out of the seventeen categories is exchanged in detail by this department at two or more stages of design process. The marketing and Quality Assurance departments are more than moderately involved in three out of the four stages of product design and Table 4.6 shows that information from only four out of the seventeen information categories is exchanged in detail by these departments during two or more stages of the design process.

Hypothesis 8 states that for each department, the level of information content exchanged is different for each stage of the concurrent engineering design process. The results displayed in Table 4.6 show partial support for hypothesis eight. The level of information content exchanged changes through the four stages of the design process: thirteen out of seventeen categories for design and Manufacturing, sixteen out of seventeen categories for Project Management, eleven out of seventeen categories for top management, and nine out of seventeen categories for the Sales department. The level of information content exchanged remains constant through all four stages of the design process for more than 50% of the categories for the remaining five departments.

CHAPTER 5

BUILDING AN INFORMATION INTERCHANGE SUPPORT SYSTEM

Building a prototype information interchange support system (IISS) for a CE team involve the sharing of data, information, and other intellectual assets among many team members. Because of this characteristic, the system development process can be more complicated, longer and involves more risk. The development process recommended for workgroups has five stages (Kroenke, 1992): define the problem, specify the requirements, evaluate the alternatives, design the system components, and implement the system. The author identifies five components of the workgroup system: hardware, programs, data, procedures, and people. Neumann (1982) provides following principal categories of information system attributes: timeliness, content, format, and cost. Timeliness is not a single attribute, but a class of attributes all related to the time factor in information update and retrieval. Content attributes relate to the meaning of information to decision makers. The format of reported information has many possible attributes -- The medium by which the report is provided, the way the data are arranged in the report, and the graphic setting of the report.

The IISS is developed in following steps: the conceptual design of an IISS, system design methodology and tools, detail design of an IISS, and evaluation of the IISS. The purpose of the IISS is to improve the communication among CE team members. The problem with sequential product development is that very little information is exchanged. There is a need for interdepartmental communication and harmony for the success of a new product. However, the unrestricted flow of information in concurrent engineering product development may generate a lot of information. There may be the danger of an information explosion and the difficulty of finding appropriate pieces of information.

When the product is designed for the first time considering manufacturing limitations (input required from manufacturing and production), customer's needs (input required from sales, marketing or directly from customer), the availability and cost of materials (input required from purchasing and suppliers), and company goals (input from Top Management), then there will be fewer changes required in the design at the production stage. One of the goals of concurrent engineering is to design a product "right" the first time (Hall, 1991). To design a product right the first time, appropriate information should be brought in from individual departmental experts to the right people on the concurrent engineering design team during the right time or stage. A computer-based information system can help a CE team to have this optimum information exchange.

When a design process is controlled in this manner, the appropriate information exchange will occur among the concurrent engineering team members, and there will be less probability of team members receiving the massive amount of information shown in Figure 2.7.

5.1 The Conceptual Design of an IISS

This research explores the management of an effective information exchange among concurrent engineering team members. A literature search in both the information technology and information systems inspired the idea of employing information filters to manage the appropriate exchange of information among concurrent engineering team members. Information filtering is not new. More than a decade ago, Peter Dennig (1982) pointed out that "the visibility of personal computers, individual workstations, and local area networks has focused most of the attention on generating information -- the process of producing documents and disseminating them. It is now time to focus more attention on receiving information -- the process of controlling and filtering information that reaches the persons who must use it." In November 1991, Bellcore in cooperation with ACM SIGOIS hosted a Workshop on "High Performance Information Filtering" in Morristown, New Jersey. Belkin and Croft (1992) determined that information filtering and information retrieval are both concerned with getting information to the people who need it. Loeb (1992) has defined information filters as mediators between information sources and their users. Information sources as well as information users both do not have a mutual knowledge that can guide them in finding the most relevant information in a given situation. In this research, the author considers "information filters" as a third party mediator between information sources and information users. This mediator should have both the knowledge and the functionality to examine information in the sources and to forward the information they consider relevant to individual users. Goldberg et al. (1992) describe an experimental mail system developed at the Xerox Palo Alto Research Center. The authors point out that the several mail systems support filtering based on a document's contents. According to these researchers, the better solution is for the user to specify a filter that scans all lists, selecting interesting documents. They conclude that more effective filtering can be done by involving humans in the filtering process Their system supports collaborative filtering, in which people help one another to filter by recording their reactions to the documents they read. These reactions, generally called annotations, can be accessed by other filters, similar to moderated newsgroups. However, moderated newsgroups have a single moderator where authors' systems have many moderators.

5.1.1 The Concept of Information Filters and Pumps Based on Survey Findings

The first page of the questionnaire determines the involvement of different departments during different stages of the product design process. The design and project management departments are highly involved during all stages of the process. The marketing and research and development departments are highly involved during the first two stages of the process. However, their involvement level is moderate in the third and fourth stages of the process. The purchasing and manufacturing departments whose involvement levels are low during the first and second stages become highly involved during the third and fourth stages. Based on the level of involvement, their need for information can be judged. Highly involved departments will certainly need detailed information; whereas, moderately involved departments will need summary information. Departments which are not involved will not need any information.

The highly involved departments will get detail information without any filters between them and their sources. These departments will also not need any notification because being highly involved makes them read the database at least 3-4 times a day. Thus these people do not need any filters to block information nor they do need any pump like device which will take the information to them.

Some departments are not highly involved during a product design stage, but they care about the category under which the information falls. These departments will also need to get detailed information. Since at a given stage, these departments are only moderately involved, they need a pump like device which will take the detail information to them.

Some departments are not highly involved, and they do not need to know the particular information category. These departments need to get only a summary of activities. They need a filter to give them just a summary.

The departments that are involved at low level in the product development and not interested in any information category will not receive any information. They will need a filter to block all information. However, they will require a pump if any other departments need information from these departments.

Thus, a literature review, a survey analysis, and a case study of the participating firm helped to identify the following filters:

1. The involvement filter
2. The information category filter

5.1.2. The Involvement Filter

As explained in the previous section, the design and project management departments are highly involved during all stages of the product design process. The marketing and research and development departments are highly involved during first two stages of the product design process and moderately involved during the last two stages. The involvement of the purchasing and manufacturing departments is low during the first and second stages. They become highly involved during the third and fourth stages. Thus, the involvement filter is time dependent and depends on the stage of the product design process. Departments which are highly involved do not need any filters to block information. They also do not need any pump to receive information. Their high involvement causes them to read all the information in various reports and forces them to contribute to ongoing discussions. Departments which are moderately involved need the involvement filter to block detailed information. These departments just need notification on the availability of weekly reports and summaries of issue resolutions. At this point, a master document can be visualized to add or remove the names of people on the team as the product moves from one design stage to the another. The program manager who coordinates new product development program can compose such document. A team member's name can be listed under his department and under the team working together during that stage of the product design process. This will serve two objectives. Consider the following scenario. The department 'X' is moderately involved at stage 1. The department 'Y' wants some information or the expert's advice from department 'X' on a certain issue. Then a team member from department 'Y' can choose to open an issue discussion with a team member from department 'X'. Listing team members department-wise in the master document will allow this to happen. In this case there will be detailed information flow from the team member of the department 'X' to the team member of the department 'Y' even though department 'X' is only moderately involved at that stage. In the other scenario when the team member of department 'X' is not involved in the issue discussion, he just needs to have the summary information after the issue is resolved. Having the team member's name under the team list in the master document will allow this to happen.

The top executives of each department who are further away from daily activities also need to be briefed regularly on the progress of the new product development project and various related issues. Having the names of these executives listed in the master document will allow the program manager to send them weekly summary information.

5.1.3. The Information Category Filter

The questionnaire identifies 17 broad information categories. Analyzing responses about the information exchange requirements helped to determine which departments send (to others) or receive (from others) these information categories and during what stage of the product design process. The analysis clearly identified which departments needed to exchange detailed information and which departments needed to exchange summary information. Although design and project management departments are highly involved through all stages of the product design process, they do not need details of all information categories. The design department, for example, may just need summary information about "Labor issues" and "Distribution issues." On the other hand, the finance department has low to moderate involvement through all stages of the product design process, but some information categories like "Capital investment in tools and technologies" are exchanged in detail by that department. These examples explain the need for another filter based on the information category which is independent of departmental involvement during a given stage in the product design process.

The concept of forming a master document can be extended further to include information categories. Every department is interested in one or more of the information categories since either they need information from other departments about that category or they have information to send to other departments about that category. These interests are independent of their involvement in the product design and independent of the stage of the product design. Thus, if department "X" always has information to dissipate on category "I" then the names of the team members of department "X" will be listed under information category "I". Similarly, if department "X" is always interested in knowing information on category "J", then the names of the team members of department "X" will also be listed under information category "J". A master document with the names of team members under various categories is shown in Figure 5.1.

Product Name
Master Document

Prepared By Department
Stage Number

Department List
Marketing: Gary Moon
Design: Steve Best
|
|

Team List: Richard Hamilton, Robert Clark, Mark Steven...

Executive List: Pat Skalko, Gary Ray, Ron Spitler........

Information Category List
IC i: Mike Smith, Ron Hampton........
IC j: Mark Arena, Tom Hank.........
|
|

Figure 5.1. Concept of Master Document

A conceptual sketch of the involvement filter and the information category filter with an information pump is shown in Figure 5.2. The departments are classified into four categories based on their involvement levels and are shown by circles. Two filters are shown by rectangles, and the pump to dissipate the information is shown by a rectangle with rounded corners. These filters act in series. First the involvement filter will act when the master document is formed based on the involvement of different departments at a given stage of the product design process. Then an information category filter will act based on the category under which the information falls. The big circle, encompassing a highly involved group, information filters, and an information pump, represents a new product information source domain.

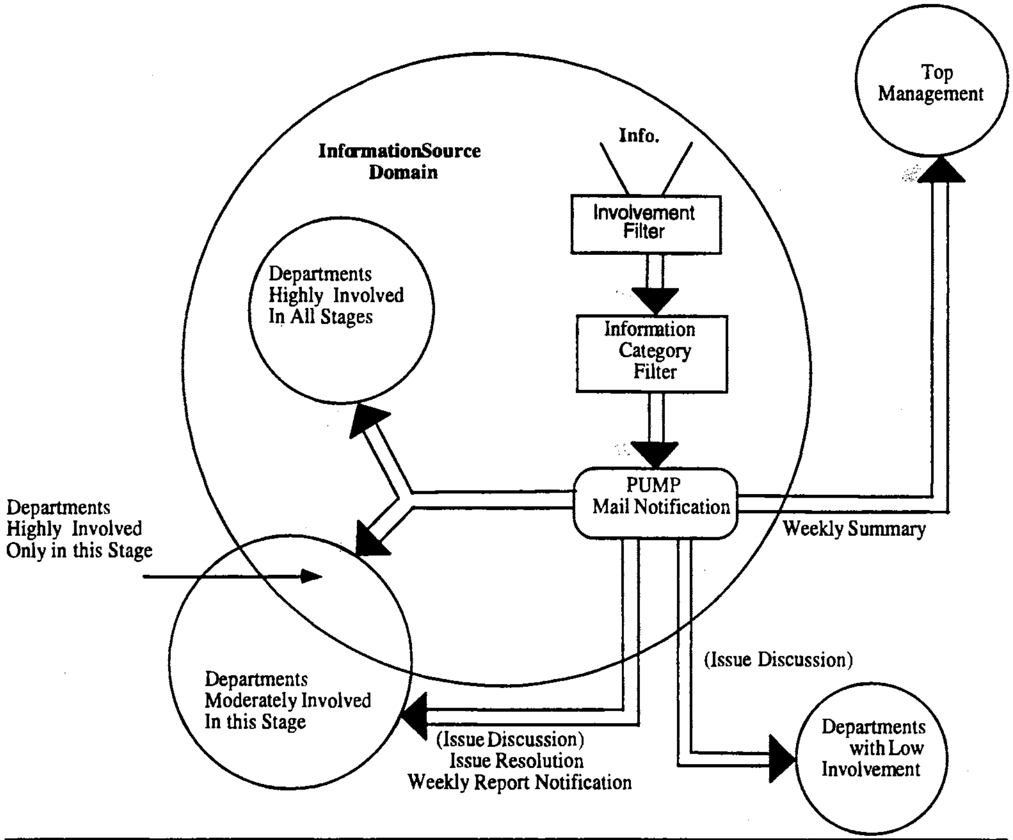


Figure 5.2. Conceptual Architecture of IISS

5.2 System Design Methodology and Tools

In implementing the findings of the survey and the concepts illustrated in the previous section, this research required the support from a large design and manufacturing company. This support was given by our industrial partner, a leading manufacturer of computer disc drives. They will be referred as CDD in this research to conceal their real identity. CDD uses concurrent engineering teams to develop their new products and has the necessary computer infra-structure in place. They develop many distinct models in very high volumes. The product and process design activities are distributed in three locations throughout the United States. The manufacturing plant is situated in Singapore and dealer networks are distributed around the world.

A case study approach was taken to study the concurrent engineering product development process at CDD In order to understand the complex process of developing products in a concurrent engineering environment, the following methods were used.

1) Attending concurrent engineering team meetings,

2) Studying Standard Operating Procedures (SOPs)

3) Informal discussions and meetings with the key people involved in product development.

5.2.1 Attending Concurrent Engineering Team Meetings

The concurrent engineering team at CDD meets once in a week. This team has representatives from design, manufacturing engineering, materials, production, program management, reliability, quality engineering, customer quality, supplier quality, heads and media, marketing, costing, and advanced technology departments. The program manager from the program management department is the leader of this team. He takes care of the organizational work like forming the concurrent engineering team in consultation with departmental executives, scheduling meetings, forming an agenda, assigning team actions, and tracking the progress of those actions. The concurrent engineering team is comprised of senior engineers and/or managers from each department. The organizational structure of CDD and the composition of team is illustrated in Figure 5.3.

