

**The Application of System Engineering Methodologies in  
Support of the Lean Enterprise Transformation**

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SUBMITTED TO THE SYSTEM DESIGN AND MANAGEMENT PROGRAM IN PARTIAL  
FULFILLMENT OF REQUIREMENTS FOR THE DEGREE OF

MASTERS OF SCIENCE IN ENGINEERING AND MANAGEMENT  
AT THE  
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

FEBRUARY, 2001

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Submitted to the System Design and Management Program in Partial Fulfillment of Requirements for the Degree of Masters of Science in Engineering and Management

## **Abstract**

Present-day large-scale manufacturers are faced with a market environment characterized by dramatically increased competitive pressures and international influences. The impact on businesses, across a broad industrial spectrum, may be observed through the increased incidence of corporate mergers, joint ventures and consolidations. As the subject companies have encountered this new competitive environment, they are being forced to radically alter their traditional business practices in an effort to remain competitive and in many cases to merely survive.

One organizational initiative gaining increasing acceptance across a diverse constituency is the concept of the lean enterprise. The underlying principle of the Lean Enterprise Initiative is that of customer value maximization. The successful Lean Transformation requires a holistic understanding of the systemic interactions that exist among the myriad stakeholders comprising the modern industrial corporation irrespective of the specific market occupancy. These evolving market-driven realities result in intense pressure on manufacturers to cut costs and streamline processes, through improved efficiency across the entire value stream.

Unfortunately, the organizational structure extant in most corporations is the result of many years of evolutionary forces and uncoordinated local implementations. This dynamic is especially prevalent in mature companies, whose organizational structure has evolved in a relatively non-integrated manner, as evidenced by the high degree of fragmentation existing in their infrastructure and manufacturing processes. As corporations attempt to change, the existing organizational structure represents a nearly insurmountable political and cultural impediment.

This thesis shall provide an enterprise-wide examination of the organizational structure and processes of a typical large-scale aerospace manufacturer from a systemic perspective. The evolutionary derived organizational and process inefficiencies, which act as sources of *muda* and barriers to lean implementation shall be identified. It shall then demonstrate the viability and the utility of various Systems Engineering methodologies as key enablers of the organizational change initiatives mandated by the Lean Enterprise Transformation.

## *Acknowledgements*

The authors would like to thank several principal proponents of the System Design and Management program at Sikorsky Aircraft. The short list includes former Vice President of Engineering, Don Gover, Director of Employee Education, Lee Teft, former Director of Development Operations Jack Fischer and former Vice President of Development Operations John Carpino for their personal support of both the program and our individual involvement. We would also like to express our heartfelt gratitude to the many faculty members who have had such a profound effect on our educational experience. Additional thanks is extended to the many members of the SDM administrative staff who have endeavored to continuously improve the quality of the program and to ensure that our experience has been of a positive nature. In this regard, special recognition must go to Anna Barkley, who more than any individual has demonstrated a tremendous commitment to the success of the SDM program and the quality of the learning experience. Her departure from the program shall not be without regret. We wish her the best as she pursues new career opportunities.

Finally, Dave and I would like to reserve our greatest expression of gratitude for our families, without whose support none of this would have been possible. Their belief in our abilities, continuous encouragement and willingness to sacrifice throughout this two year journey have enabled us to overcome our doubts, forced us to remain focused and ultimately to succeed. Their understanding of our absences, both while away at school and when occupied with various coursework at home, has been unfailing, despite numerous difficult and trying situations. To all of them, Christy, Greta, Matthew, Meaghan and Joshua, we say "Thank you", "We love you" and "Honey, you will never have to take out the trash or shovel snow again." We hope that above all our effort and dedication to this course of study can serve as an example for others that hard work and persistence can reap tangible rewards.

Brian W. Millard

David L. Cocuzzo

I would also like to add a special dedication to my Mother, Marian Cocuzzo, who died November 22, 1999 while I was on campus. Last but certainly not least, I would like to thank my co-author, Brian Millard, who gave a push when required and has been an unfailing friend in more than just schoolwork. It is rare to have such support in life and I indeed believe myself to be most fortunate.

David L. Cocuzzo

## **Biographical Notes**

**David Lenard Cocuzzo** was born in Bridgeport, CT in 1959. In 1977 Mr. Cocuzzo attended Boston University and subsequently the University of Massachusetts, Amherst, receiving a Bachelor of Science in Mechanical Engineering in 1984. He was elected to the Tau Beta Pi Engineering Honor Society in 1982. Mr. Cocuzzo is presently employed at Sikorsky Aircraft subsidiary of United Technologies as Senior Technical Engineer, Airframe Systems Design and Development. Mr. Cocuzzo is married to Margreta Albright, and has three children, Matthew, Meaghan and Joshua.

**Brian Winfield Millard** was born August 18, 1962 in Johnstown, Pennsylvania. He earned an undergraduate degree in Electrical Engineering Technology at the University of Pittsburgh in 1984. Following graduation, he accepted an offer of employment with General Dynamics, Valley Systems Division in Pomona, California. In 1986, he returned to the East Coast to pursue an opportunity with the Sikorsky Aircraft Division of United Technologies Corporation. Following a moderately successful independent business venture in 1994 and 1995, he returned to the aerospace industry by taking a position with Kaman Aerospace Corporation. Several months later, he returned to Sikorsky Aircraft, where he is currently employed as the Electrical Product Development Team Leader for the S-92 Commercial Helicopter Program. In addition, Mr. Millard has been appointed as a Designated Engineering Representative (DER) by the Federal Aviation Administration. Brian and his wife, Christy, of 16 years currently reside in Oxford, Connecticut.

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# **Executive Summary**

## **Problem Statement**

The Lean Enterprise Transformation is gaining widespread popularity across a diverse industrial environment as corporations attempt to adapt to increasingly dynamic competitive marketplace. Unfortunately, radical process change initiatives are frequently unsuccessful. A major determinant in many cases is a general lack of awareness of the organizational discontinuities that result from years of evolutionary forces and uncoordinated local implementations. This research shall employ systems engineering methodologies to provide an enterprise-wide examination of the organizational structure of a typical large-scale aerospace manufacturer.

## **Originality Requirement**

The organizational examination forming the core of this research introduces a unique sequential application of the Lean Enterprise Value Stream Map and Process Timeline, in combination with Quality Function Deployment (QFD) and Design Structure Matrix (DSM). While the application of systems engineering methodologies in the context of organizational design is not entirely unprecedented, it is believed that the combinatorial application of QFD and DSM has not been demonstrated as proposed herein. In addition, their utility in support of the Lean Enterprise Transformation has not been examined.

## **Content and Conclusion(s)**

The analytical methods developed in this thesis employ modified versions of QFD and DSM to validate the findings of the initial Lean Enterprise analysis. As employed here, the focus of the QFD is the identification of the required design process participants in relationship to the

satisfaction of customer needs, rather than the traditional needs versus design attributes determination. The QFD was constructed for the purpose of establishing a *Figure of Merit* for each organizational constituent such that the relative importance of each subgroup in generating customer value may be quantified. The DSM is then employed to examine the relationships extant within the organization from three different perspectives and to illustrate the discontinuities and inefficiencies that have been hypothesized within the commentary of this work. The DSM is then manipulated in conjunction with the QFD derived *Figures of Merit* to propose an optimized and aligned organizational structure. In this context, the unique combined serial application of QFD and DSM to perform organizational design from a systems perspective is intended to validate the lean modeling techniques and to serve as an enabler of the lean enterprise transformation by eliminating organization-based barriers.

The proposed methodologies have been utilized to examine Sikorsky Aircraft's engineering organization. The combined QFD/DSM analysis clearly illuminates the presence of structural deficiencies within the current organization. Furthermore, the Systems Engineering tools support the findings of the Lean Enterprise Value Stream map and Process Timeline. The thesis indicates that the proposed methods are applicable to organizational design efforts in advance of the Lean Enterprise Transformation.

### **System Design and Management Principles**

The proposed methods incorporated in this work seek to extend the utility of two accepted Systems Engineering methodologies in conjunction with the Lean Enterprise concepts. Both QFD and DSM have been utilized in an attempt to establish organizational design. Throughout this treatise, the organization has been identified and contemplated as a complex subsystem

within the context of the Product Development Process (PDP). The underlying principle of the proposed methodology is the accurate identification and management of the system interfaces with respect to customer value.

### **Engineering and Management Content**

The engineering content within this document is concentrated in the Systems Engineering analysis of the PDP organization. The case study employed to demonstrate the veracity of the proposed modeling tool focused on the Engineering organization at Sikorsky Aircraft and employed a variety of engineering source data in the formulation of the QFD and DSM matrices. Ultimately, the proposed technique is intended to facilitate and support management activities relative to organizational complexities impeding change initiatives.

## **1. Introduction**

Companies today are being confronted with new competitive pressures that mandate increased efficiencies irrespective of their specific industry or market segment. At stake in many cases is the very survival of the organization or enterprise. Unfortunately, the organizational structure of most companies is a major contributor to the inefficiencies and tensions that plague the firm. This is predominantly due to the fact that in most cases the organization and processes that represent the foundation of the company have evolved in an unplanned and essentially haphazard fashion as the technology and the diffusion processes have matured. While the evolutionary process suggested is fundamentally insidious in nature, it may be revealed through an understanding of technology S-curves, product lifecycles, and diffusion which will be discussed briefly in Section 2. The lack of a holistic perspective during the evolutionary formation of the organization is manifested in the form of organizational inefficiencies and discontinuities that jeopardize the survival of the firm and result in major impediments to many attempts to reengineer the corporation.