Concurrent engineering team members use several modes such as the telephone, voice mail, E-mail, and informal and formal meetings to exchange information with each other. Team members use weekly meetings to present their department's reports of the work done to rest of the team. They discuss issues or new concerns, if any, in their development work. The weekly meeting is also used to settle trade-offs and make decisions. Based on the decisions and work performed, the program manager assigns

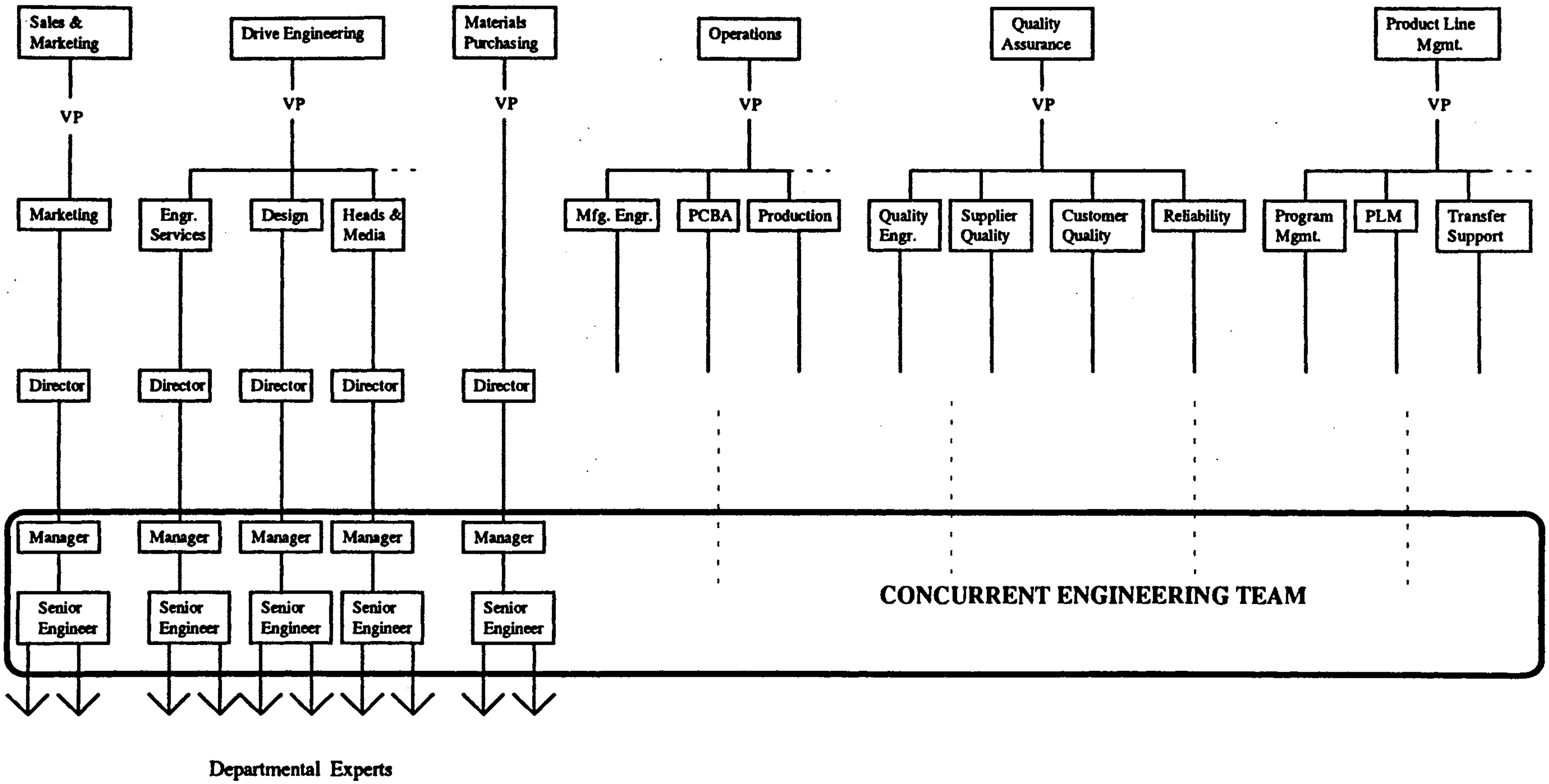


Figure 5.3. Organizational Structure and Composition of CE Team in CDD Inc.

actions to team members. Thus, the format of the information exchange for a typical concurrent engineering team can be listed as follows:

i) Information exchange through discussion on various issues,

ii) Information exchange through reports of work performed, and

iii) Information exchange through specific task assignment.

It was noticed that the team members were using overhead transparencies to display and read key points from their reports. Reading these reports from the transparencies used to consume a lot of meeting time. When a team member was presenting his report, some members wrote the points down in their log books while others relied on their memories. Some team members made copies of their reports and distributed them to others. They discussed a lot of issues but there was no secretarial service employed to write down different key points of the discussion. Even though decisions were formally recorded by the program manager, the intent or rationale behind the decisions was lost. While assigning team actions, a lot of time used to be lost in routing. The normal practice for the program manager was to type all actions and send them through a secretary. Then they would wait till the team member performed the action and sent in a report on the performed action.

These drawbacks in team communication provided an ideal situation for developing an information interchange support system that would aim at removing these obvious drawbacks.

5.2.2 Studying Standard Operating Procedures (SOPs)

CDD had prepared documents on Standard Operating Procedures to get ISO 9000 certification. These documents helped to understand the different stages in their product development process. These documents served as supporting material for making comparisons between the stages identified in the questionnaire and CDD's product design stages. This comparison is shown in Figure 5.4. Studying of these Standard Operating Procedures also helped to determine which departments will most likely exchange information categories listed on the third page of the questionnaire. Table 5.1 illustrates the departments in CDD that are responsible for generating the information in the categories listed on the third page of the questionnaire.

5.2.3 Informal Discussions and Meetings

The third method of having informal discussions with the key people involved in the product development process helped to put all of the jigsaw puzzle together. Several discussions were held with major players and the program manager. Since they were going to use this system, their contributions were very valuable. First, the 17 information categories listed in questionnaire were discussed. They removed some of the categories which were not relevant to their work and added many more categories which were more appropriate to their work. The final number of information categories was 29. Then, the different stages in the product design process and nomenclature were discussed. The four stages of the product design identified in the questionnaire were shown to them. They wanted to expand the scope of the system beyond product design. They requested to include two additional stages as follows: i) manufacturing installation and ii) production. As shown in Figure 5.4., CDD's "Engineering Model Build and Test" is equivalent to the "Detail Design and Review" stage of the questionnaire and CDD's "Customer Development Unit Build and Test" is equivalent to the "Prototype Build and Test" stage of the questionnaire. Although the system has extended its scope beyond product design, it will be tested only in the second, third, and fourth stages of the product design process.

Table 5.1

CDD's Product Development Information Sources

Information Categories in Questionnaire (Page 3)	Where Information can be found in CDD	Department Responsible for generating Information
Company goals & policies	Company Policy Document	Top Management
Budget for new product	3 Year Plan	Marketing
Capital investment in tools\technologies	3 Year Plan	Marketing
Consumer preferences & needs	Market Requirements (MR)	Marketing
Product mix and synergy	3 Year Plan	Marketing
Forecast of sales volume, revenue, gross margins	Market Requirements (MR)	Marketing
Dimensional, material, functional & modularity issues	Design Requirements Engr. Dev. Plans	Design Engineering Design Engineering
Product maintenance, repair, ease of Assembly & disassembly	Customer Service and Repair Plan	Customer Service and Repair
Manufacturing process issues: e.g., layout, capacities & schedule	Pre-Production Inventory Authorization (PIA)	Program Management
Quality & reliability issues: e.g., quality of supplier's parts	Quality Plan	Quality Assurance
Safety issues: e.g., safety of product, processes & operation	Business Plan 2 Mfg. Project Plan	Product Management Manufacturing
Environmental pollution, disposal & recyclability issues	End-Of-Life Plan Customer Notification	Accounts Management Accounts Management
Labor issues	Pre-Production Inventory Authorization (PIA)	Program Management
Availability, quality and cost of parts & materials	Material Plan	Material Control
Product scheduling & time to the market	3 Year Plan	Marketing
Distribution issues	Business Plan 2	Product Management
Product retirement, legal & liability Issues	End-Of-Life Plan Customer Notification	Accounts Management Accounts Management

CDD's Product Development Stages	Product Design Stages in Model
Planning Stage	
Forming 3 Year Plan	
Forming Market Requirements (MR)	Forming Product Specifications
Forming Design Requirements (DR)	Forming Product Specifications
Forming Business Plan 1	Forming Product Specifications
Forming Product Plan	Forming Product Specifications
Forming Engineering Project Plan	Conceptual Design & Review
Concept Design	Conceptual Design & Review
Concept Design Review	Conceptual Design & Review
Development Stage	
Engineering Model Build	Detail Design & Review
Engineering Model Test	Detail Design & Review
Manuacturing Project Plan	Detail Design & Review
Material Plan	Detail Design & Review
Reliability (MTBF) Plan	Detail Design & Review
Reliability Test Plans	Detail Design & Review
Cost Plan	Detail Design & Review
Pre-Production Inventory Authorization	Detail Design & Review
Verification Stage	
Business Plan 2	Prototypes Build & Test
Customer Development Unit (CDU) Build	Prototypes Build & Test
Design Maturity Test to Spec on CDU	Prototypes Build & Test
Installing Manufacturing Facilities	Prototypes Build & Test
Introduction Stage	
Customer Test Unit (CTU) Build	Prototypes Build & Test
Ongoing Reliability Test on CTU	Prototypes Build & Test
Reliability Demonstration Test	Prototypes Build & Test
Design Maturity Test to Margin on CTU	Prototypes Build & Test
Customer Qualifiation	
Production Stage	
End-Of-Life Stage Plan	
Product Maturity Test	
Transfer to other Mfg. Sites (If required)	
Ramping	
End-Of-Life Stage	
Customer Notification	
Final Production	

Figure 5.4. Relating CDD's Product Design Stages to Model's Product Design Stages

There will be no opportunity to test the system in the product specification stage because CDD's concurrent engineering team is formed after this stage.

5.2.4 A Description of the Tool Used for the Development of an IISS

Lotus Notes, a group communication software, was used to build a prototype information interchange support system. CDD, which is participating in this research has Lotus Notes. At the beginning of this research, the use of Lotus Notes at CDD was mainly limited to the Advanced Technology department. The Advanced Technology department used Lotus Notes to store departmental databases and to communicate through an electronic mail feature. Company executives were aware of the potential use of Lotus Notes in developing new products. Apart from a few people in Engineering and in Advanced Technology, many people from other departments simply did not have access to Notes. Now the situation has changed. People who participate in CE teams are making efforts to use Lotus Notes so that they can use an IISS and benefit from it.

Lotus Notes is a distributed database with a built-in wide area connectivity, automated document routing, and personal e-mail. As explained in chapter 2, Lotus Notes is an information manager for work groups. Using Notes, a group of people can share information across a computer network even if those people are in different parts of the world. The superior electronic mail capabilities of Lotus Notes make it ideal for product development purposes. Within Notes, a user can easily send a message, attach documents, pictures, CAD drawings or other forms of data to that message. Notes allows the user to electronically sign every document that the user mails even those composed in other software packages. The user can encrypt individual documents and mail the key only to select recipients. These security features enable users to communicate about confidential topics. The second major use of Notes is through its database functions. In

Notes, the user can design a form to build information bases. These users may then access these databases to communicate with each other. The databases can include discussions about a given project, status reports, individual personnel assessments, request forms, or just a collection of messages kept for future reference. If properly used and maintained, this type of system can reduce paper load and increase the user's ability to communicate with others in the group. The superior E-mail facility, feature of electronic signature, other security measures, and the ease of database operations make Lotus Notes an ideal group communication software to use in the product development process in a concurrent engineering environment.

Notes applications can generally be divided into five major types: tracking applications, broadcast applications, reference applications, discussion applications, and work flow applications. Tracking applications are characterized by a combination of subjective and objective information that is continuously updated. These applications are usually highly interactive with many users contributing to a collection of information. For example, a project status report can track the ongoing progress of personnel on a number of projects. Broadcast applications are characterized by fairly static information, sometimes time-critical, that needs to be available to a wide variety of people. For example, a newsletter can advise employees of company events. Reference applications are similar to broadcast applications, except that the documents are meant to be used as a consolidated reference library. For example, a policy and procedure handbook can maintain a single up-to-date copy of company policies. Discussion applications support structured and unstructured group communication. They provide a forum for dialogue on topics of common interest and include the ability to address new topics and respond to existing documents. For example, feedback or opinion databases let the users respond informally on any topic. Work flow applications may involve the users of the other types of applications described above. Work flow applications use macros to automate routine tasks, such as routing forms to various people, mailing out reminders, and automatically performing batch updates on documents at specified intervals. For example, the conference room schedule tracks conference room reservations. This application also mails out reminders about the meetings scheduled in each conference room to the designated participants.

5.2.5 Two Types of Information

Two types of information appear in a form: i) static and ii) variable.

Static information is text or graphics that remains constant on every document created with the form. Static information might include the form name, field labels, and data entry instructions.

Variable information is information entered into fields -- the date, a part number, part specifications, performance specifications; this information will change from document to document. This is the real data for the application. Some of the information is entered by the user; whereas, some of the information such as dates, department number, and document number can be computed for the user.

Many of CDD's executives and engineers use other applications such as spreadsheet and Microsoft Project in their work. The external data in these applications can be imported by using the object, linking and embedding (OLE) features. The OLE applications can be activated in composing, editing, and reading modes.

5.2.6 Adding Fields to a Form

Once the form is defined, the developer can add fields to it. Fields are the means by which data is entered into Notes and stored into Notes. A form can only accept and display data for which there are fields. The field's characteristics are defined by using the "field definition" dialog box. Notes supports nine data types for a field, which are explained below.

i) Text: The texts consists of letters, punctuation, space, and numbers that are not used mathematically,

ii) Numbers: Numerical information is any information that can be used mathematically,

iii) Time: Time information is comprised of letters and numbers separated by punctuation, and is used to define a specific date and/or time, usually in the format MM/DD/YY HH:MM:SS,

iv) Keywords: Keywords are predetermined entries for a field. The user chooses the value(s) for the field from the predefined list of keywords. Using keywords lends consistency to the values that appear in IISS documents. Each user has the same set of values to choose from when entering information into a keyword field. There are three methods for displaying the list of keywords to users: check boxes, radio buttons, and standard field. Check boxes present a vertical list of check boxes, each representing a user list item. Users can select any number of items. Radio buttons present a vertical list of radio buttons, each representing user list item. Users can select only one item. In standard field, users can press ENTER to display a dialog box listing all items, can press SPACE to cycle through the list or type the first letter of the appropriate item to display it.

v) Rich Text: Rich text information may be text, enhanced text, or graphics. A field is defined as a rich text if it includes pictures or graphs, popups, buttons, or embedded OLE objects. If the user needs to use text attributes such as bold, italics, underlining, or color then the field should also be rich text type.

vi) Author Names: Author names is a text list of names that includes who can edit a given document. If the designer wants to assign editor access to a document to multiple users, he can list the user names in the author names field. This is useful in work flow applications where a document is passed from a person to person, and each is responsible for updating a specific set of information.

vii) Reader Names: Reader names is a text list of names that indicates who can read a given document.

viii) Names: Names are stored internally in Notes using the canonical format of the distinguished format. The names field is used to display a list of user names or server names when an author names or reader names field is inappropriate.

ix) Section: A section is a special type of field that defines an area on a form, and governs all fields and text within that area.

In developing an IISS application, most of these fields are used in different forms. The fields that are most commonly found in all forms are: text, Number, time, keywords, author's name, and sections.

5.2.7 Designing Views

In a Notes database, a view lists documents and provides means of accessing them (Application Developer's Reference, Lotus Notes Release 3, 1993). Every database must have at least one view. Many databases have multiple views. Each view can display all, or a subset of, the documents in the database. Typically, a view will list the document titles, author names, creation dates, and similar information. Different views may display the same documents, but sort them differently, for example, by date or by author.

The aim of view design is to make it easy for users to find the documents that they want to read. The developer should design a view to show as much information about the documents available as possible, without cluttering the view. A view has a selection formula which determines which documents appear in a view. Every view must have a selection formula. If it is not defined, Notes uses the default formula to select all the documents.

5.2.8 Security

Security is a vital issue in the application development. In addition to protecting a IISS's design from unauthorized modification, security measures protect the data stored within an application (Application Developer's Reference, Lotus Notes Release 3, 1993). The security measures ensure that only specific people see certain information. The security arrangements can control the operations that each user can perform within a particular application.

5.2.8.1 Levels of Security: Notes provides the means of protecting the data on multiple levels; each level of security refines the previous level, restricting information to an ever-smaller group of users. The access allowed at one level cannot override a previous level. For example, users with depositor access to an IISS cannot be given reader access to particular documents; however, users with reader access can be locked out of some documents. The "Notes server" is first level of protection in the Notes security system. Before users can work on application stored on a Notes server, they must gain access to the server itself. Access is controlled through a series of statements in the server's file; the Notes administrator maintains this file. The next is "application-level Security." Every application has an access control list, which specifies exactly who can access the application and what those users can do. Access levels range from "application manager" to "no access." The next level is security is called "view-level security." Generally, all of the public views in an IISS are available to all users with reader access or better. The designer can restrict access to a view by defining a reader access list for the view. The next level security is called "form-level security." The designer can create a read access list for a form, and then all documents composed with that form automatically inherit that reader access list. The designer can additionally create a composer access list for a form to control which users are allowed to compose documents with the form. At the "document-level security" if the form used to create the document already has a reader access list, that list is used as the default for the document, and is updated by the "Edit-Security-Read Access" command. Second, if the form contains a reader names field, the user can enter a list of allowed readers when he creates the document. Within a document, access to certain sections can be controlled. This is called as "section-level security." A document can contain one or more sections; a section controls access to all of the fields within its boundaries. Each section within a form can have its own edit access list, which controls who can modify the fields within the section. Anyone with read access to the document can read the section; only those specifically listed as editors can modify it. Each section in the document can have a different list of editors. The final level of Security is the "field-level security." When designing a form, the designer can designate specific fields as encryptable. When the user composes a document, he can optionally encrypt keys associated with the document. Only the fields that are encryptable are hidden; the remaining fields are still displayed.

5.3 Detail Design of an IISS

The conceptual framework developed in section 5.1 is based on the validated communication model of CE design process and the information collected in a longitudinal study of the product development process at CDD. Based on this conceptual framework and the capabilities of Notes, following architecture of an IISS is envisioned.

Figure 5.5 shows four different parts of the system. Each part uses a separate form and the detailed description of these forms appears in the following sections.

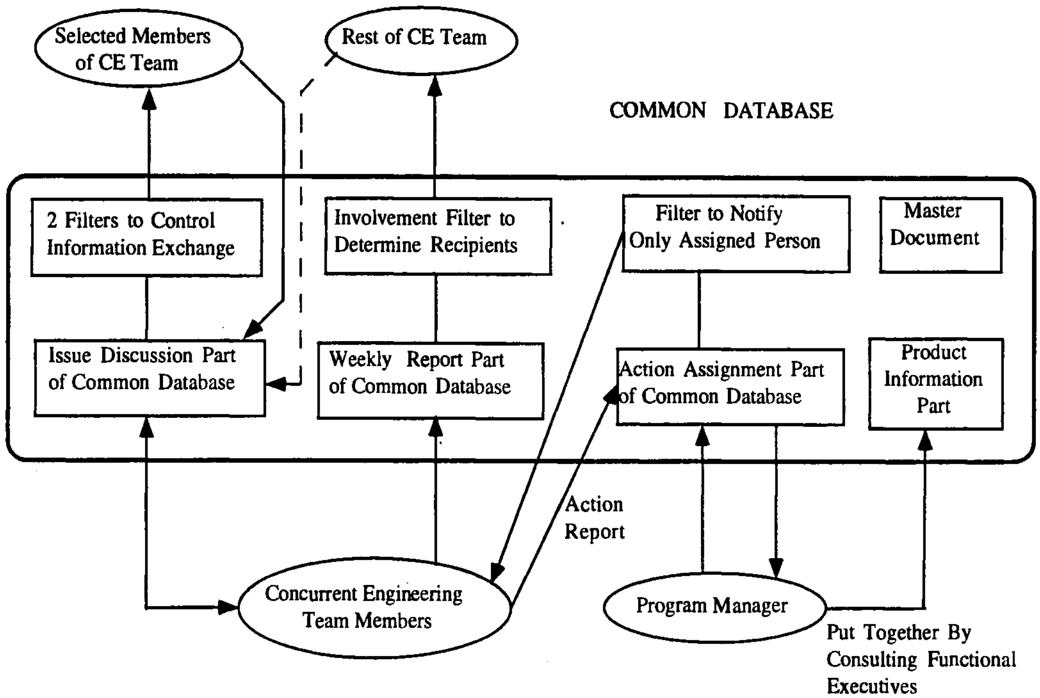


Figure 5.5. Different parts of an Information Interchange Support System (IISS)

This is a common database application and there are different levels of access to the different parts of the IISS. CDD's new product information such as product name, current development stage, and a list of people on the new product development team can be found in the IISS under product information part. A master document lists team member's name by the information category they care about as well as by the department they represent. This document is composed by the program manager in consultation with all departments. Everyone can read this document.

If a team member wants to start the discussion on some issue, then he can use the issue discussion part of the IISS. Two filters associated with this part are: i) information category filter, and ii) involvement filter. Team members will have to choose the information category under which the intended discussion falls. Then the information category filter will seek the team members listed under that category in the master document and will send mail notification to these members inviting them to join in discussion. Each team member will also have to choose the department(s) with which he or she wants to have a discussion. Then the involvement filter will seek the team members listed under that department in the master document and will send mail notification to these members inviting them to join in discussion. Then there are some team members who are highly involved in the development at that stage and seek new information in the IISS at least three to four times a day. They will become aware of the discussion even if they do not receive notification. If they want, they can contribute to the discussion. Team members who receive mail notification will contribute to the discussion in the same document. The originator will describe the issue following a series of discussions by the appropriate team members. Once the team members arrive at a consensus, then the issue originator or the program manager can close the issue by entering a resolution.

A team member can use the weekly report part of the IISS to prepare a departmental report on the week's work. The rest of the team members involved in the product development at that stage will receive mail notifications that a weekly report from department "X" is posted in the IISS. This will help a team member get the weekly report to rest of the team members well before team's weekly meeting. Thus, team members can come prepared to weekly team meetings and spend valuable meeting time in settling trade-offs and making decisions on important matters.

The program manager can use the team action part of the IISS to assign tasks to a particular team member. The member to whom a task is assigned will receive mail notification. The team member can report on the performed action and notify the program manager. This will help program manager to track assigned work more efficiently.

5.3.1 Defining the IISS Application

Notes applications can generally be divided into five major types: tracking applications, broadcast applications, reference applications, discussion applications, and workflow applications. The IISS is a combination of above mentioned applications. This application can be used as a "tracking application" by the project manager and CE team. It can be used as a "reference application" throughout the product development process by the CE team. It can certainly be used as a "discussion application" as there is a specific form which will allow a team member to start discussion on the development related issues with appropriate members of the CE team. The program managers can use the team action form to assign actions to a particular team member. Since he is routing the form with his electronic signature to the team member and that team member can add his report and route the form back to the program manager, this can be considered as a "workflow automation application." Team members can use weekly report forms of the IISS to broadcast their reports to the rest of the team members. Hence, the IISS can be considered as a "broadcast application."

5.3.2 A Description of the Various Forms Used in the IISS

One purpose of the IISS is to discuss issues and their resolution on two new product development programs from the concept stage to the production stage. This system is intended to discuss firmware issues, hardware issues, customer issues, and any other related issues that are related to development of two new products in CDD. The second purpose of this IISS is for CDD's product development team to prepare the weekly status reports that they present in team meeting once every week. The third purpose of this IISS is to assign and track team actions.

To meet the above goals, IISS contains four forms: i) an issue discussion form, ii) a team actions form, iii) a weekly report form, and iv) a product information master document form.

5.3.3 Product Information Master Document Form

A list of the people on CDD's product development team can be found by category as well as by department in a master document. This document is composed by using the "Product Information Master Document Form" by the program manager in consultation with all departments. Everyone has "Read access" to this document which can be seen under the view name "Master". After composing the document, the form is hidden and can be accessed by the person who will have "Manager Access" to the IISS. This person will be the leader of the CE team. The program manager is the leader in CDD. Since he composes this master document, he can change it or upgrade it whenever necessary. The master document also contains the brand name of the new product and the current development stage of the new product. When new product development moves to the next stage, the program manager will do appropriate changes in this document; that is, changing the stage name and adding appropriate people to the team for that stage. If there is transfer of people from one project to another project, then he may need to do the appropriate changes in the master document. Figure 5.6 shows the part of the document composed by using this form. The design of the master form is based on the concept shown in Figure 5.1.

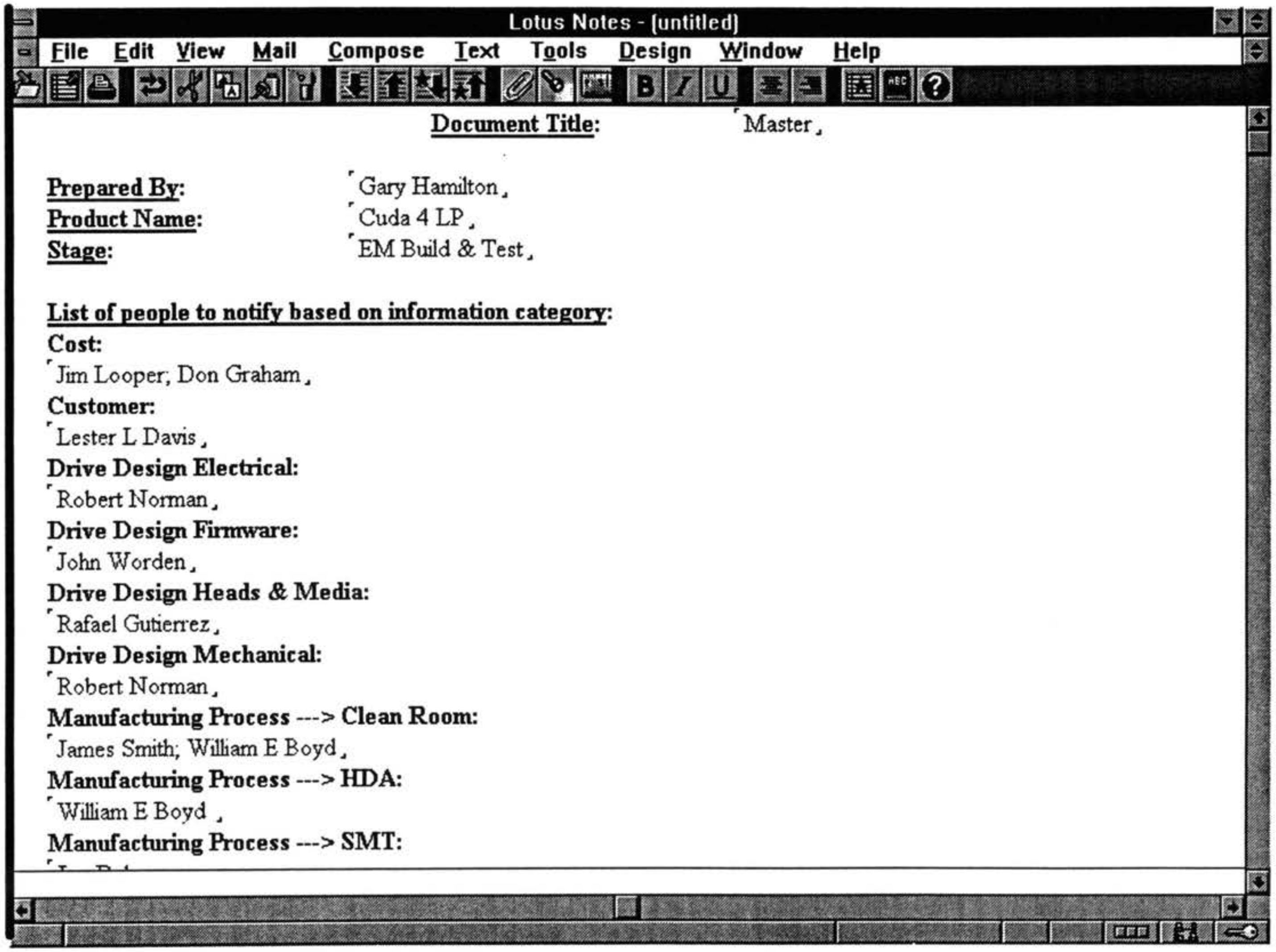


Figure 5.6. An Example of A Master Document

5.3.4 The Issue Discussion Form

CDD's product development team can use this form of the IISS to share thoughts and ideas. Almost any person or department that has information to share with the team members can use this form.