This thesis shall examine one particular company occupying a leadership position in one specific industry. The subject company, Sikorsky Aircraft, shall first be analyzed in an effort to explain how and why the evolutionary process occurs. The next section of this thesis shall focus on the basic premise of the Lean Enterprise concept, the Value Chain Map. This tool shall be employed, in combination with process timeline and clockspeed<sup>1</sup> analysis, to identify the organizational and process inefficiencies that exist due to the evolutionary derived structure.

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<sup>1</sup> Fine, Charles H. *Clockspeed*. New York, NY; Harper Collins, 1998.

The ultimate goal of this thesis shall be the demonstration of the utility of a variety of Systems Engineering methodologies in support of the Lean Enterprise Transformation. This work shall illustrate the effectiveness of the subject tools as both an enabler of the initial development of the lean organizational structure and processes, and to support the subsequent transition to lean principles. Applications of Quality Function Deployment (QFD) and Design Structure Matrices (DSM) shall be proposed within this lean enterprise framework. Further, these methodologies shall be employed to substantiate the advantages of the lean enterprise systematization relative to the existing processes. The following paragraphs will provide insight into the company's current state of affairs by examining its market, technologies and customers. While the analysis contained herein shall be presented from the perspective of Sikorsky Aircraft, the basic causal forces that exist are not peculiar to the subject or its industry. Similar motivating factors are universally resident in other industrial markets and environments. Therefore, it is our opinion that the techniques and methodologies that will be presented are applicable across the industrial spectrum. This new technique, employing many of the concepts of systems architecture, systems optimization and systems engineering combined with market research techniques, will allow development of a comprehensive technology strategy and represents a key component of the lean enterprise transformation.

An examination of Sikorsky Aircraft Corporation has been conducted from the perspective of the principles of the lean enterprise. Sikorsky Aircraft was selected as a representative corporation, typical of the large-scale manufacturing firms found across the industrial compass. The case

study seeks to identify the numerous sources of non-value activities and waste, known as *muda*<sup>2</sup>, that originate due to the evolutionary nature of corporate organizational and process architectures, and present a structured systems-based approach to their elimination. The resultant inefficient patchwork organizational and process structure is characteristic of many firms, irrespective of their market segment. The political and cultural inertia that results from these organizational structures is a key component of corporate inefficiency and represents a significant impediment to lean enterprise transformation initiatives.

This case study has been divided into several distinct phases each with a specific focus. The first part of the analysis is intended to provide the reader with an overview of the subject company, enabling the audience to better understand the subsequent analysis. Section 2 of the document shall provide a historical perspective of the company and provide insight into the corporation's customers and products. In addition, a brief explanation of technology S-curves and technology diffusion as it relates to product lifecycles has been included. This discussion is intended to identify the combination of internal and external forces that result in the evolutionary changes that influence the organizational structure of the typical corporation.

Sections 3 and 4 present an analysis of the corporation utilizing the fundamental tools of Lean Enterprise transformation, including Value Stream mapping and Process Timeline Analysis. The goal of these sections has been to identify the inefficiencies, sources of *muda*, change barriers and lean opportunities residing within a typical manufacturing firm as a result of the evolutionary

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<sup>2</sup> Womack, James P. and Jones, Daniel T. *Lean Thinking: Banish Waste and Create Wealth in Your Corporation*. New York, NY; Simon & Schuster, 1996.

nature of their organizational and process development. Such organizational and process discontinuities represent a major causal determinant of the failure of many organizational change initiatives. The resultant value stream map and process timeline have been analyzed within the context of the current organizational structure at Sikorsky Aircraft. Examination of the data obtained from this analysis revealed several major organizational deficiencies that are significant sources of *muda* and represent major opportunities for process and organizational improvement.

Section 5 demonstrates the utility of a pair of Systems Engineering methodologies in support of the Lean Enterprise Transformation. These tools have been applied for two distinct purposes. The first is to validate the conclusions generated from the initial lean enterprise evaluation. The second goal is to provide an examination of the corporation from a systems perspective, leading to an optimized organizational structure.

Applications of Quality Function Deployment (QFD) and Design Structure Matrix (DSM) have been proposed within this lean enterprise framework. The first methodology, Quality Function Deployment (QFD) has been utilized to identify the relative importance of a representative sampling of customer needs typical of a derivative aircraft development program. These needs have been correlated to the cognizant functional disciplines required to implement the design features necessary to generate customer value relative to the stated need. Based on the weighted customer needs, a ranking of functional importance for each technical discipline has been derived. In addition, the QFD has been utilized to identify functional interactions at a relatively high level of abstraction. The second tool, Design Structure Matrix (DSM) has been employed to further analyze the functional interactions and the relative customer value contribution

provided by each functional discipline. To ensure that the subsequent organizational conclusions are sufficiently robust, the corporation has been examined through three lenses, organization, process and information flow. Throughout this analysis, DSM has been utilized to both evaluate the current structure and to propose superior alternatives. The DSM methodology has been employed to provide an easily discernible method of graphically contrasting the current and proposed alternatives.

This section illustrates the effectiveness of the subject tools to substantiate the lean enterprise principles and as an enabler of the transformation effort through initial development of the lean organizational structure and processes. This new technique, employing many of the concepts of systems architecture and systems engineering, combined with an understanding of organizational processes, allows development of a comprehensive organizational strategy and represents a key component of the lean enterprise transformation.

Finally, during this analysis, it was recognized that employee related issues represent significant barriers to the lean transition. Three primary forms of employee resistance have been identified in Section 6. While these barriers represent potentially serious threats to the success of the transition, they are fundamentally related to the lack of vision and poor communication that result from the fragmentation prevalent throughout the organization and its processes. As such, these threats may be mitigated through improved communication and establishment of a clear company vision as advanced by the proposed enabling system-oriented organizational transformation initiative.



## **2. Sikorsky Aircraft**

The following paragraphs present a brief synopsis of the complexities that are primary determinants of the organizational fragmentation proposed herein. The discussion contained within this section is intended to enable a better understanding of the forces that act as the catalyst for the evolutionary change dynamic hypothesized. The authors believe that this understanding is essential to recognition and acceptance of the role of organizational discontinuities as an impediment to change. Once acknowledged, the imperative of structured organizational design as proposed herein becomes conspicuous. An appreciation for the frequently unrecognized fragmented and conflictive nature of the corporate priorities identified in the following paragraphs is critical to the ensuing conversation contained in subsequent sections of this document. The following paragraphs will examine the corporate landscape from the perspective of customers, needs, products. Finally, the organizational history of the corporation shall be explored to illustrate the changes that have occurred. While written from the viewpoint of the subject corporation, Sikorsky Aircraft, the issues addressed by the following paragraphs are typical for a wide range of industries and their constituents.

### **2.1 Company Background**

Sikorsky Aircraft Corporation, a subsidiary of United Technologies Corporation (UTC), is a world leader in the design and manufacture of advanced helicopters for commercial, industrial and military uses. Sikorsky helicopters occupy a dominant international position in the intermediate to heavy range of 11,700 lb. (5,300 kg.) to 73,500 lb. (33,000 kg.) gross weight. They are used by all five branches of the United States armed forces, military services and commercial operators in more than 40 nations. Based in Stratford, Connecticut, Sikorsky has

outlying facilities in other Connecticut locations, as well as Florida and Alabama. The total area of buildings owned or leased by Sikorsky comprises more than 3.7 million square feet. Revenues in 1999 were \$1.4 billion. Sikorsky is currently undergoing a restructuring, with a major consolidation of outlying resources.

Since the early 1970s, core programs at Sikorsky have been based on the H-60 aircraft; primarily the U.S. Army “Blackhawk” and the “Seahawk” series for the U.S. Navy. H-60 derivative aircraft are being fielded for a multiplicity of missions with other branches of the U.S. military, several foreign military sales and limited commercial variants. In addition, Sikorsky also manufactures the free world’s largest rotary wing aircraft, the H-53 family of heavy-lift helicopters. In the commercial market segment, Sikorsky is represented mainly by the S-76 helicopter, which is deployed for a variety of missions by nations around the world. Primary applications include executive transport, utility transport, medical evacuation, search and rescue, as well as a number of paramilitary roles. H-60 commercial models are primarily produced as limited niche-market upscale VIP transport.

Future contributors include the RAH-66 “Comanche” in the military segment and the S-92 “Helibus” in the commercial sector. The Comanche is being developed for the U.S. Army and is currently engaged in a flight test program in advance of full-scale production. The S-92 is also undergoing flight test with initial type certification scheduled for the first quarter of 2002. The two aircraft are expected to become the principal revenue contributors as the company moves into the 21<sup>st</sup> century.

Despite the presence of these future contributors, Sikorsky Aircraft's business revolves predominantly around variations based upon a common platform. The utilization of proven platform architectures to develop derivative products is a common practice in many industrial segments. While this business case is less dominant in high clockspeed industries, in the case of Sikorsky Aircraft and many other corporations, relatively long product lifecycles place greater emphasis on the employment of this strategy. For this reason, the following sections of this work will focus on the typical platform-based, derivative development activity that represents the predominance of Sikorsky Aircraft's market opportunities.