This discussion form resembles an an informal meeting place, where the members of a team can share ideas and comments. Like a physical meeting, each member of the team reads what others have to say and types his own opinions. However, unlike a physical meeting, the participants do not have to be in the same room at the same time to share information. People can participate when it is convenient for them to do so.

This form will help in taking appropriate information to the right people at the right time.

5.3.4.1 The important features of this form: This form uses two filters: i) an information category filter and ii) an involvement filter. These filters are formulas which help retrieve names from the master document and which send mail notification to the retrieved names. Working of the discussion document with two filters in series is shown in Figure 5.7. Thus, when the user chooses an information category, the team members interested in that category are chosen. Their names are retrieved from a master document. Then a mail notification is sent saying "contribute in issue opened by (author's name) on (topic name)." Similarly when the user chooses the department name(s) to start a discussion, the names of the team members listed under that department name in a master document are retrieved. Then a similar mail notification is sent to them.

a) Title Selection: The user can enter and select from the list or add his own title for the issue he is going to discuss.

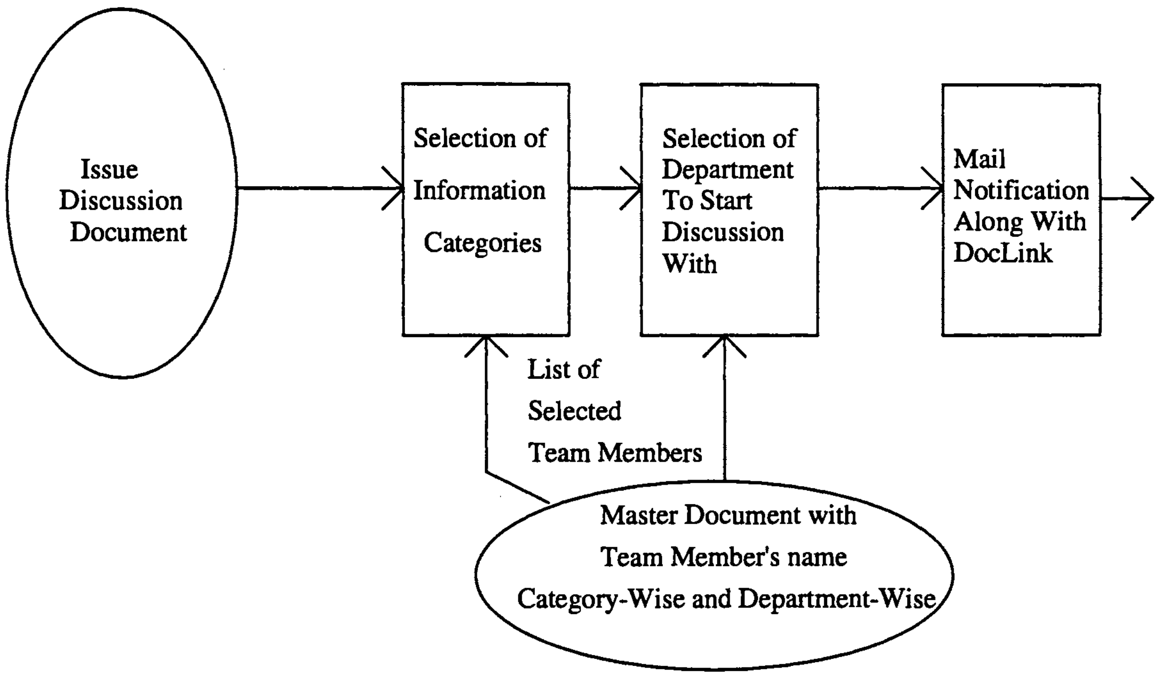


Figure 5.7 Working of the Discussion Document With Two Filters in Series

b) Selection of Category: The user can enter and select the appropriate category under which issue title falls. There are 29 categories listed in alphabetical order. He can select more than one category at a time. For example, a issue like "Data flex design" can fall under two categories: 1) Drive design --> Mechanical and 2) Drive design --> Electrical.

c) Selection of Department: The user can enter and select appropriate department(s) with which he wants to start an issue discussion.

d) Issue Open (Mail) Notification: This is a most useful and unique feature of this form. Based on selected categories and selected departments, appropriate members' names are found in the master document and they are notified by mail that "contribute in issue opened by (author's name) on: (issue title)".

e) "Rich Text" Body and Resolution Fields: The body field, where actual ideas and thoughts are shared, is a rich text field. Similarly a resolution field, where a resolution is entered, is a rich text field. Bold, italicized or underlined text may be used as well as graphs, Gantt charts or objects created in other applications.

f) Menu Buttons: For ease of operation, this form has "Edit Document" menu button in read mode and "Save and Close document?" menu button in edit mode.

g) Issue Resolved (Mail) Notification: When the issue is resolved and an issue resolution date appears, the team is notified by mail that a "Consensus arrived on: (issue topic and date). Resolution is (actual resolution). Click here to see details --> (Doclink)." Anyone interested in the details can click this mail attached doclink and see the details without opening up the IISS. Only the issue originator and program manager will able to enter information in this field.

h) Background Macro: A background macro will run once a week to give a weekly report by mail to higher level executives. This report will contain a list of new issues opened up for the discussion and a list of issues resolved since the last report was sent in.

Figure 5.8 shows the part of the document composed by using this form.

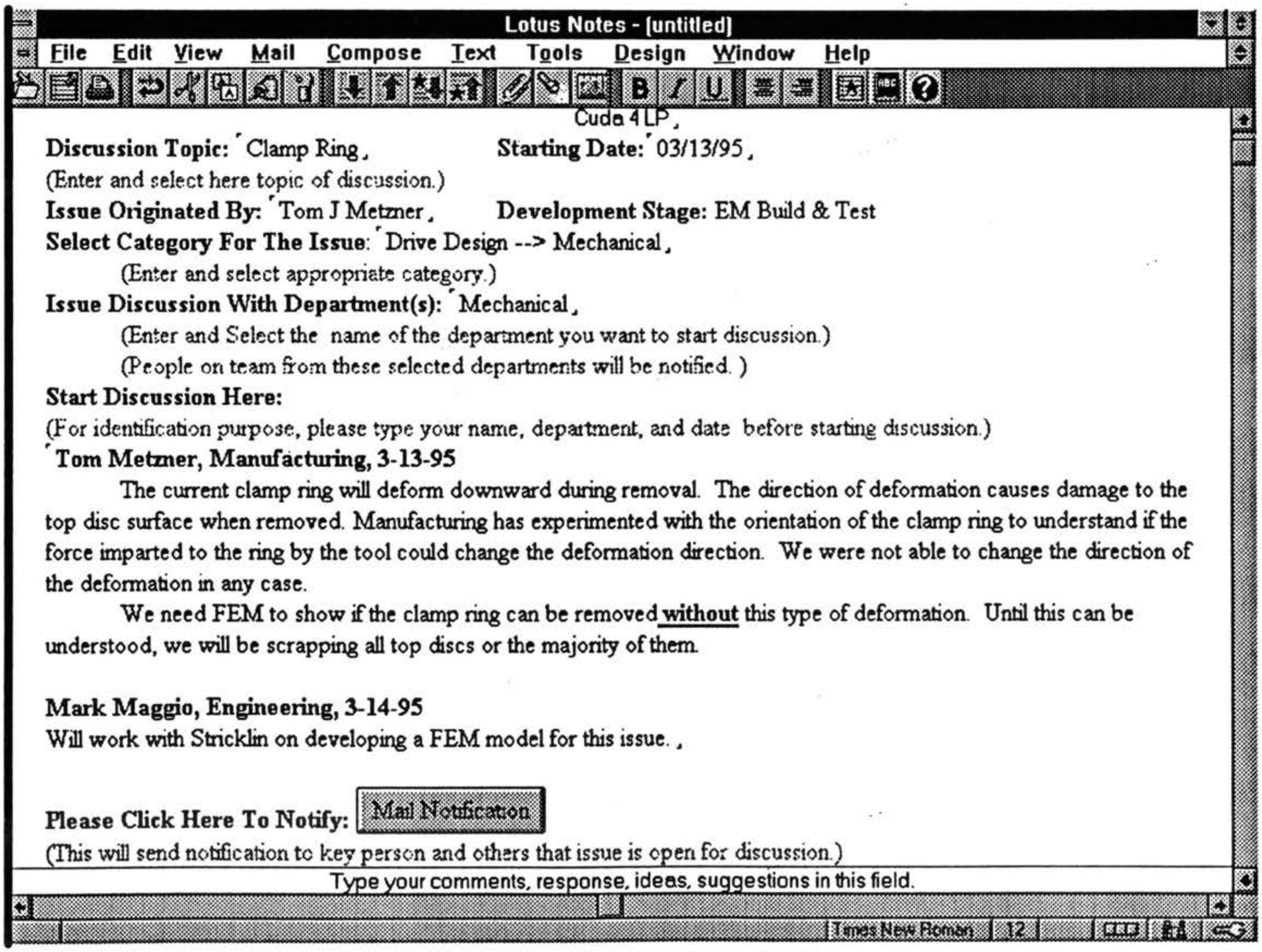


Figure 5.8. An Example of A Discussion Document

5.3.5 Team Actions Form

The program manager can assign actions to team members by using this form. Only the program manager and the member to whom the action is assigned will be able to edit this document. Everybody else will have "Read-Only" access to the document.

5.3.5.1. Important features of this form: This form does not use any filters. It uses the in-built feature of Notes to allow a predefined member to edit the document and block the rest of the CE team from editing the document. The team member to whom the action is assigned is given editing access to the document. He can type his completed action report and send it back to the program manager. Everyone else can read the report but will not be able even accidentally to change the report.

a) Action Assigned (Mail) Notification: When actions are assigned to a team member, he will receive mail notification: "Following action(s) are assigned to you. Click here to see details --> (Doclink)." The notified member can click this mail attached to doclink or open up the document through the IISS via "Actions (All)" view.
b) "Rich Text" Report Field: The field where the author will start typing his action status report is a rich text field. Bold, italicized or underlined text may be used as well as graphs, Gantt charts or objects created in other applications.
c) Report Posted (Mail) Notification: The team member, after typing his action status report, can notify the program manager by clicking a menu button. The program manager will be notified that "following actions are taken. Click here to see details --> (Doclink)." The program manager can click this mail attached to doclink or open up a document through the IISS.

Figure 5.9 shows the part of the document composed by using this form.

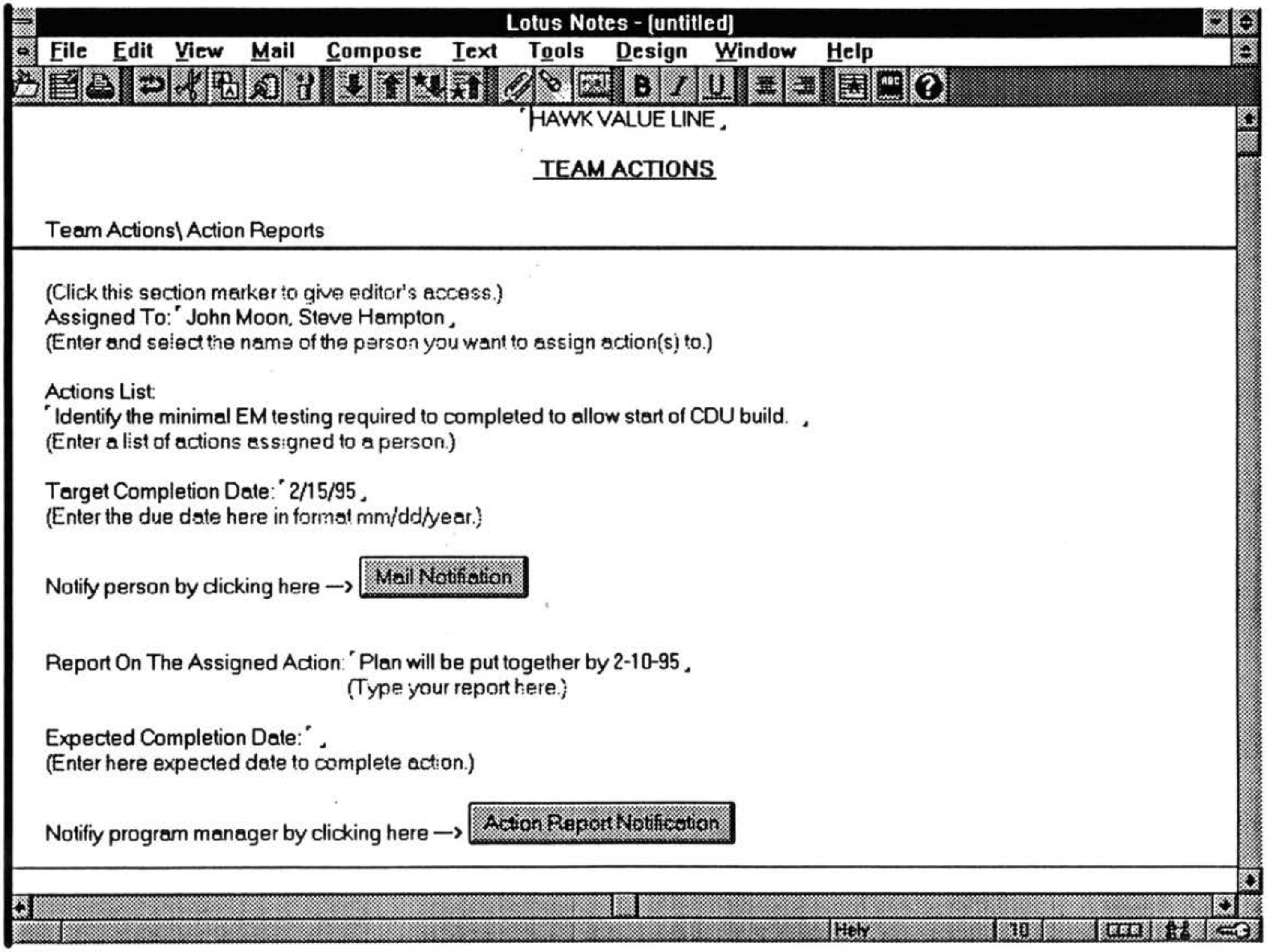


Figure 5.9. An Example of A Team Action Document

5.3.6 Weekly Report Form

CDD's product development team can use this form of the IISS to prepare weekly status reports that they present in the team meeting once every week. This way, a report will be available for every team member to read before he comes to meeting. Thus valuable meeting time will be used in arriving at decisions and settling trade-offs. Another advantage lies in the fact that all the reports will be electronically available in a single place.

The working of this form is shown in Figure 5.10.

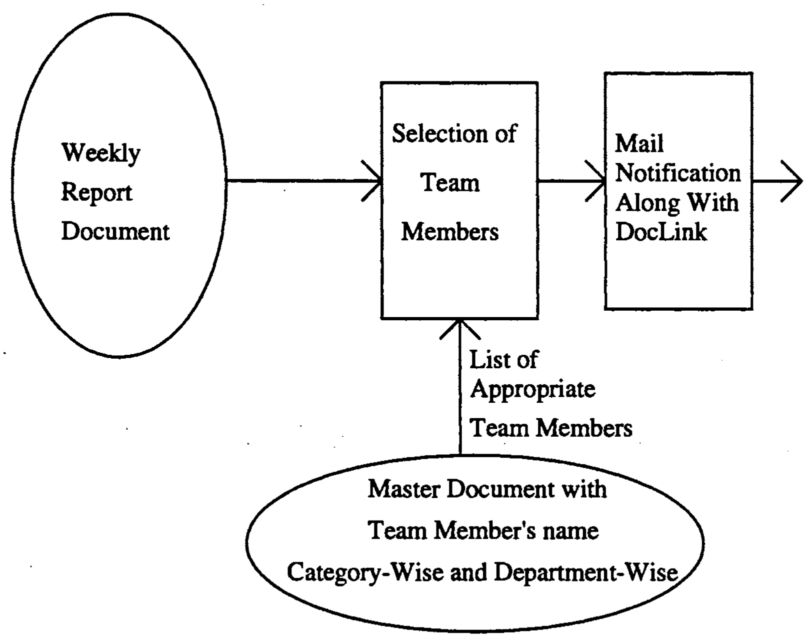


Figure 5.10 Working of Weekly Report Document With Involvement Filter

5.3.6.1 Important features of this form: This form uses the involvement filter to retrieve all team members' names listed under a field called "Team" in the master document. Then a mail notification is sent to the team that the "Weekly report of the (department name) is posted." The departments which are highly involved in a given stage of the product design process may read that report immediately; whereas, the departments which are moderately involved may read it when it is convenient. They will know that the report exists but, since they are moderately involved during a given stage, they may not have a pressing need to read it immediately.

a) Default information: The following information will be listed by default for the user: 1) start date, 2) finish date, 3) user name, 4) list of team members to whom notification can be sent. The department name of the user will be available in the list of keywords, so the user should enter and select that name.

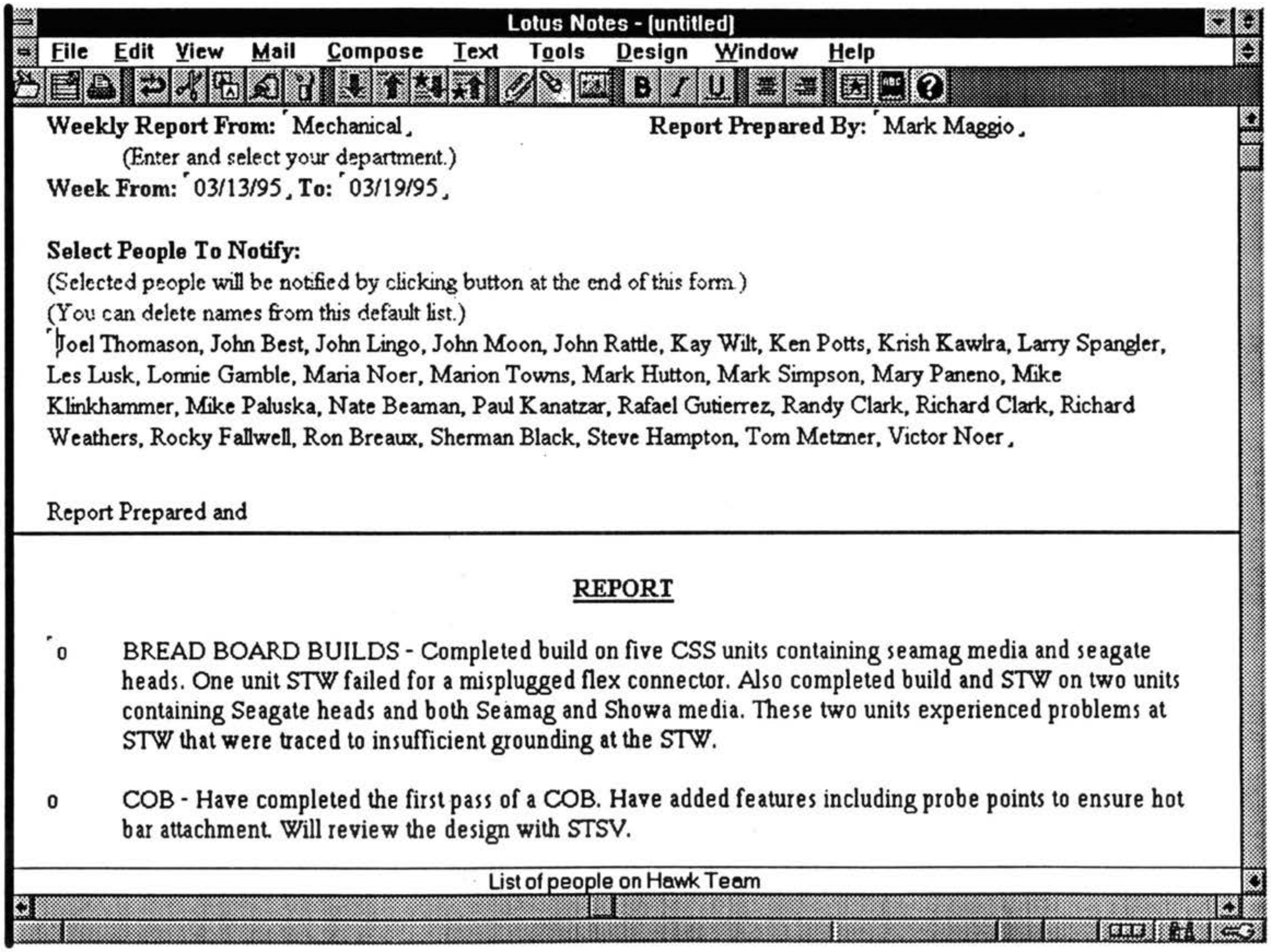
b) Reserved section: The field where the author will start typing his department's weekly status report is reserved for only the author. This means that only author can edit the information and everyone else can only read it. The author's name and signature will appear automatically once he saves the document.

c) "Rich Text" report field: The field where author will start typing his department's weekly status report is a rich text field. Bold, italicized, or underlined text may be used as well as graphs, Gantt charts or files and objects created in other applications.

d) Menu buttons: For the ease of operation, this form has "Save Report?", "Spell Check Report?", and "Close Report?" menu buttons in edit mode and "Close Report?" menu button in read mode.

e) Report posted (mail) notification: When the report is ready and saved in the IISS, team members can be notified by clicking the mail notification button: "Weekly report of (department) is posted. Click here to see details --> (Doclink)." The notified person can click this mail attached to doclink or open up the document through the IISS.

Figure 5.11 shows the part of the document composed by using this form.


Lotus Notes - [untitled]

File Edit View Mail Compose Text Tools Design Window Help

Weekly Report From: Mechanical **Report Prepared By:** Mark Maggio

(Enter and select your department.)

Week From: 03/13/95 **To:** 03/19/95

Select People To Notify:

(Selected people will be notified by clicking button at the end of this form.)

(You can delete names from this default list.)

Joel Thomason, John Best, John Lingo, John Moon, John Rattle, Kay Wilt, Ken Potts, Krish Kawlra, Larry Spangler, Les Lusk, Lonnie Gamble, Maria Noer, Marion Towns, Mark Hutton, Mark Simpson, Mary Paneno, Mike Klinkhammer, Mike Paluska, Nate Beaman, Paul Kanatzar, Rafael Gutierrez, Randy Clark, Richard Clark, Richard Weathers, Rocky Fallwell, Ron Breaux, Sherman Black, Steve Hampton, Tom Metzner, Victor Noer

Report Prepared and

REPORT

o BREAD BOARD BUILDS - Completed build on five CSS units containing seamag media and seagate heads. One unit STW failed for a misplugged flex connector. Also completed build and STW on two units containing Seagate heads and both Seamag and Showa media. These two units experienced problems at STW that were traced to insufficient grounding at the STW.

o COB - Have completed the first pass of a COB. Have added features including probe points to ensure hot bar attachment. Will review the design with STSV.

List of people on Hawk Team

Figure 5. 11. An Example of A Weekly Report Document

5.3.7 Views of IISS

In a Notes application, a view lists documents and provides means of accessing them. Every application must have at least one view. Each view can display all or a subset of the documents in the IISS. Typically, a view will list the document titles, possibly with author's names, creation dates, and similar information. The aim of view design is to make it easy for users to find the documents that they want to read.

The IISS contains the following views.

a) "Actions (All)\Assigned To": This view shows the assigned actions by person's name.

b) 'Issue Discussion By' i) Access History: This view shows who have accessed and contributed to the discussion and ii) Category: This view shows discussion documents by issue category.

c) Issue Discussion: i) Details: This view shows the content of the discussion and ii) Summary: This view shows a summary of the discussion.

d) Master Document: This view shows the master document.

e) Weekly Reports: This view shows weekly status reports of all departments.

Figure 5.12 shows a view of discussion documents by category and Figure 5.13 shows a view of weekly reports of various departments.

5.3.8 Security in the IISS Application

Everyone in CDD has at least "read access" to IISS. The members of the CE team have "editor access" to IISS. This means that they can modify discussion documents by adding information at the end of it, but they cannot delete any documents. The resolution section in the discussion document is reserved for the issue originator and the program manager. This means that only the issue originator or the program manager can enter the resolution and change the status of the issue as "Resolved." The report section of the weekly report form is reserved for the author of the report. This means that everyone can read the report but cannot modify it even by an accident. The action part of the team action form is reserved for the author. The author can define access to the second part in which the responsible person whom the action is assigned can enter his report. This means that only the action assignor can edit the first part of the document and only action assignee can edit the second part of the document.

Issue Title	Product Stage	StartDate	Issue Status	Resolved
7200 rpm motor	EM Build & Test	03/24/95	Open	
Appearance of Doclink in Mail Message	EM Build & Test	03/24/95	Open	
Chip-on-Flex	EM Build & Test	03/13/95	Open	
Clamp Ring	EM Build & Test	03/13/95	Open	
Configuration	EM Build & Test	03/15/95	Open	
Embedded Servo	Concept	03/07/95	Open	
Interfaces (Ultra SCSI & Fiber Channel)	EM Build & Test	03/29/95	Open	
Magnetic Latch	EM Build & Test	03/07/95	Open	
Media (Laser Zone Texture)	EM Build & Test	03/23/95	Open	
PRML Read Channel (SSI)	Concept	02/20/95	Open	

Figure 5.12. A View in IISS Showing Discussion Documents

Weekly Report From	From Date	To Date	Prepared By
Electrical			
	02/13/95	02/20/95	Ron Metzner
	02/21/95	02/28/95	Ron Metzner
	03/01/95	03/08/95	Ron Metzner
	03/15/95	03/22/95	Ron Metzner
	03/08/95	03/15/95	Ron Metzner
Heads & Media			
	03/16/95	03/23/95	Rafael Gutierrez
Manufacturing			
	02/20/95	02/27/95	Stan Bramel
Materials			
	02/20/95	02/27/95	Kay K Wilt
	03/06/95	03/10/95	Kay K Wilt
	03/13/95	03/17/95	Kay K Wilt
	03/20/95	03/27/95	Kay K Wilt
	03/27/95	03/31/95	Kay K Wilt
Mechanical			
	02/13/95	02/20/95	Mark Maggio
	02/20/95	02/27/95	Mark Maggio
	02/25/95	03/03/95	Mark Maggio
	03/06/95	03/12/95	Mark Maggio
	03/13/95	03/19/95	Mark Maggio
PCC			
	02/21/95	02/28/95	Brent VanDerVliet
	03/30/95	03/06/95	Brent VanDerVliet
	03/09/95	03/16/95	Brent VanDerVliet
Program Management			
	02/20/95	02/27/95	Gary Hamilton

5.13 A View in IISS Showing Weekly Report Documents

5.4 Evaluation of the IISS

After developing an application in Lotus Notes, the IISS is debugged and tested. Application Developer's Reference for Lotus Notes Release 3 gives a checklist for the developer to use in testing and debugging the application. The next step is to review the design with the end users. Two CE teams in CDD have used the IISS. One team used it for more than three months spanning two stages of the product design process. These two stages are i) detail design and review and ii) prototype build and test. The second team used it for more than two months. Three methods used to evaluate the IISS were as follows.

i) Attending CE meetings and judging the effect system had on CE team's working,

ii) Informal talks with users of the system and the program managers, and

iii) Formal questionnaire to measure the user satisfaction.

5.4.1 Attending CE meetings

The most important, visible effect after the CE team started using IISS was saving 30 minutes of the meeting time. Prior to IISS team members were using overhead transparencies to display and read key points from their reports. Reading these reports aloud consume a lot of meeting time. When a team member was presenting his report, some members wrote the points down in their log books while others relied on their memories. Some team members made copies of their reports and distributed them to others. Now team members are using the IISS to post their department's weekly progress reports. Thus, reports are available to all CE team members well before the meeting time. Some team members get time to go through the report and come to the weekly meeting prepared. Some team members do not get time to read before the meeting but they know where the report exists and can update themselves as soon as they find time. The team members from the highly involved departments are now refusing to read the reports from the transparencies as they used to do prior to availability of the IISS.

The team members discuss various issues in the team meetings. They do not employ any secretarial service to write down the key points of the discussion. As a result of this the intent or the rationale behind arriving at certain decisions was always lost prior to use of the IISS. After the introduction of the IISS, they have started using 'Issue Discussion Form' of the IISS to discuss the development related issues. It has not completely replaced the issue discussion in meetings. However, sometimes they have continued their issue discussion in meetings after an original start on the IISS. The content of the discussion that happened on the IISS remains captured for every one to see whereas the part of the discussion that happened in meeting is lost.