### **2.1.1 The Customer**

A complexity that is a powerful contributing factor to the phenomena at the core of our analytical focus is the milieu of "customers" served by any company. As will be revealed in the following discourse, the "customer" encompasses a much larger constituency than what is traditionally considered. The inevitable conflict that occurs in the attempt to satiate these diverse stakeholders aids the concealment of the ultimate effect of many parochial actions within the corporation. In fact, the failure to fully appreciate the multitude of customers and their seemingly contradictory needs is a primary impetus for the lack of coordinated decision-making and process development.

From the enterprise perspective, there are many customers of Sikorsky Aircraft's products. In relation to any company, these stakeholders may be categorized as internal and external customers. Internally, Sikorsky aircraft is a wholly owned subsidiary of United Technologies Corporation. From this viewpoint, UTC is therefore a customer of Sikorsky Aircraft, as the

activities of Sikorsky contribute not only to their own bottom line but UTC's as well. Additionally, the UTC corporate shareholders are an important element of Sikorsky's customer base and ultimately, they must be satisfied with the company's value generation. Finally, the remaining internal customer may be seen as Sikorsky's own management. While these individuals have the most direct influence on the corporation's resources and activities, their compensation is directly tied to company performance. Increasing our focus may identify additional internal customers, such that the interdependent relationships between functional groups or disciplines are considered.

Externally, the customer may be identified in a more traditional sense. The individual purchaser of the aircraft is the most recognizable customer. However, from a broader perspective, it must be realized that due to the high acquisition and operating cost, the purchaser is seldom an individual. Although, an individual purchasing agent may be the most visible "customer", this individual is typically a representative of a larger corporate customer. In some cases, this true background purchaser may be a government entity. In either case, the customer base is generally much broader and may include stockholders or taxpayers. The passengers served by the aircraft are obvious customers, as are the maintenance personnel and perhaps ultimately, the pilots.

In the context of the preceding discussion, the 'Enterprise Customer' may be identified as the aircraft operations personnel, including the pilots and maintenance personnel, as these people comprise the end user and are the focal point of the Value Stream. To remain competitive, Sikorsky Aircraft must maximize the value provided to the End User. To this end, the remainder of this work will focus predominantly on the End User. The justification for this focus is that the

lean transition introduces many self-perpetuating principles. The underlying premise of the lean transformation is that enterprise performance is directly proportional to customer satisfaction. High levels of customer satisfaction equate to increased sales and accordingly increased gross revenues. Adherence to lean philosophies acts to reduce operating expenses and hence the Cost of Goods Sold (COGS). Decreased COGS enables the realization of greater net revenues and profits. This in turn generates satisfaction at the corporate level, for shareholders and all other stakeholders. From this perspective, it becomes apparent that the “lean metrics” aimed at optimizing value production and determining customer satisfaction will be the basis for the success of the lean organization and subsequently the lean enterprise.

### **2.1.2 Needs**

A second area of equal complexity and conflict is the accurate identification of customer needs. Identification of the needs satisfied by the enterprise is contingent upon the perspective from which the corporation is examined. As has been previously discussed, numerous diverse “customers” are served by the enterprise. Each of these customers possesses a unique, and often conflicting, set of requirements. Balancing the myriad needs of this multitude of internal and external customers represents a major challenge.

Perhaps the most obvious customer for the enterprise is the individual purchasing agent whom is responsible for the contractual issues and negotiations related to the aircraft acquisition. Typically, the desires of the purchasing agent are administrative in nature and include low cost, specification compliance, schedule performance and contractual adherence. Although these requirements are the most obvious, it must be recognized that other needs exist that may in fact

be of relatively greater importance. These needs are those established, often unofficially, by the previously identified end users of the product. The end user is comprised of the pilots as well as maintenance and logistics personnel. Pilots are generally concerned with issues of technical performance, operational capabilities, mission fulfillment and aircraft survivability. Maintenance personnel usually tend to have greater focus on issues of reliability, maintainability, scheduled inspections, support equipment requirements and the quality of technical publications. From the logistics perspective, needs are expressed in terms of parts commonality and interchangeability, overhaul and repair, life-cycle support plans, manuals and spare parts availability.

Examining the enterprise with an internal perspective reveals a significant number of internal customers. It may be rationalized that each member of the design, development and manufacturing effort is a customer of the preceding activity. While this is obviously true, such internal relationships are frequently overlooked. Of equal importance are the needs of company management, shareholders and the parent corporation. From the viewpoint of Sikorsky Aircraft and UTC, the needs may be generally identified as profit, schedule performance (often closely linked to profit via late delivery penalties) and “customer” satisfaction. More narrowly, the shareholders of the corporation will be primarily concerned with the share price that will be linked to ROI.

In many cases, an intriguing relationship exists between the enterprise and the customer. This peculiarity arises from the enterprise’s reliance on the customer for the supply of Customer Furnished Equipment (CFE). Because the enterprise is dependent on the customer’s

identification and on-time delivery of CFE, a curious situation arises wherein the enterprise becomes a customer of its customer. Therefore, the enterprise's ability to satisfy customer needs is to some extent reliant on the actions of the customer themselves.

The fundamental precept of the Lean Enterprise concept is the maximization of customer value through a comprehensive understanding of the customer's needs and the corporate value stream enabling the minimization of non-value added activities. As stated in the previous paragraph, the End User shall be considered the primary customer with all other concerned parties representing supporting activities. The methodologies to be presented in subsequent sections shall be based upon this basic tenet.

### **2.1.3 Products**

Inciting additional challenges, the products produced and delivered by the enterprise are as diverse as the customers and needs discussed in the preceding paragraphs. While the principal end item produced by the company is by far the most highly visible product, a significant number of supplementary products are also necessary to address the needs of individual constituents with the larger customer context. However, the majority of these less visible products may be considered subservient to the primary product. As such, the continued marketability of these items is based entirely upon the success and the continued demand for the major product. This realization is directly related to the relationship that exists between the various customers and their individual needs. From this perspective, the primary product logically commands the focus of the lean enterprise analysis. This fact shall form the basis of the remainder of this document.

#### **2.1.4 Organization Structure**

As has been previously argued, organizational structures within industry tend to be evolutionary and cyclical in nature. A number of factors influence the organization, and result in a relatively high rate of restructuring in an attempt to address the changing priorities inherent to evolving customer and market demographics. Many of these organizational changes can be traced to the dynamics of technology maturation and diffusion. The following paragraphs will describe the effects of these forces from the perspective of the helicopter industry. Once again, it is important to realize that Sikorsky Aircraft has been utilized as a representative example of the larger industrial populace.

##### **2.1.4.1 Functional Organizations**

The design and manufacture of medium and heavy lift helicopters is labor and capital intensive. Additionally, specialized manufacturing facilities are required. Due to the specialized technologies employed and the relatively low production volumes, these facilities have exhibited a high degree of vertical integration. These characteristics have led the constituent firms to establish geographically centralized and co-located facilities to perform all required tasks. Within the individual companies, the organizational structure tends to evolve over the life of the aircraft. That is, as the product advances along the technology S-curve, the organizational structure invariably changes in an effort to maximize efficiencies.

Traditionally, the internal organizations have evolved in a repeatable fashion linked directly to the progression of a particular helicopter model along its S-curve. Initially, the organization resembles the small firm in that as the new aircraft is being developed, innovation is highly



valued. Therefore, a relatively small, cohesive cross-functional team is established with the singular focus of bringing the new model to market. At this stage, the primary team focus is performance and schedule. As the technology matures, and the product is launched, this team is generally capable of refining the aircraft through incorporation of incremental changes and shifting focus to the early adopters. As product diffusion begins to occur, increased product demand creates pressure on the original product development team. Simultaneously, the low appropriability of the basic technology combined with market success lead to sharp increases in competitive threat. In response, the internal organizational structure begins to evolve into a ***functionally based matrix organization***. The matrix organization is characterized by the presence of a lightweight or heavyweight project manager. The distinguishing factor is the amount of control exerted by the project manager. When project control lies predominantly with the functional management structure, the project manager is described as lightweight. Conversely, the heavyweight project manager exerts primary authority and the functional management plays a secondary role. While variations of lightweight and heavyweight project managers exist, the important issue is the emergence of functional departments. This shift enables the development of critical functionally based technical skills to support the increased need for incremental change in response to emergent competitive pressures and increased product demand. This type of organizational shift is also commensurate with the need for increased attention to process improvements. This evolutionary scenario is especially relevant from the perspective of the military aircraft market, where relatively high-production volumes and limited, or in the extreme, single customers are the norm. The fact that the traditional medium and heavy lift helicopter markets have been almost solely comprised of the United