5.4.2 Informal Talks with Users of the System and the Program Managers

The program managers seem to be very excited about the IISS. The first team and its program manager have been using IISS since December 1994. After seeing the obvious benefits for the first team by using this system, the second team's program manager insisted on using the IISS. The second program started in February 1995 and the team has been using IISS from week 1. The program managers said they have reports from all the departments in one place. The second team's program manager identified seven possible issue discussion titles. He wanted to have these titles as default titles. He has opened many discussion documents with these default titles. The third form of "Team Action" was not planned in the original design but added later after request from both team managers. This form allows them or any other managers to assign team actions to the appropriate team members.

The team members from the materials department are happy because after introduction of the IISS, they are getting other department reports on time. The IISS has saved them the trouble of printing their 12 page "Excel Sheet" report, making several copies, and distributing these copies to team members.

The quality engineer said that the "Weekly Report Form" is a very useful way of taking information to team members. He liked the concept of the "Issue Discussion Form" but was not sure how team members would receive it.

The manager of the "Heads and Media" department liked the whole concept of the IISS and wanted a similar system designed for his department's internal use. A meeting was called with his department's people to discuss the smaller version of the IISS for the "Heads and Media" department.

As expected, team members from "Drive Design Engineering" are using the IISS frequently. The team members from these departments are posting their reports every week. They are refusing to read these reports line by line as they used to do prior to the IISS. They are also using the "Issue Discussion Form" to open up new discussion documents.

As the first team moved in the "Prototype Build and Test" stage, more and more team members from manufacturing engineering have been opening up new discussion documents and posting their weekly reports.

5.4.3 Formal Questionnaire to Measure User Satisfaction of IISS

The frequent users of the system were asked to fill out a questionnaire about their experiences with the IISS. DeLone and McLean (1992) introduced a comprehensive taxonomy to organize diverse research in the area of Information Systems Success. This taxonomy posits six major dimensions or categories: information system quality, information quality, use, user satisfaction, individual impact, and organization impact. Doll et al. (1988) suggested a twelve-item instrument that measures five components of end-user satisfaction: content, accuracy, format, ease of use, and timeliness. Nickell and Pinto (1986) developed a twenty-item computer attitude scale (CAS) to measure attitudes towards computers. This questionnaire was designed by referring to these scales. The questions were to be answered on a five-point scale. In addition, they were asked to write down additional comments on how to improve the IISS.

The five point scale is shown in Figure 5.14. The scoring used in this section was performed as follows: a value of one through five was assigned to the responses, with one being assigned to "strongly disagree" and five being assigned to "strongly agree." The mean value of the scores was determined. The higher the average score, the more positive the users felt about the statement responded to.

strongly disagree	disagree	neither agree nor disagree	agree	strongly agree
1	2	3	4	5

Figure 5.14. User Satisfaction Measurement Questionnaire Scale

Table 5.2 lists the questions on the satisfaction analysis questionnaire. For each question, the distribution of individual responses is shown as well as the average score. The actual questionnaire which was used to test user satisfaction is given in Appendix C.

Table 5.2 Simple Analysis of User Satisfaction Questionnaire

	strongly disagree 1	disagree 2	neither agree nor disagree 3	agree 4	strongly agree 5	Median	Mean
Content Scale **Mean 3.73, α = 0.65**							
1) The issue discussion form is very helpful in starting discussion with appropriate people.	0	1	7	16	2	4.0	3.73
2) The issue discussion by using the database is a better method of discussion than a phone call or a meeting.	0	6	9	9	2	3.0	3.27
3) This method captures the content of the discussion which may be useful for future problem solving.	0	0	3	22	1	4.0	3.92
4) Posting weekly reports in the database has allowed me to be better prepared for meetings.	0	1	10	12	3	4.0	3.65
5) In my opinion, the mail notification and doclink attachments are very useful.	0	2	5	17	6	4.0	4.08
Accuracy Scale **Mean 3.38, α = 0.75**							
7) The user interface of the database always functions properly and never does strange or unexpected things.	1	2	15	6	2	3.0	3.23
8) The information that appears in the columns of different views of the database is always correct.	1	0	13	8	4	3.0	3.54
Format Scale **Mean 3.57, α = 0.55**							
9) The document formats are very useful. (on screen or in print).	0	1	9	14	1	4.0	3.60
13) The database is very easy to use.	0	1	5	16	4	4.0	3.88
14) The help statements within the database are very useful.	0	1	18	6	1	3.0	3.27

Table 5.2 Simple Analysis of User Satisfaction Questionnaire (Continued)

	strongly agree 1	disagre 2	neither agree nor disagree 3	agree 4	strongly agree 5	Median	Mean
Usefulness Scale **Mean 3.94, $\alpha = 0.65$**							
6) Using this database, team members can very effectively track team actions and the development activities.	0	2	5	17	2	4.0	3.73
10) Having all reports, issue discussions and team actions in one location is a major advantage.	0	0	0	19	7	4.0	4.27
11) Use of this database will make the product development process much more efficient.	0	2	2	19	2	4.0	3.84
12) Use of this database reduced a lot of paper work.	1	0	8	13	4	4.0	3.73
15) This database is very useful in submitting weekly reports.	0	1	7	13	5	4.0	3.85
16) A database like this should definitely be used on future projects.	0	0	0	18	7	4.0	4.28
Timeliness **Mean 3.60, $\alpha = 0.67$**							
18) By using this database I get the information I need from other departments in time.	0	1	11	11	2	4.0	3.56
19) This method of issue discussion saves a lot of time.	0	1	9	13	2	4.0	3.64
Other Questions							
17) A database of this type should be expanded to cover more people involved in new product development.	0	1	10	10	4	4.0	3.68
20) The method of posting weekly reports in the database has shortened weekly meeting time considerably.	0	1	8	13	3	4.0	3.72

Table 5.2 Simple Analysis of User Satisfaction Questionnaire (Continued)

	strongly agree 1	disagre 2	neither agree nor disagree 3	agree 4	strongly agree 5	Medi-an	Mean
Optimistic Attitude **Mean 4.28, α = 0.78**							
21) The use of computers in general is enhancing the quality and efficiency of my work at CDD .	0	0	1	13	11	4.0	4.40
22) Life is easier and faster with computers and computer applications.	0	1	2	16	6	4.0	4.08
23) Computers are a fast and efficient means of getting information.	0	0	1	15	9	4.0	4.32
24) Computers can eliminate a lot of tedious work for people.	0	0	1	15	9	4.0	4.32
Pessimistic Attitude **Mean 2.54, α = 0.67**							
25) I am concerned that networks and shared databases will go too far in reducing person to person contacts.	2	9	7	6	1	3.0	2.80
26) Computer applications are difficult to understand and frustrating to work with.	3	16	2	4	0	2.0	2.28

5.4.2 Discussion on the Evaluation Results of the System

Forty questionnaires were distributed among the members of two NPD teams in CDD Twenty-six questionnaires were returned yielding a 65.0 percent response rate. Observe Figure 5.3 which shows the organizational structure of CDD. Six major departments are divided into nineteen subdivisions. Two persons from each subdivision, the manager and the project engineer, participate in the NPD teams. The questionnaires were distributed at the team meetings for two different products. The return responses cover most of the project engineers working on the two teams as they attend team meetings regularly. The remaining responses are from the managers who attended team meetings on the days of the distribution of the questionnaire. Fourteen managers did not return the questionnaire either because they were still unfamiliar with system or because they simply did not have time to complete them.

Table 5.2 lists the questions on the user satisfaction measurement questionnaire. For each question, the distribution of individual responses is shown, as well as the median and the mean score. The IISS has three forms: i) issue discussion, ii) weekly report, and iii) team action. The results are analyzed to determine their acceptance by the users of the system. The results are also analyzed on the basis of five components of end-user satisfaction -- content, accuracy, format, ease of use (or usefulness), and timeliness (or time) as suggested by Doll et al. (1988). Questions twenty-one through twenty-six measure the computer attitudes of the participants. These questions are based on the Computer Attitude Scale (CAS) developed by Nickell and Pinto (1986). A high correlation between CAS and Doll's (1988) five components would suggest that dissatisfaction with the system might be the result of a person's attitude toward computers.

5.4.2.1 <u>Acceptance of the Issue Discussion Form</u>: In Table 5.2, questions one through three and question nineteen measure the response for the issue discussion part of the IISS. Observe that the responses to questions one, three and nineteen have a median of 4.0 and means 3.73, 3.92, and 3.64, respectively. These numbers indicate that more than half the respondents are above 4.0 on the five-point Likert type scale and agree or strongly agree with the following three statements:

i) The issue discussion form is very useful in starting a discussion with the appropriate people.

ii) This method captures the content of the discussion which may be useful for future problem solving.

iii) This method of issue discussion saves a lot of time.

Question two have median of 3.0 and mean of 3.27. In the distribution, eleven out of twenty-six respondents agree or strongly agree that the issue discussion form works better than a phone call or meeting. Nine respondents neither agree nor disagree with above statement, and six respondents disagree with the statement.

Considering the high median value for the three out of four questions, users seem to be satisfied with the issue discussion form of the IISS.

5.4.2.2 <u>Acceptance of the Weekly Report Form</u>: In Table 5.2, questions four, fifteen, and twenty measure the response for the weekly report form. Observe that the responses to questions four, fifteen and twenty have a median of 4.0 and a mean of 3.65, 3.85, and 3.72, respectively. These numbers indicate that more than half of the respondents are above 4.0 on the five-point Likert type scale and agree or strongly agree with the following three statements:

i) Posting weekly reports in the system has allowed me to be better prepared for meetings.

ii) This system is very useful in submitting weekly reports.

iii) The method of posting weekly reports in the database has shortened weekly meeting time considerably.

Considering the high median value for all three questions, the users seem to be satisfied with the weekly report form of the IISS.

5.4.2.3 <u>Acceptance of Team Action Form</u>: In Table 5.2, question six measures the response for the team action form. Observe that the responses to these questions have a median of 4.0 and a mean of 3.73. These responses indicate that more than half the respondents are above 4.0 on the five-point Likert type scale and agree or strongly agree with the following statement:

i) Using this system, team members can very effectively track team actions and the development activities.

Considering the high median value for the question, users seem to be satisfied with the team action form of the IISS.

5.4.2.4 General Acceptance of the IISS: In Table 5.2, questions ten, eleven, thirteen, and sixteen through eighteen measure the general acceptance of the IISS. Observe that the responses to questions ten, eleven, thirteen, and sixteen through eighteen have a median of 4.0 and a mean of 4.27, 3.84, 3.88, 4.28, 3.68, and 3.56, respectively. These numbers indicate that more than half of the respondents are above 4.0 on the five-point Likert type scale and agree or strongly agree with the following six statements:

i) Having all reports, issue discussions, and team actions in one location is a major advantage.

ii) Use of this database will make the product development process much more efficient.

iii) The database is very easy to use.

iv) A database like this should definitely be used on future projects.

v) A database like this should be expanded to cover more people involved in new product development.

vi) By using this database, I get the information I need from other departments in time.

Considering the high median value for all six questions, the users seem to be satisfied and accept the IISS.

5.4.2.4 Results of the Evaluation based on the Content of the IISS: In Table 5.2, questions one through five, measure the response for the content part of the IISS.

Observe questions one and three through five have a median of 4.0 and mean values of 3.73, 3.92, 3.65, and 4.08, respectively. These numbers indicate that more than half of the respondents are above 4.0 on the five-point Likert type scale and agree or strongly agree with the content of the IISS.

The response to question two has a median of 3.0 and a mean of 3.27. Eleven out of twenty-six respondents agree or strongly agree that the issue discussion by using the system is a better method of discussion than a phone call or meeting. Nine respondents neither agree nor disagree with the above statement and six respondents disagree with the statement.

Observe the reliability coefficient of 0.65 in Table 5.2 for the content scale. This score indicates that the content scale is adequately reliable. Considering the high median value for the five out of six questions, users seem to be satisfied with the content of the IISS.

5.4.2.5 Results of the Evaluation Based on the Accuracy of the IISS: In Table 5.2, questions seven and eight measure responses about the accuracy of the IISS. Observe that responses to questions seven and eight have a median of 3.0 and mean values of 3.23 and 3.54, respectively. In the distribution for question seven, eight out of twenty-six respondents agree or strongly agree that the user interface of the system always functions properly and never does strange or unexpected things. Fifteen respondents neither agree nor disagree with above statement, and three respondents disagree or strongly disagree with the statement.

Observe the reliability coefficient of 0.75 in Table 5.2 for the accuracy scale. This score indicates that the accuracy scale is adequately reliable.

The IISS is a network based database and resides on one server while all the users' accounts are on other servers. If one of the servers is down, then the users cannot get to the system. Users may click on the link to the document, but they will not be able to open it. If a file is attached to a report or an issue document, then the user must have the appropriate software to open that file. That is, to open a file attachment with an ".XLS" extension, each user must have access to the "Microsoft Excel" program. These are just some of the reasons why a high number of respondents neither agree nor disagree with question seven. At this point, additional information is required from the respondents experiencing strange things.

5.4.2.6 Results of the Evaluation Based on the Format of the IISS: In Table 5.2, questions nine, thirteen and fourteen measure the responses about the format of the IISS. Observe the responses to questions nine and thirteen have a median of 4.0 and mean values of 3.60 and 3.88, respectively. These numbers indicate that more than half of the respondents are above 4.0 on the five-point Likert type scale and agree or strongly agree with the format of the various forms used in the IISS.

Question fourteen has a median of 3.0 and a mean of 3.27. In the distribution, seven out of twenty-six respondents agree or strongly agree that the help statements within the IISS are very useful. Eighteen respondents neither agree nor disagree with above statement and one respondent disagrees with the statement. These responses were surprise since every field in the system is accompanied by help statements typed in attention-getting red below the field. In fact, this particular way to show help statements were suggested by some of the users.

Observe the reliability coefficient of 0.55 in Table 5.2 for the format scale. This score indicates that the format scale is adequately reliable.

Considering the high median value for the two out of three questions, the users seem to be satisfied with the overall format of the IISS.

5.4.2.7 Results of the Evaluation Based on the Usefulness of the IISS: In Table 5.2, questions six, ten through twelve, fifteen, and sixteen measure the response for the usefulness or ease of use of the IISS. Observe that the responses to all these questions have a median of 4.0 and mean values of 3.73, 4.27, 3.84, 3.73, 3.85, and 4.28, respectively. These numbers indicate that more than half of the respondents are above 4.0 on the five-point Likert type scale and agree or strongly agree with the usefulness of the IISS.

Observe the reliability coefficient of 0.65 in Table 5.2 for the usefulness scale. This score indicates that the usefulness scale is adequately reliable.