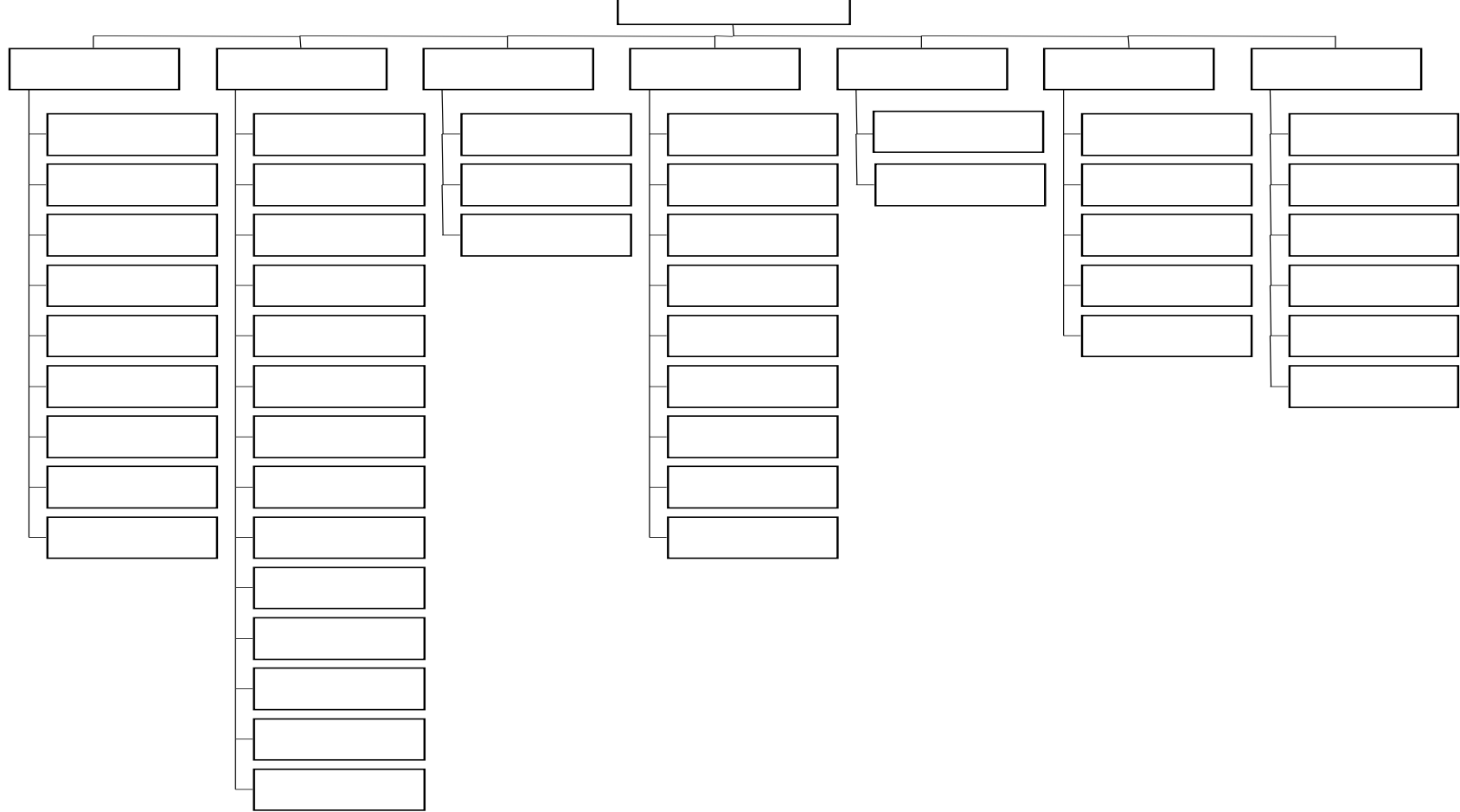
States military has supported this type of evolutionary organizational structure and the geographically centered, vertically integrated firm.

#### **2.1.4.1.1 Functional Organization at Sikorsky**

The aforementioned engineering functional organization as it had evolved until recently is depicted in Figure 2.1. Seven functional branches were required to address all aspects of the production engineering process. Each branch consisted of groupings of similar functional competencies. Within a functional branch, individual functional groups often had common employee skill requirements. Despite this commonality of requirements within the functional branch, resources were seldom shared among different disciplines.

To attain a high level of expertise within a particular functional competency, long tenure was normally required. Generally, advancement within the functional group was directly associated with tenure and competence. Because of this incentive system, individuals rarely moved across functional groups, thus developing strong group loyalties, a significant cultural icon at Sikorsky. Broad and effective informal communication networks were established across functional groups as a result of this constancy of employees within the differing functional disciplines. In general, an atmosphere of cooperation existed between functional groups within a branch. Communication between branches, however, was often less than satisfactory. The functions that were largest in scope and number of employees were given the primary allocation of resources.

Handling QualAvionicsAnalysisSoftwareElec Fit CntlMission SystemsCrew SystemsTactical SystemsInteg. ProductsSimulationAvionic &Fit Cntl SystemsTransmission



**Figure 2.1: The Sikorsky Functional Engineering Organization**

Within this organizational structure, direct communication between the Engineering community and the customer was virtually nonexistent. Customer requirements and objectives were relayed to the functional groups by the Product Line Program Engineering Management (PEM) department. This was the singular engineering link to the customer. Individuals received direction from both their functional supervision as well as the PEM. Conflicting instructions from functional management and the PEM were a common occurrence. Since the functional manager controlled incentives, functional group or branch instructions were often given precedence over customer requirements.

#### **2.1.4.2 Team Based Organizations**

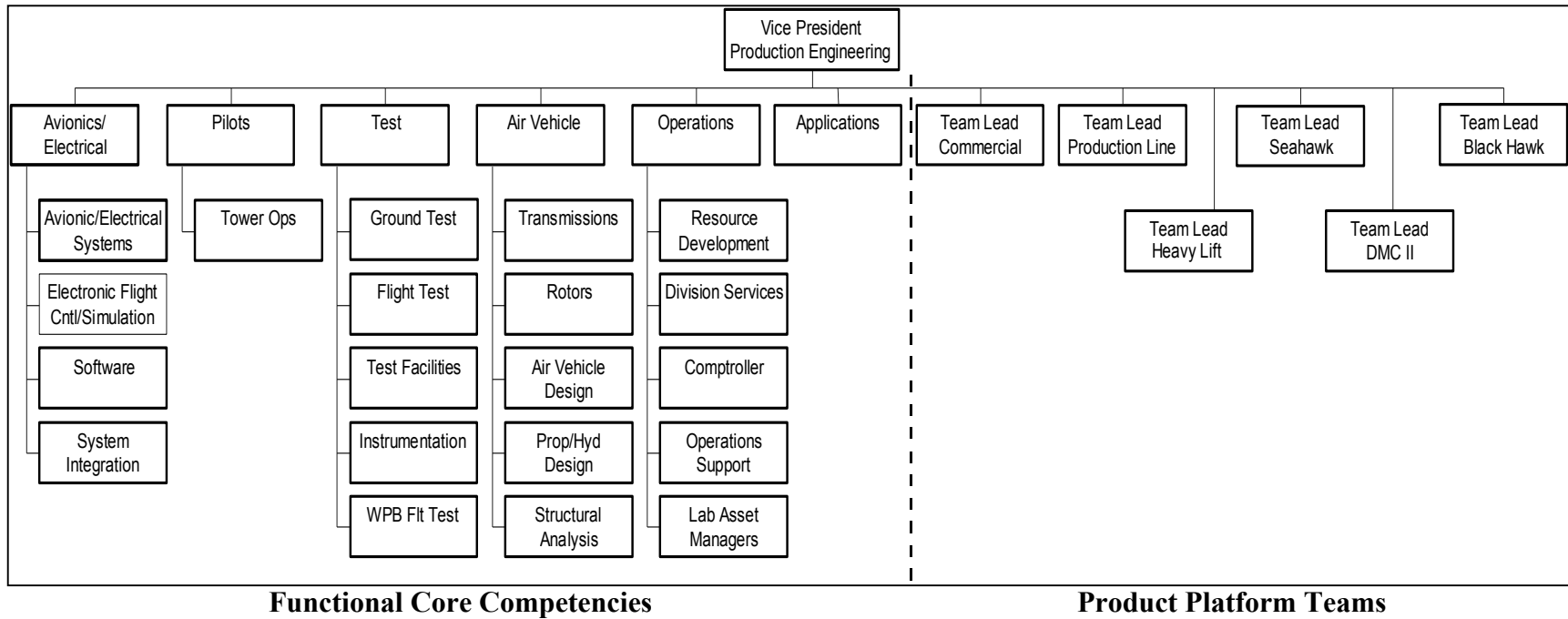
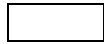
In recent years, the helicopter market has undergone dramatic changes in all weight classes. This change can be primarily seen as a decrease in domestic demand accompanied by the simultaneous increase in international demand. This shift in market strength and demographic has resulted in the emergence of new and intensified competitive pressures. The new market is increasingly characterized by international customers, small production volumes and highly customized, customer-peculiar configurations. This new market-driven environment has created a need for the associated restructuring of the helicopter manufacturer, in both internal and external terms. Internally, the firms have begun a shift to *platform teams* comprised of representatives of each functional discipline. These teams enable an increased customer focus that is commensurate with the realities of the redefined market. The strength of these platform teams is similar to what has been described for the early development teams of the traditional organization: agility and product focus. It is important to realize that in the new market environment, with its increasingly frequent single aircraft customer, product focus is

synonymous with customer focus. Of equal importance is the recognition that both the product and process S-curves are well advanced and highly mature. As both product and process technology has diffused, customer perceived value has increasingly become defined in terms of acquisition cost, which is directly proportional to speed to market and the ability to efficiently develop customer specific configurations, both of which are the theoretical strengths of the platform team.

#### **2.1.4.2.1 Platform Teams at Sikorsky**

The product platform team process was envisioned and developed as a method to provide a single point of focus for the customer. Additionally, it was thought that the collocated platform team would eliminate confusion, by enabling team members to focus their efforts on a specific set of customer requirements and team objectives. These Product Platform Teams represent the full-scale implementation of a prototype platform team that was earlier established within Sikorsky's Development Manufacturing Center. The goal of this prototype effort was to create an autonomous team, comprised of highly skilled individuals from each functional branch that would be responsible for all aspects of the entire aircraft development process from requirement definition to product delivery. This team also interacted directly with the customer throughout the entire project cycle. A process benchmark of industry competitors served as the basis for this prototype platform team.

This team-based platform organization, depicted in Figure 2.2, comprises functional core competency groups as well as product platform teams. Readily apparent is an approximately



**Figure 2.2: Platform Team Reorganization, 1998**

fifty-percent reduction in the number of functional groups within the functional branches. The most notable change is the reduction of resource groups within the Air Vehicle branch from fourteen to five. The intent was to eliminate the duplication of skills and consolidate resources that required extensive interface. In certain instances the existing functional core group leader would assume the new responsibility of technical consultant and a replacement group leader could be introduced from outside of the group competence. The new role of the functional core competencies would be to provide a skilled manpower base, through core competency development, for deployment to the product platform teams.

The organizational basis for the individual platform teams is a specific product line. The intent of this arrangement was to enhance team focus and management control to ensure that customer expectations were met or exceeded. Collocation of the product team resources would enable the team leader to efficiently utilize member skills without the limitations and restrictions normally imposed by functional boundaries. Improved cross-functional communication could result as functional “stovepipes” would be eliminated. Collocation could provide opportunities for better communication between individuals of interfacing departments throughout the design process. The “over the fence” handoff effect of the previous functional organization could be eliminated, thus resulting in theoretically better integrated products. Collocation could also provide a means of cross training team members in functional core areas that they may not have been exposed to previously. Reallocation and relocation of resources would also signify an important shift in authority from the Functional Group Manager to the Platform Team Leader.

### **2.1.4.3 External Perspectives**

From an external perspective, the vertically integrated and geographically centric firm is also undergoing radical changes. As the focus has become increasingly international, domestic manufacturers have been forced to employ various methodologies to gain access to foreign markets. The two methods most frequently encountered have been offset and partnerships. Increasingly, the helicopter manufacturers have entered into offset agreements with international customers, wherein a predetermined percentage of the aircraft has been derived from sources within the customer's country. These offset agreements enable the customer to reduce costs through domestic production of portions of the aircraft, while simultaneously providing access to the foreign market for the helicopter firm. Partnerships on the other hand provide the same market penetration advantages but also enable the prime contractor to reduce costs for the basic aircraft for all potential customers. This geographic decentralization and shift from vertical to horizontal integration enables the exploitation of lower cost labor and manufacturing capabilities from various international sources.

The challenge with these approaches is the transitional costs when moving from this historically vertically integrated structure to a nearly virtual company. Just the simple step of giving up control over design or manufacture of certain portions of the aircraft is painful, and in the early stages will usually increase costs due to the "watchdog" behavior of core employees. This would include, for example, putting employees onsite at a partner facility or duplicating inspection and checking functions. This is a learning curve in which the statements of work must clearly delineate responsibilities and state deliverables. Not far separated from this is the delicate balancing act between gaining a business opportunity and giving up the core technology base. In



the extreme, this can be a loss of competitive advantage; in the norm, there is risk of technology stagnation, as the chosen partner does not bring anything new to the table.

The organizational structures and changes described are typical throughout the helicopter industry and many other industries as well. The ability to react to the rapidly changing competitive arena is a critical component to success in the emerging world market. In this new environment, the need for sound technology strategy becomes exponentially more important as appropriability and complementary assets are exchanged for market access and market share. The challenge in the future will be the ability to formulate and manage a holistic plan for continuous organization and process improvement that eliminates the shortcomings attributable to the deficient evolutionary proclivity that now predominates. The utilization of systems engineering methodologies to support the lean enterprise transformation that will be suggested in the following sections is intended to identify organizational structural requirements from a systems perspective. It is believed that this revolutionary combination of systems and lean philosophies will serve as a critical enabler of successful lean enterprise transformation initiatives.

## **2.2 Technology S-curves**

The technological development that occurs for all products is a primary determinant of the manufacturing firm's market environment. Figure 2.3 presents a typical technology S-curve.<sup>3</sup> The S-curve provides a graphical method of charting relative maturity of a specific technology.

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<sup>3</sup> Foster, R. *Innovation, The Attacker's Advantage*. New York, NY; Simon & Schuster, 1986.

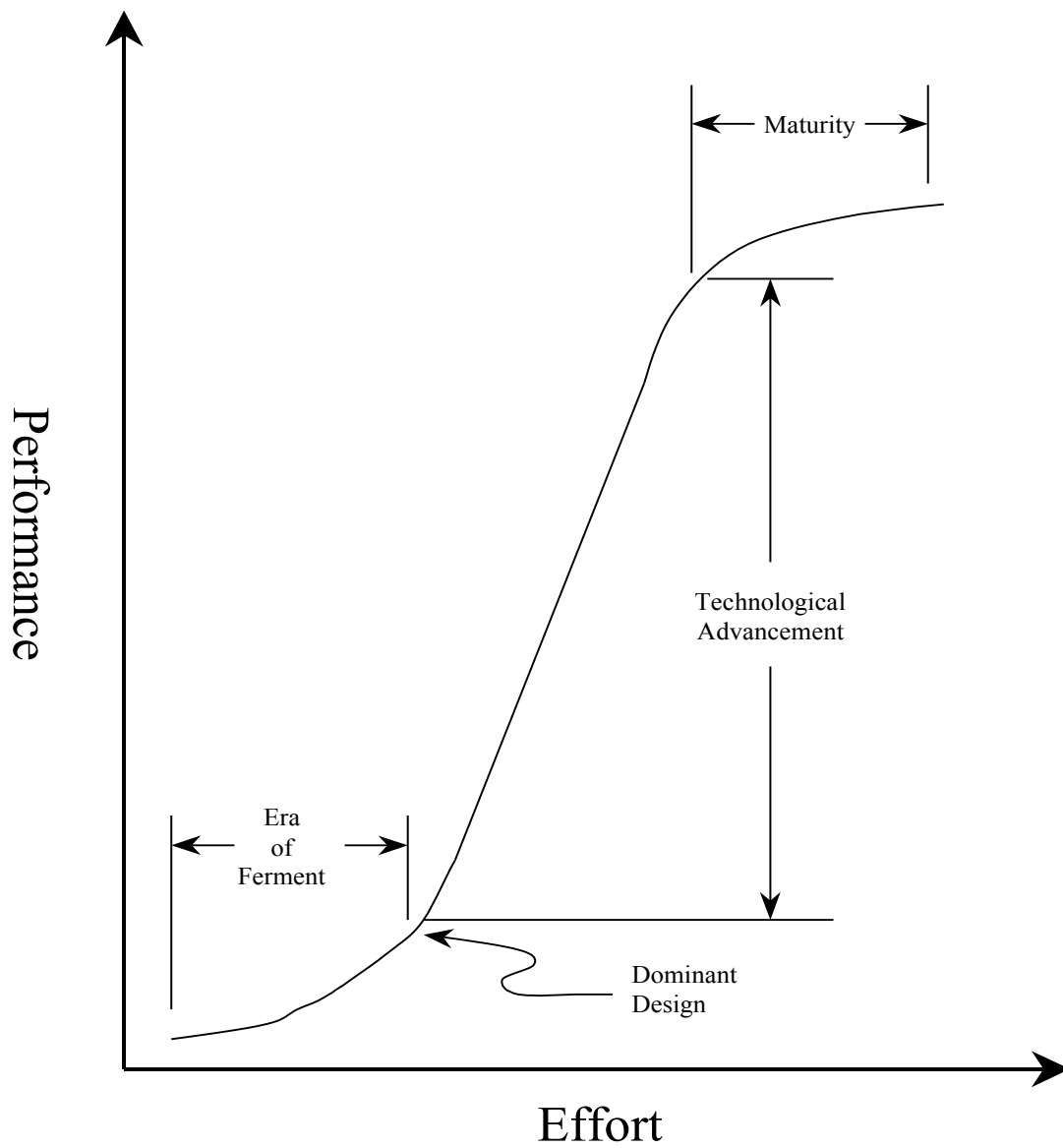


Figure 2.3: Typical Technology S-curve

The initial flat curvature represents the “Era of Ferment”, the period of technology development during which multiple design approaches are pursued in parallel. As refinements occur, ultimately a dominant design emerges as represented by the lower point on the curve where the slope suddenly begins to increase more rapidly. The steeper, linear portion of the curve represents the period of greatest technological advancement as the dominant design has been established and the various industry participants concentrate on continuous and relatively steady incremental improvements. Ultimately, the curve will begin to flatten as the limits of the subject technology begin to slow the rate of advancement, indicating product maturity and market saturation. The relative length and slope of the S-curve is indicative of the product lifecycle and the industry clockspeed<sup>4</sup>.

The evolutionary nature of the resident market segment as the product technology advances along the technology S-curve should result in compensating changes to the organizational and process structures of the company in an effort to remain competitive<sup>5</sup>. The rate of change of both the market and the firm’s structures are directly proportional to the technology clockspeed. Clockspeed may be defined as the rate of maturation of the subject technology. Those technologies with slow clockspeeds are more likely to experience sub-optimal evolutionary changes within their organizational and process architectures. This is due to the insidious nature of the slow rate of change, which is often undetected or, when recognized, unappreciated. This is particularly evident within slow clockspeed industries that may measure product lifecycles in decades, as exemplified by Sikorsky Aircraft.

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<sup>4</sup> Fine, Charles H. *Clockspeed*. New York, NY; Harper Collins, 1998.

<sup>5</sup> Utterback, James M. *Mastering the Dynamics of Innovation*. Boston, MA; HBS Press, 1994.