Considering the high median value for all six questions, the users seem to be satisfied with the usefulness of the IISS.

5.4.2.8 Results of the Evaluation Based on the Timeliness of the IISS: In Table 5.2, questions eighteen and nineteen measure responses about the timeliness of the IISS. Observe that the responses to both of these questions have a median of 4.0 and mean values of 3.56, and 3.64, respectively. This indicates that more than half of the respondents are above 4.0 on the five-point Likert type scale and agree or strongly agree with the timeliness of the IISS.

Observe the reliability coefficient of 0.67 in Table 5.2 for the timeliness scale. This score indicates that the timeliness scale is adequately reliable.

Considering the high median value for all three questions, the users seem to be satisfied with the timeliness of the IISS.

5.4.2.9 Computer Attitudes of Respondents: In Table 5.2, questions twenty-one through twenty-six measure the computer attitudes of respondents. The highest value on the scale is 4.83 and the lowest is 3.33. Sixteen out of twenty-five respondents have value 4.0 or higher on this scale. These numbers indicate that 64 percent of the respondents have a very positive attitude towards computers and computer applications.

Seven out of twenty-five responses have values 3.5 or lower on this scale and two responses have values between 3.5 to 4.0.

Observe the reliability coefficients of 0.78 and 0.67 in Table 5.2 for the computer attitude scale. This score indicates that the CAS is adequately reliable.

Considering the lowest value of 3.33 on this scale, all respondents are above average on the scale with a middle point of 3.0.

CHAPTER 6

CONCLUSIONS AND FUTURE SCOPE

The new contributions that this research makes to CE product design can be listed as follows:

i) The research proposes a communication model for concurrent engineering design and then validates this model using data from industry. Statistical analysis of the data provides results for the involvement of departments and the interactions of departments during product design stages. Network diagrams, showing the involvement of departments and the communication links between departments during each stage of the product design, are one of the major contributions of this research.

ii) The research also identifies seventeen broad information categories and considers ten departments in an organization. Data is collected on information exchange requirements for each category during each stage of the product design for each of ten departments. An analysis of the results suggests the information exchange requirements for each department during the four stages of the product design process. Determining the level of information needed by each department during each stage of product design is a second major contrubution of this research.

iii) The results of the information exchange requirements are used in building an information interchange support system for the NPD team. This system integrates the results of departmental involvement and information exchange requirements. This system is evaluated for user satisfaction by using scales on content, accuracy, format, usefulness, timeliness, and computer attitudes. The success of such an information system is a third major contribution of this research.

6.1 Conclusions on the Survey Analysis

The survey had three pages. The first page of the survey determined the levels of departmental involvement in a successful new product design project. The second page of the survey determined the levels of departmental interactions in a successful new product design project. The third page determined the information exchange requirements for each department in a successful new product design project. The following sections conclude the results of each page of the survey.

6.1.1 Conclusions on the Levels of Departmental Involvement in the CE Product Design

Results of the first page analysis suggests that human resources allocated to a team from various functional areas can be scheduled in an efficient manner by recognizing their levels of involvement appropriately. Research results confirm that teams tend to have different functional units forming the core group during various stages of the product design phase of the new product development process. Marketing, design, research and development, and project management departments form the core group during stage 1 (product specification) and stage 2 (conceptual design and review). Manufacturing, design, purchasing, and project management departments form the core group during stage 3 (detail design and review). The quality assurance department joins the core group of stage 3 during stage 4 (prototypes build and test). Project management department is usually responsible for coordinating the new product development process; whereas, design department is responsible for major development activities during the design phase of the product development process. Hence both project management and design departments need to be involved actively throughout the product design process. The marketing department needs to play a very critical role during the early stages of product design. If the product idea comes from marketing department, then it will play a very critical role in defining the specification of the new product. Once detailed specifications have been developed, marketing department can assume a slightly less active role until a prototype is built, at which stage marketing department's input becomes critical again. If the product idea comes from research findings, then research and development will play a very critical role in defining the specifications of the new product. Whether the product idea comes from marketing or from the research laboratory, research and development department's input is critical in stage 2 (conceptual design and review) as the design department tries to integrate different concepts in forming conceptual designs. Once the conceptual designs are evaluated, research and development can assume a slightly less active role. Manufacturing, purchasing, and quality assurance departments are expected to play more vital roles as the product design approaches stage 3 (detail design and review) and stage 4 (prototypes build and test). The manufacturing department will give input on available processes, will start process planning, and will actually build a prototype during stage 4. The purchasing department will bring its and suppliers' input on the availability of parts and materials. It will procure materials required for the prototype build and will develop long term relationships with suppliers. The quality Assurance will plan and conduct tests for critical components and prototypes. These results are summarized in Table 6.1. While these results may be intuitive, this survey provides one of the first empirical examinations of organizations following a dynamic approach to product design team composition.

Table 6.1

Major Players and Peripheral Players by Stages

Product Design Stages	Players at Center	Players at Periphery
1 Product Specification	Marketing, Design, R. & D., Project Management	Top Management, Sales, Manufacturing, Purchasing,
2 Conceptual Design and Review	Marketing, Design, R. & D., Project Management	Top Management, Sales, Manufacturing, Purchasing, Quality Assurance, Finance
3 Detail Design and Review	Design, Manufacturing, Project Management, Purchasing	Marketing, Qua. Assurance, R. & D., Top Management, Finance, Sales
4 Prototype Build and Test	Project Management, Design, Manufacturing, Qua. Assur., Purchasing	Marketing, Top Mgmt., Finance, Sales, R. & D.

6.1.2 Conclusions on the Levels of Departmental Interactions in the CE Product Design

An analysis of second page responses revealed that the departments which form a core group during a given stage have higher levels of interaction between them than departments at the periphery. Thus, the levels of interaction between marketing, design, research and development, and project management departments (which form the core group at stage 1 and stage 2) are higher than their levels of interaction with departments at the periphery and much higher than levels of interaction between departments at the periphery. The exceptions to this observation are the interactions between marketing and sales departments and between design and research and development departments. The sales department stays at the periphery during all stages of the product design process. However, it maintains a fairly high level of interaction with the marketing department throughout the product design process. Similarly, research and development is not a member of the core group during stages 3 and 4 but maintains its high level of interaction with the design department.

6.1.3 Conclusions on Information Exchange in the CE Product Design

The results of the third page analysis confirm that an information technology should be employed to maintain an optimum level of communication between departments. The results also suggest that for each stage of the CE design process, departments having high levels of involvement in the design process will exchange detailed information than departments having moderate and low levels of involvement. Thus, communication is more detailed among central departments at a particular stage; whereas, other departments that are at the periphery need to receive summary information.

As discussed in section 2.2.4, Nam Suh advocates proper control of the design process to satisfy the second design axiom which states that best design always has minimum information content. The meaning of proper control of the design process can be interpreted as bringing to the design process the appropriate information at the appropriate time. By developing a model of who communicates with whom during each stage of the engineering design process and what the content of such information would be, a technologically based support system was developed so that a CE team gets important information on a timely basis.

6.2 Use of the IISS in the CE New Product Design Project

The IISS have three major forms for users: i) an issue discussion form, ii) a weekly report form, and iii) a team action form.

Three methods used to evaluate the IISS (Refer chapter 5, section 5.4) revealed that the issue discussion form in IISS is very useful in starting a discussion with the appropriate people and this method of issue discussion captures the content of the discussion. The users strongly agree that capturing the content of the discussion might be useful on the future projects. The IISS evaluation results also suggest that this method of an issue discussion saves a lot of time for users.

An evaluation of the weekly report form of the IISS revealed that by posting weekly reports in the IISS has allowed the users to be better prepared for meetings. The evaluation of this form also suggests that this method of posting weekly reports in the IISS has helped CE team to shorten its weekly meeting time considerably.

An evaluation of the team action form of the IISS revealed that team members can very effectively track team actions and the development activities by using the IISS.

Thus, it can be concluded that the IISS developed in Lotus Notes can keep all product development reports in a single database, can generate a development history for future use, can make the reports and documents generation process easy for team members, can reduce product development time by form routing, can enhance effective communication between members of the CE team, and can make it easy for the management to track product development activities.

Some of the specific benefits of using IISS for the team can be summarized as follows:

- CE team meetings are shortened by at least 30 minutes,
- Reduction in paper work,
- All reports and documents are available in a single repository,

- Capturing of design rationale,
- Effective tracking of product development activities,
- Easy access to appropriate information whenever required, and
- No drowning in an ocean of information.

6.3 Future Scope

This research has examined only the product design phase of the new product development process. Other phases of the new product development process need to be divided into similar small stages where the different roles and communication processes can be examined. Models formed and validated at other phases of the new product development process can be integrated into a single comprehensive model for an entire new product development process. This way human resources can be efficiently allocated over entire life cycle of the product and between different new product development projects.

The developed IISS does not have the capability to combine ten documents into a single document by taking relevant information from each document. This is because the present version of Lotus Notes does not have this capability. The Notes application programming interface with 'C' language should be explored to add this capability to this information system.

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APPENDIX A

QUESTIONNAIRE ON PRODUCT DESIGN

A.1 Cover Letter

Oklahoma State University

COLLEGE OF ENGINEERING, ARCHITECTURE AND TECHNOLOGY

School of Mechanical and Aerospace Engineering
Stillwater, Oklahoma 74078
Engineering North 218
405-744-5900
FAX 405-744-7873

Date: April 15, 1994

Mr. Norman Ehlers
VP -- Purchase & Supply
Ford Motor Co.
The American Rd.
Dearborn, MI 48121

Dear Mr. Ehlers:

The last few years have witnessed the growth of a new product development approach where key people from various departments work together to reduce product development time, to meet customer needs, and to improve the product quality. We are a team of researchers from engineering and business colleges, who are conducting research to understand the communication patterns and content of information interchange during this process. Specifically, our research attempts to answer the following questions:

- What role does each department play at each stage of the product design process?
- How much interaction takes place among various departments at each stage of the design process?
- What information is exchanged among various departments at each stage of the design process?

We need your help to accomplish these objectives. To do this, please think of a successful new product development project that you will use as a reference to complete the attached questionnaire. We have provided an example of responses on each page following the directions.

The complete new product development process involves many steps, from idea generation through product roll out. However, this research concentrates on four stages of the product design process: 1) Product specification, 2) conceptual design and review, 3) detail design and review, 4) prototype build and test. These are defined further on the first page of the questionnaire. For this study, please assume that sales and/or marketing represent customer inputs, and the purchasing department represents supplier inputs.

We realize your time is extremely valuable, but your response will make an important contribution to our research. All responses are confidential. Results will be reported only in an aggregate form. Naturally, we will be delighted to share the results with you. Please provide your name and address on the questionnaire you return. Thank you very much for your willingness to assist in this research.

Sincerely,

Atul Deosthali	Ron Delahoussaye	Ramesh Sharda	Gary Frankwick
Ph. D. Candidate	Asst. Professor	Conoco/Dupont Professor of	Asst. Professor
Mechanical Engg.	Mechanical Engg.	Management of Technology	Marketing

QUESTIONNAIRE ON NEW PRODUCT DESIGN PROCESS

1) Based on the successful project, please indicate the level of involvement for each department at each of the four stages of the design process.
Use a scale of "1" to "9" where: "1" = No Involvement, "3" = Low Involvement, "5" = Moderate Involvement, "7" = High Involvement, "9" = Maximum Involvement.

Departments in a Firm	STAGE 1 FORMING PRODUCT SPECIFICATIONS Detailed specifications about the new product are formed by the concerned departments.	STAGE 2 CONCEPTUAL DESIGN & REVIEW Design Department uses the product specifications to create multiple conceptual designs in the form of sketches, informative notes etc. These conceptual designs are evaluated to select some for creating detailed designs at the next stage.	STAGE 3 DETAIL DESIGN & REVIEW The arrangement, form, dimensions and surface properties etc. of all individual parts are determined, the materials & processes specified, the technical and economic feasibility re-checked, and the drawings and production documents are produced.	STAGE 4 PROTOTYPE BUILD & TEST Prototypes are built (by using actual production line if possible) to closely resemble the finished product so that form, fit, function and aesthetics can be assessed. Resultant changes are made and the product re-evaluated before volume production parts are tooled and produced.
Example: Department X	9	7	5	3

Marketing / Customer Input				
Design				
Top Management				
Research & Development				
Finance / Accounting				
Purchasing / Supplier Input				
Mfg. (Includes Pro. Planning & Prod.)				
Quality Control				
Sales / Customer Input				
Project Management				
Any other dept. Please specify				

2) Based on the successful project, please indicate the level of interaction between each pair of departments at each of the four stages of the design process. Use a scale of "1" to "9" where:

"1" = No Interaction, "3" = Low Interaction, "5" = Moderate Interaction, "7" = High Interaction, "9" = Very High Interaction

Example:	Marketing	Design	Top Mgmt.	R. & D.	Finance / Acctg.	Purchasing	Production	Quality Control	Sales	Project Mgmt.	Marketing	Design	Top Mgmt.	R. & D.	Finance / Acctg.	Purchasing	Production	Quality Control	Sales	Project Mgmt.
Depatment X	9	8	7	5	5	3	3	1	5	5	5	9	3	3	3	3	3	1	3	5

Departments	Stage 1: Product Specification									
Marketing										
Design										
Top Mgmt.										
R. & D.										
Finance / Acctg.										
Purchasing										
Production										
Quality Control										
Sales										

Departments	Stage 2: Conceptual Design and Review									
Marketing										
Design										
Top Mgmt.										
R. & D.										
Finance / Acctg.										
Purchasing										
Production										
Quality Control										
Sales										

	Marketing	Design	Top Mgmt.	R. & D.	Finance / Acctg.	Purchasing	Production	Quality Control	Sales	Project Mgmt.
Departments	Stage 3: Detail Design and Review									
Marketing										
Design										
Top Mgmt.										
R. & D.										
Finance / Acctg.										
Purchasing										
Production										
Quality Control										
Sales										

	Marketing	Design	Top Mgmt.	R. & D.	Finance / Acctg.	Purchasing	Production	Quality Control	Sales	Project Mgmt.
Departments	Stage 4: Prototype Build and Test									
Marketing										
Design										
Top Mgmt.										
R. & D.										
Finance / Acctg.										
Purchasing										
Production										
Quality Control										
Sales										

3) To complete this page, feel free to consult with team participants from other departments of the company. Please circle the stage numbers at which the departments (listed across the top) need to send/receive information listed in the left hand column. Please note that we are not determining the importance of the information category to any of the departments. We want to know which departments specifically send or receive such information at a particular stage.