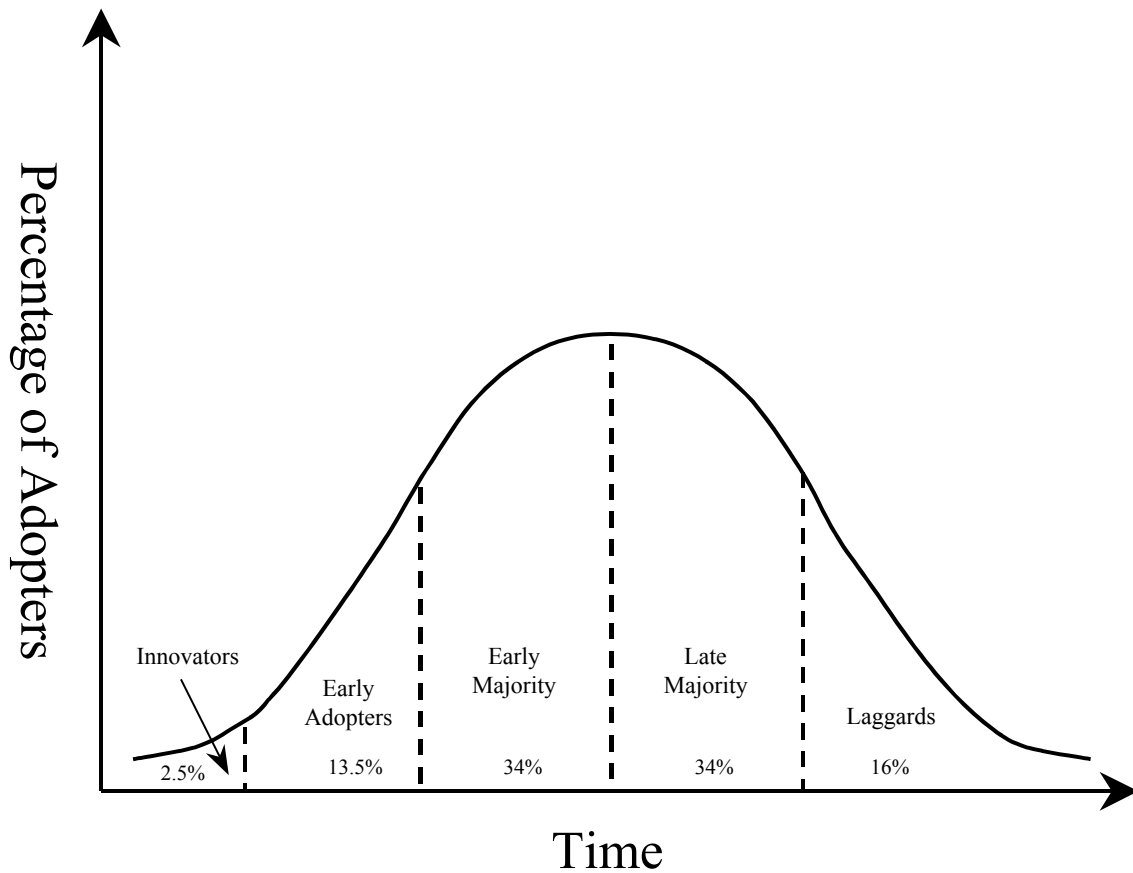
### **2.3 Technology Diffusion**

Technology diffusion refers to the rate of acceptance of a given product or technology by the market constituents. It also seeks to characterize the technology adopters in terms of their relative innovativeness. From this perspective, the technology diffusion curve or Technology Adoption Life Cycle<sup>6</sup> shown in Figure 2.4 can be recognized as a major determinant of the market environment. The curve illustrates a normal distribution of the total adopters of any given technology. The slope of the curve at any point reflects the rate of adoption, while the area under the curve is proportional to the number of adopters. The bell-shaped distribution has been subdivided into five distinct regions, each representative of a different adopter category. Each category of adopter may be characterized by a distinct set of personality traits and product or technology preferences. As the diffusion process advances, the number of adopters will increase and the relative importance of various technological features changes dramatically as each class of customer becomes dominant in the marketplace. The failure of firms to adequately recognize and address this dynamic environment in a comprehensive manner, is a significant factor in the undetected evolutionary nature of organizational and process changes that may be observed in most firms, regardless of the industry.

Due to the significantly different market imperatives and segment populations characteristic of each adopter class, companies must undergo fundamental process and organizational change to remain competitive. It is imperative that such changes be undertaken within the context of a comprehensive plan that recognizes the technology diffusion process. Unfortunately, the

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<sup>6</sup> Moore, Geoffrey A. *Crossing the Chasm*, Revised Edition. New York, NY; Harper Collins, 1999.



**Figure 2.4: Technology Adoption Life Cycle**

changes that typically occur are more commonly incorporated in a reactionary manner without a true understanding of the underlying forces. Furthermore, such reactionary adjustments are generally myopically executed at an extremely localized level within the organization, abetting the insidious nature of the organization's evolution. This lack of system-level cognition is manifested in the fragmented, misaligned organizational and process policies that plague many industries today.

### **3. Lean Enterprise Analysis**

#### **3.1 Value Stream Mapping**

Equipped with a better understanding of the customers and products, it is possible to gain greater insight into the value generation network of any enterprise. This network is depicted in the form of a graphical construct known as a “Value Stream Map.” The Sikorsky Value Stream has been mapped and is presented as Figure 3.1. The value stream map depicts the various participants in the customer value generation process and identifies their interactions with interconnecting arrows. The weight and direction of the arrows is relevant to the analysis. The direction of the arrow indicates the process flow, while the relative importance of the interaction is indicated by the weight of the arrow. From a customer value perspective, dark heavy arrows indicate major interactions, while lighter arrows represent interactions of lesser importance. Examination of the Sikorsky Value Stream reveals that customer value starts with the initial customer contact shown in the upper left corner and flows through the participants of the pre-contract proposal effort. The activity next transitions into the design phase following contract award. As the design activity is completed, the value generation focus shifts to the procurement and manufacturing activity. Finally, the process culminates with delivery of the product deliverable to the customer. The value stream illustrated by Figure 3.1 is essentially a cyclical process flowing left to right, commencing with the customer, flowing through proposal, design, manufacturing and returning to the customer. The Value Stream map of Figure 3.1 has been divided into two principal phases as denoted by the dashed vertical line located at the approximate center of the diagram. Shown to the left of the dashed line are the pre-contract marketing and proposal activities, while those to the right are representative of the post contract award activities. Examination of the map reveals a number of significant findings. First, lightweight arrows represent a significant number of

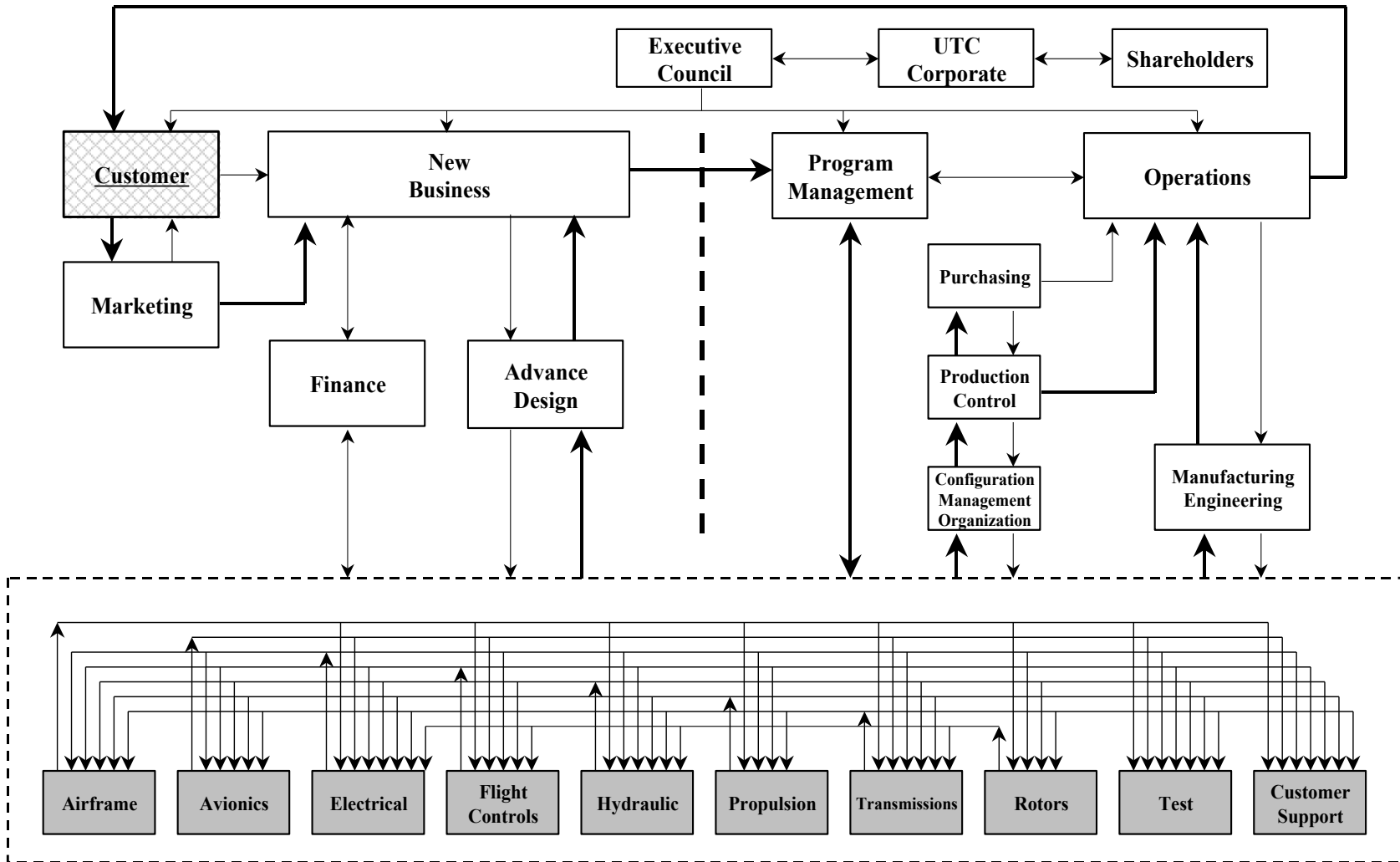


Figure 3.1: The Sikorsky Value Stream

interactions. While in many cases, such as the connection between Finance and Engineering, these interactions represent oversight functions, their presence in many cases is indicative of the *muda* inducing process or organizational inefficiencies that we have postulated. Of particular interest are the sequential lightweight interconnections that exist between multiple organizations, such as that illustrated between New Business, Advanced Design and Engineering. Relationships of this type are primary candidates for process and organizational change initiatives, as the implication is that the multiple weak hand-offs are unnecessary. This is particularly true in the example cited, as the flow in the opposite direction is quite strong. Also, it is important to realize that in many cases, the additional intra-organizational transitions are seldom comprised of a single transaction. Rather, these relationships are generally highly iterative in nature, resulting in significant sources of non-value-added activity and the unnecessary consumption of both personnel and schedule resources. The presence of excessive iterations and repetitive flow paths are indicators of the characteristic fragmentation that originates due to poorly orchestrated organizational adaptation and process development.

Of equal importance, is the realization that Engineering is the only organizational constituency shown to transcend the pre- and post-contract phases of the value stream map. Additionally, Engineering represents the primary source of the majority of heavy arrows. This mapping indicates that the ability to generate customer value is principally focused within the design engineering community. While this realization may appear intuitively obvious, it is frequently overlooked or unrecognized in many corporations today. As has been previously postulated, this is in no small part due to the evolutionary forces that inexorably shape the organizations and processes of corporations across the industrial spectrum. From the Engineering perspective, the



numerous functional disciplines comprising the Engineering organization necessitate a significantly greater number of interactions than the remainder of the organization mapped in Figure 3.1. Based on these observations, it is believed that the internal organizational structure of the Engineering department is the most heavily impacted by the evolutionary fragmentation that exists within the majority of industrial firms.

### **3.2 The Process Timeline**

The process that ultimately results in the delivery of an aircraft to the customer is presented graphically by the value stream map of Figure 3.1. The Gantt chart included as Figure 3.2 illustrates the timeline associated with the implied value stream activities. Note that the schedule has been structured in a relative format, with the initial activity start time identified as zero ( $t=0$ ). The length of each activity bar is representative of the associated task duration. It must be noted that the subject schedule represented by the Gantt chart of Figure 3.2 is at relatively high level of abstraction and as such has somewhat limited ability to illustrate the *muda* inherent to the myriad lower level tasks incorporated in each activity line item. Nonetheless, the Gantt chart provides valuable insight into the potential improvements that may be afforded by the coordinated approach to be advanced by this work.

The Gantt chart illustrates the relative duration of each task comprising the process flow through the organization. The chart also provides some insight into the negative impact on process flow times when compared to the value stream map of Figure 3.1. An examination of Figure 3.2 reveals that the task bars corresponding to the more iterative process phases of the value stream, such as engineering, are significantly longer in duration. While iteration is often intentionally incorporated into the product development process to improve quality through design

convergence, a significant percentage of the repetition is of an unintentional nature. Much of this unintentional or “dysfunctional iteration”<sup>7</sup> is directly attributable to the organizational and process discontinuities arising from the postulated evolutionary succession. Therefore, it is our contention that a large portion of the inherent iteration may be reduced or eliminated through improved cognizance and management of organizational structures. The resultant cycle time reduction will yield reduced time to market, providing significant and sustainable competitive advantage.

Figure 3.2 also illustrates the concurrency imposed on the various activities comprising the value stream. When considered in conjunction with the weak transitions identified and discussed in the preceding value stream discourse, it becomes apparent that opportunities exist to reduce or in some extreme cases to eliminate the need for concurrent activities. The complexity of the development effort, extreme concurrency and the extended/dispersed nature of the development team result in significant inefficiencies and communications difficulties. The shorter cycle time provided by the reduction of unintentional and intentional iterations enabled by effective organization and process designs may also provide substantial advantages in the

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<sup>7</sup> Clausing, D. *Total Quality Development: A Step-by-Step Guide to World-Class Concurrent Engineering*. New York, NY; ASME Press, 1994.

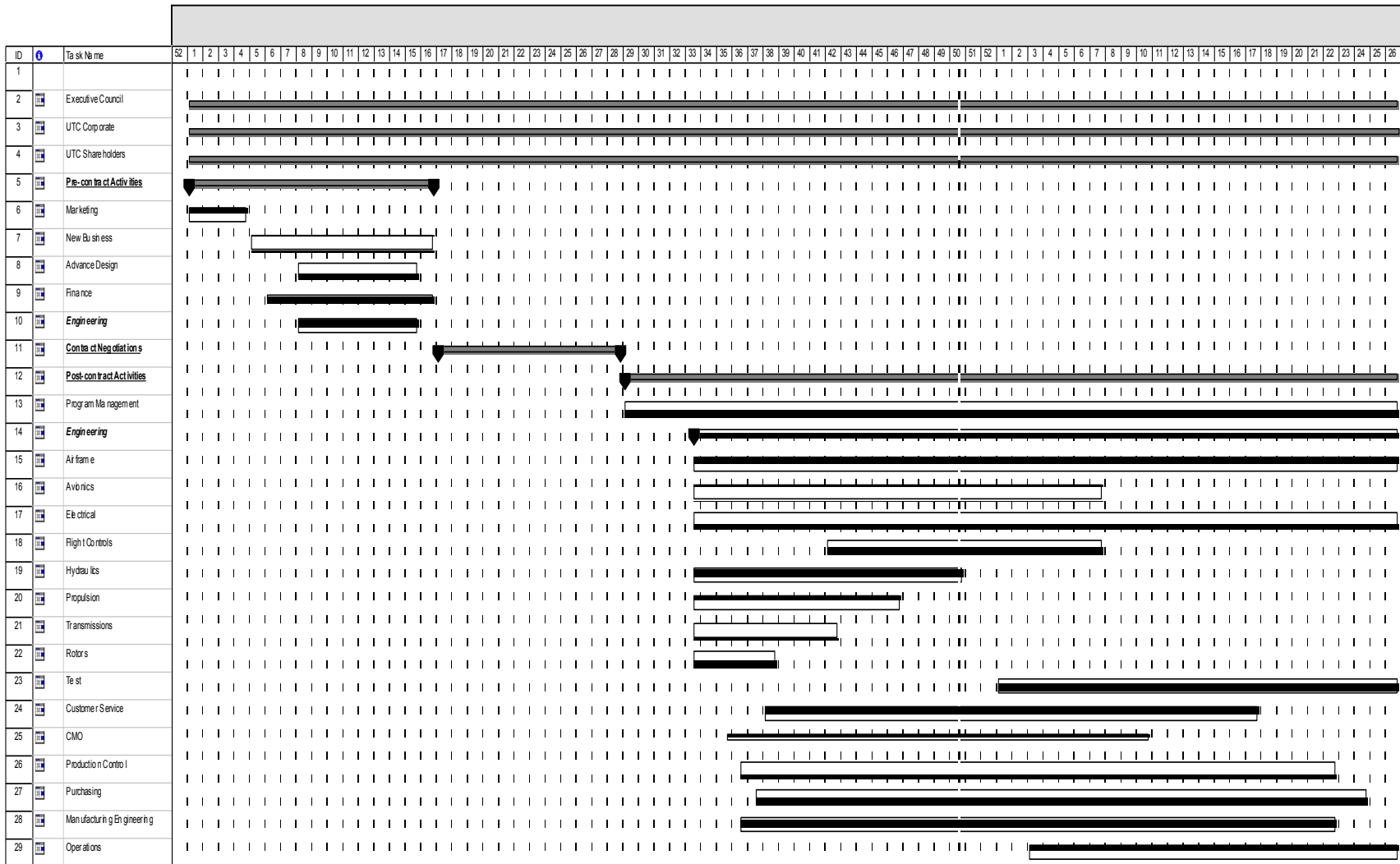


Figure 3.2: The Process Timeline

form of reduced requirements for concurrent activities. The reduction of concurrency will further reduce iterations as subsequent steps in the product development cycle will be executed with more complete data, reducing the effects of rework. Improved product quality will also be realized through these improvements.

Although design and process concurrency is in common usage throughout most industry today as a means of decreasing time-to-market, when looked at in a holistic or system sense, however, it becomes apparent that concurrency cannot always be used as a blanket solution for inherent process inefficiencies. There are a number of processes that are necessarily serial in nature, and excessive concurrency will only serve to increase iteration and overall time-to-market. This is where engineering tools such as DSM can serve to show the optimum level of concurrency by identifying necessary feed-forward and feedback relationships between processes. This thesis examines the feed-forward and feedback relationships between engineering functions, which will enable identification of optimum iterative subcycles and the associated optimal organizational groupings.