Stages: 1 = Product Specification 2 = Conceptual Design & Review 3 = Detail Design & Review 4 = Prototype Build & Test

Information Categories	Marketing	Design	Top Mgmt.	R. & D.	Finance/ Accountin	Purchasin	Manufa- cturing	Quality Control	Sales	Project Mgmt.
Example: Information Category X	① 2 3 4	① ② ③ ④	① 2 3 4	① ② 3 4	1 2 3 4	1 2 ③ ④	1 ② ③ ④	1 2 3 ④	1 2 3 ④	① ② ③ ④
Company goals & policies	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
Budget for new product	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
Capital investment in tools & technologies	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
Consumer preferences & needs	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
Product mix and synergy	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
Forecast of sales volume, revenue, gross margins	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
Dimensional, material, functional & modularity issues	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
Product maintenance, repair, ease of Assembly/disassem	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
Manufacturing process issues: e. g. layout, capacities & schedule	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
Quality & reliability issues: e.g. quality of supplier's part	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
Safety issues: safety of product, processes operation	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
Environmental pollution, disposal & recyclability issues	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
Labor issues	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
Availability, quality and cost of parts & materials	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
Product scheduling & time to the market	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
Distribution issues	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
Product retirement, legal & liability Issues	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4

4) Background Information:

Please describe the product you had in mind while completing this questionnaire.____

Company Information: Number of employees: ____________,

Annual Sales: ____________

Functional area of the person completing questionnaire:

______ Marketing ______ Design

______ R. & D. ______ Top Mgmt.

______ Finance ______ Purchasing

______ Production ______ Quality control

______ Sales ______ Project Mgmt.

______ Other (Please specify) ________________

Educational background of person completing questionnaire: (Check all that apply)

______ Engineering ______ Business

______ Liberal Arts / Humanities ______ Physical Sciences

______ Life Sciences ______Agriculture Tech.

______ Computer Science ______ Law

______ Behavioral Sciences ______Other:

____

Number of years professional experience:

______ 0 -- 5

______ 6 -- 10

______ 11 -- 15

______ 16 and more

Optional Information

Name: ______________________________

Company: ______________________________

Address: ______________________________

Phone No.: ________________, Fax No.: ________________

________ Check here if you wish to receive a copy of the results.

A.2 Follow Up Letter

Oklahoma State University

COLLEGE OF ENGINEERING, ARCHITECTURE AND TECHNOLOGY

School of Mechanical and Aerospace Engineering
Stillwater, Oklahoma 74078
Engineering North 218
405-744-5900
FAX 405-744-7873

Date: July 15, 1994

Mr. William Avery
VP -- Product Operations
Encore Computer Corp.
6901 W. Sunrise Blvd.
Fort Lauderdale, FL 33313

Dear Mr. Avery:

A few months ago we requested you to complete a mail questionnaire on new product design. In the event you haven't mailed the completed questionnaire, would you please consider doing so? Your response is very important and the aggregate results can be useful to understand the roles of different departments and the information exchanged during a successful product design process. We realize your time is extremely valuable. **If you are unable to complete the questionnaire due to time constraints or due to other reasons, would you please pass it to the members from your department and/or organization contributed in the new product design project?** We have enclosed another copy of the questionnaire with this letter.

Specifically, our research attempts to answer the following questions:

- What role does each department play at each stage of the product design process?
- How much interaction takes place among various departments at each stage of the design process?
- What information is exchanged among various departments at each stage of the design process?

The complete new product development process involves many steps, from idea generation through product roll out. However, this research concentrates on four stages of the product design process. These stages are defined further on the first page of the questionnaire. Please assume that sales and/or marketing represent customer inputs, the purchasing department represents supplier inputs, and the production department includes manufacturing engineering and testing. **Please think of a successful new product development project that you will use as a reference to complete the attached questionnaire.**

We will be delighted to share the results with you. Please provide your name and address on the questionnaire you return. Thank you very much for your willingness to assist in this research.

Sincerely,

Atul Deosthali	Ron Delahoussaye	Ramesh Sharda	Gary Frankwick
Ph. D. Candidate	Asst. Professor	Conoco/Dupont Professor of	Asst. Professor
Mechanical Engg.	Mechanical Engg.	Management of Technology	Marketing

APPENDIX B

LOTUS NOTES: AN OVERVIEW

Lotus Notes is a group information manager. It helps teams in effectively collecting, organizing, and sharing information over local-area networks, wide-area networks, and dial-up lines. In Notes, the database is the foundation of every application; and the terms "application" and "database" are used interchangeably. Every Notes application uses a database. Some applications use more than one database. The databases or applications are created for a particular purpose. Some databases are used for storing and composing electronic mail memos; others serve as discussion forums. Still others serve as data repositories.

Information can be mailed between Notes databases, external data can be imported into Notes, and dynamic links to other applications can be created to see up-to-the-minute changes in the data stored there. Macros can be created that run in the background, automatically performing routine operations with no user intervention.

The application databases can all be stored in one place, or they can be distributed among several Notes servers. Users can work with the application on a LAN, or they can dial-in from another location, and exchange updates over a modem line. User access to application databases can be strictly controlled. Data can even be encrypted for routing and storage.

The information within a database is organized and maintained with five basic building blocks: **views, forms, fields, sections, and documents**. This information is taken from Lotus Development Corporation's "Application Developer's Reference" manual (1993) for Lotus Notes Release 3.

B.1 Views

A view is a tabular summary of the documents in the database. Most databases have several views, each sorting, selecting, and categorizing the documents in a different way. For example, personal mail can be arranged by author in one view, by date in another, and by topic in a third. User can design private views that include only those documents in which they have an interest. A private view is accessible only to the person who created it.

B.2 Forms

A form defines the format and layout for documents. Each form can contain fields, static text, graphics, and buttons, which determines how users enter information, and then how that information is processed and displayed. When user composes a document, the form that he is using determines which fields are included in his document. A database can have number of different forms. Designing a form in a Notes database is like designing the screen layout for another application. When the designer designs a form, he designates the form attributes and formats the text that appears in the form. He specifies the nature of information that will be contained in a document by defining the form's fields.

B.3 Fields

A field is a named area of a form that contains a single type of information. Every field that designer defines must have a name and a data type. The data type determines what kind of data it will contain, for example, text, rich text (including graphics), numbers, or dates. The field's data type as well as how it will be displayed is defined when the field is added to the form. A form can have an unlimited number of fields. Depending on its data type, the value of a given field can be as small as a single character, or many pages of text and graphics.

B.4 Sections

A section is a special type of field that logically defines an area of a form or document. Within a section, designer can place fields and static text; he can then control access to that section of the document so that only authorized users can edit the data within that section. Sections are also useful for enabling a document to receive multiple "electronic signatures" used to authenticate the document's editors. A section is marked with a solid line that extends the width of the form. All fields located below the section marker "belong" to that section.

B.5 Documents

Lotus Notes uses a document-oriented database; documents are the "records" in the database; it is analogous to a "row" in a relational database. The information in a document may be entered by a user, calculated by formulas incorporated in the database design, imported from other applications, or linked to another application and dynamically updated. A document can be any size. A single document may contain only a few alphabetic or numeric characters, or several pages of text and graphics.

APPENDIX C

User Satisfaction Measurement Questionnaire

(To improve the databases designed for the new product development teams, we need your feedback.)

Please return to Atul Deosthali (Room no. 265) or Richard Clark or Gary Hamilton.

Please answer following questions based on your experience of using 'Hawk XL'\'Cuda 4 LP' database.

Product Database Name: Hawk XL \ Cuda 4 LP \ Both (Please circle those you have used.)

	Not at all	little	moderate	frequent	heavy
Please circle how often you use this database.	1	2	3	4	5

Circle the answer on the scale which most closely coincides with your opinion.

	strongly disagree	disagree	neither agree nor disagree	agree	strongly agree
1) The issue discussion form is very helpful in starting discussion with appropriate people.	1	2	3	4	5
2) This is a better method of discussion than a phone call or a meeting.	1	2	3	4	5
3) This method captures the content of the discussion which may be useful for future problem solving.	1	2	3	4	5
4) Posting weekly reports in the database has allowed me to be better prepared for the meeting.	1	2	3	4	5
5) In my opinion, the mail notification and doclink attachments are very useful.	1	2	3	4	5
6) Using this database, team members can very effectively track team actions and the development activities.	1	2	3	4	5
7) The user interface of the database always functions properly and never does strange or unexpected things.	1	2	3	4	5
8) The information that appears in the columns of different views of the database is always correct.	1	2	3	4	5

	strongly disagree	disagree	neither agree nor disagree	agree	strongly agree
9) The document formats are very useful. (on screen or in print)······	1	2	3	4	5
10) Having all reports, issue discussions and team actions in one location is a major advantage.······	1	2	3	4	5
11) Use of this database will make the product development process much more efficient.······	1	2	3	4	5
12) Use of this database reduced a lot of paper work.······	1	2	3	4	5
13) The database is very easy to use.······	1	2	3	4	5
14) The help statements within the database are very useful.······	1	2	3	4	5
15) This database is very useful in submitting weekly reports.······	1	2	3	4	5
16) A database like this should definitely be used on future projects.······	1	2	3	4	5
17) The database of this type should be expanded to cover more people involved in the new product development.······	1	2	3	4	5
18) By using this database I get the information I need from other departments in time.······	1	2	3	4	5
19) This method of issue discussion saves a lot of time.······	1	2	3	4	5
20) The method of posting weekly reports in the database has shortened weekly meeting time considerably.······	1	2	3	4	5
21) The use of computers in general is enhancing the quality and efficiency of my work at Seagate.······	1	2	3	4	5
22) Life is easy and fast with computers and computer applications.······	1	2	3	4	5
23) Computers are a fast and efficient means of getting information.······	1	2	3	4	5
24) Computers can eliminate a lot of tedious work for people.······	1	2	3	4	5
25) Computer networks and shared databases will completely eliminate person to person contacts.······	1	2	3	4	5
26) Computer applications are difficult to understand and frustrating to work with.······	1	2	3	4	5

My Department: ______________________

Approximate Number of product development teams I participated in the past 5 years ________

27) How might this database be improved? (Please give your comments.)

VITA

Atul G. Deosthali

Cadidate for the Degree of

Doctor of Philosophy

Dissertation: DEVELOPMENT OF AN INFORMATION INTERCHANGE SUPPORT SYSTEM FOR CONCURRENT ENGINEERING PRODUCT DESIGN

Major Field: Mechanical Engineering

Area Specialization: Concurrent Engineering Product Design

Biographical:

Personal Data: Born in Maharashtra State, India, on December 24, 1959, the son of Mr. Gajanan B. Deosthali and Mrs. Shailaja G. Deosthali.

Education: Received Bachelor Degree in Textile Engineering from the Indian Institute of Technology, Delhi, India, in May 1983. Received Master's Degree in Mechanical Engineering with Machine Design option from Bombay University, Bombay, India, in July 1988. Completed the requirements for the Doctor of Philosophy degree with a major in Mechanical and Aerospace Engineering at Oklahoma State University in May 1995.

Work History: Employed as Department Assistant; Century Spg. & Mfg. Co.•, July 1983 to February 1984. Employed as Lecturer and Assistant Workshop Supdt.; Victoria Jubilee Technical Institute, June 1984 to December 1990. Employed as Graduate Research / Teaching Assistant; Mechanical and Aerospace Engineering, Oklahoma State University, January 1991 to December 1994. Employed as Lecturer; Mechanical and Aerospace Engineering, Oklahoma State University, January 1995 to May 1995.

Professional Memberships: American Society of Mechanical Engineers, U. S. A.; Associate Member of Institute of Engineers, India.

OKLAHOMA STATE UNIVERSITY
INSTITUTIONAL REVIEW BOARD
FOR HUMAN SUBJECTS RESEARCH

Date: 12-20-93 **IRB#:** EG-94-001

Proposal Title: DEVELOPMENT OF AN INFORMATION INTERCHANGE SUPPORT SYSTEM FOR CONCURRENT ENGINEERING DESIGN

Principal Investigator(s): Atul Deosthali, Ron Delahoussaye, Ramesh Sharda, Gary Frankwick

Reviewed and Processed as: Exempt

Approval Status Recommended by Reviewer(s): Approved

APPROVAL STATUS SUBJECT TO REVIEW BY FULL INSTITUTIONAL REVIEW BOARD AT NEXT MEETING.
APPROVAL STATUS PERIOD VALID FOR ONE CALENDAR YEAR AFTER WHICH A CONTINUATION OR RENEWAL REQUEST IS REQUIRED TO BE SUBMITTED FOR BOARD APPROVAL. ANY MODIFICATIONS TO APPROVED PROJECT MUST ALSO BE SUBMITTED FOR APPROVAL.

Comments, Modifications/Conditions for Approval or Reasons for Deferral or Disapproval are as follows:

Signature: ______________________ Date: December 22, 1993
Chair of Institutional Review Board

OKLAHOMA STATE UNIVERSITY
INSTITUTIONAL REVIEW BOARD
HUMAN SUBJECTS REVIEW

Date: 03-31-95 **IRB#:** EG-94-001A

Proposal Title: DEVELOPMENT OF AN INFORMATION INTERCHANGE SUPPORT SYSTEM FOR CONCURRENT ENGINEERING DESIGN

Principal Investigator(s): Ron Delahoussaye, A.G. Deosthali, Ramesh Sharda, Gary Frankwick

Reviewed and Processed as: Modification

Approval Status Recommended by Reviewer(s): Approved

APPROVAL STATUS SUBJECT TO REVIEW BY FULL INSTITUTIONAL REVIEW BOARD AT NEXT MEETING.
APPROVAL STATUS PERIOD VALID FOR ONE CALENDAR YEAR AFTER WHICH A CONTINUATION OR RENEWAL REQUEST IS REQUIRED TO BE SUBMITTED FOR BOARD APPROVAL.
ANY MODIFICATIONS TO APPROVED PROJECT MUST ALSO BE SUBMITTED FOR APPROVAL.

Comments, Modifications/Conditions for Approval or Reasons for Deferral or Disapproval are as follows:

Modifications received and approved. Approval continued through 04-09-96.

Signature: [signature]
Chair of Institutional Review Board

Date: April 10, 1995