Analysis of the Process Timeline illustrated in Figure 3.2 also lends credence to the importance of the Engineering department in the generation of customer value. Once again, the timeline reveals that the engineering activities extend across the duration of the corporation's product delivery process. In addition, the time allocation attributable to engineering based activities represents the single largest contributor to the total process duration. Further, the duration of many of the downstream activities is directly related to the inefficiencies and resultant rework requirements that exist within the Engineering department. Therefore, engineering-based

improvements will provide associated advantages throughout all subsequent value stream operations. It is the authors' contention that the organizational improvements to be advanced herein will enable significant improvements in terms of the engineering time allocations and the aforementioned concurrency reduction opportunities.

### **3.3 Resource Allocations**

The resources allocations for a typical derivative development program and for each of the internal Sikorsky functional disciplines reflected in the value stream map of Figure 3.1 are illustrated in Table 3.1. Due to its competition sensitive nature, the data contained in the table has been normalized and provided in a generic format. The data has also been separated into pre- and post contract phases. Although the individual resource allocations for each of the engineering technical disciplines are not discernable at this level of abstraction, the cumulative total nonetheless provides valuable insight. The data has been provided in the form of Total Manhours and Average Manhours per Month. The duration for each task, as derived from the process timeline of Figure 3.2, has also been provided and is the basis for the average monthly value contained in the table. It must be noted for accuracy, that the marketing activity shown throughout this section represents only that portion directly related to the final proposal tasks and does not account for the total ongoing marketing role. Through a brief perusal, it becomes apparent once again that the resources allocated to the engineering activities consume a disproportionately large percentage of the overall program budget when compared to most other value stream components. Only the Operations discipline approaches the level of Engineering consumption. The resource allocation table also supports the previously noted observation that Engineering is the only discipline represented during both pre- and post contract phases. The

data contained in Table 3.1 provides additional justification for the transition to an Engineering focus for the remainder of this analysis. Subsequent examination of the Operations function is also warranted and is in fact recommended as the next step in the Lean Enterprise Transformation.

<b>Resource Allocations ~ Normalized Manpower</b>				
<b>ID #</b>	<b>Discipline</b>	<b>Duration (Weeks)</b>	<b>Total Manhours</b>	<b>Average Men/Month</b>
<b><i>Pre-Contract</i></b>				
1	Marketing	4	36	9.0
2	New Business	12	36	3.0
3	Finance	11	18	1.6
4	Advance Design	8	36	4.5
5	Engineering	8	152	19.0
<b><i>Post-Contract</i></b>				
6	Program Management	50	842	16.8
7	Engineering	46	4265	92.7
8	CMO	38	449	11.8
9	Production Control	38	287	7.6
10	Purchasing	39	287	7.4
11	Manufacturing Engineering	38	842	22.2
12	Operations	32	2750	85.9

**Table 3.1: Typical Program Resource Allocations**

### **3.4 Lean Enterprise Analysis Conclusion**

Based upon both the Value Stream Map of Figure 3.1 and the Process Timeline of Figure 3.2, it is apparent that the engineering discipline as an inclusive entity exhibits the highest degree of interaction, and is responsible for the majority of the product lead time. The existence of extremely high interaction requirements is predominantly due to the extreme specialization that exists within the department. While undoubtedly necessary, the technological specialization is a major factor in the organizational misalignment and fragmentation that is such a large determinant in the ability of corporations to successfully adapt to the emerging competitive environments throughout all industries. It is the opinion of the authors, that in this example, the engineering organization, with its clear linkage to customer value generation and resource consumptive nature, represents the greatest opportunity for organizational improvement based upon the concepts to be proposed herein. Based on the findings of this section, the remainder of this work will focus on the internal aspects of the Engineering department and their external relationships with the other constituents of the corporate organization. Section 4 shall continue the lean enterprise analysis with specific focus on the Engineering department. The increased resolution that the subsequent dialogue affords will enable greater analytical integrity.

#### **4. Lean Engineering Organization Analysis**

##### **4.1 Engineering Value Stream Mapping**

To achieve greater fidelity in the ensuing organizational analysis requires an increase in the resolution of the value stream mapping that was conducted in the previous section. To this end, the high-level engineering representation contained in the Sikorsky Value Stream Map of Figure 3.1 has been isolated and mapped with greater detail in the sub-level value stream map that follows. Presented as Figure 4.1, the Engineering Value Stream Map includes all of the specialized technical disciplines resident in the engineering organization. At this level, the true magnitude of the interactions begins to emerge. This sub-level mapping enables additional annotations with regard to the iterative nature of the subject relationships. For example, we have introduced a mapping annotation that we refer to as the *Coefficient of Iteration* (COI). The COI allows each interconnection between the various engineering disciplines to incorporate a number representing the relative number of iterations required to achieve design convergence. The inclusion of the COI makes it possible to identify the presence of design iterations that have direct implications for process durations. This added level of detail enables increased attention to sources of both intentional and unintentional iteration, many of which may be eliminated through the proposed system-oriented organizational design process. In addition, the relative importance of the data transmitted between engineering entities, as it relates to the processes and activities required to meet the typical customer-specified objectives, is indicated by the weight of the connecting arrow. Note that in some instances, the connection has been represented by a heavy line with a larger arrow to indicate the relative importance of the mapped interaction. Therefore, these heavyweight interconnections may be directly correlated to technical interfaces with high degrees of customer value generation.



Reference Figure 3.1 for Additional Value Stream Mapping

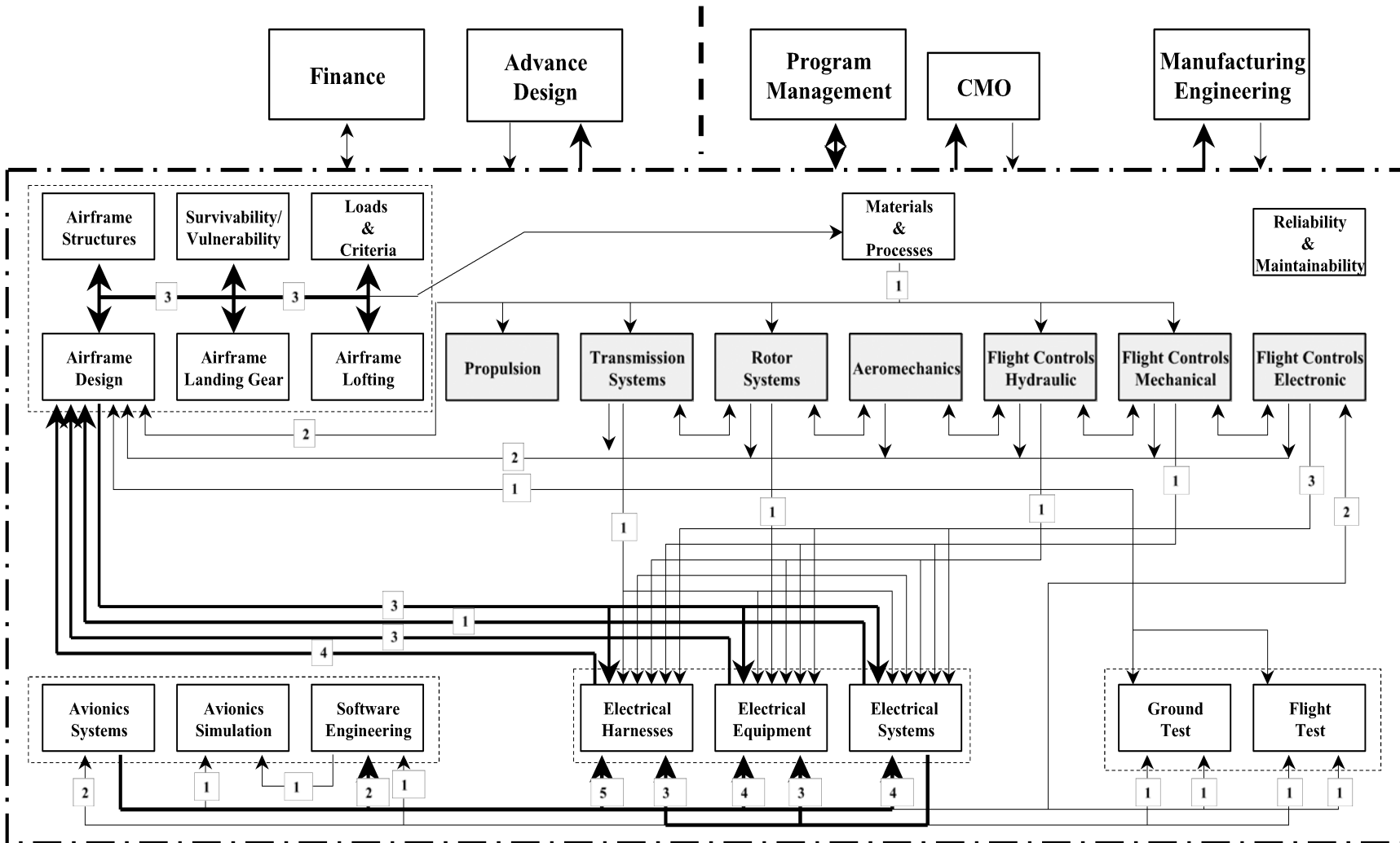


Figure 4.1: The Engineering Value Stream

Examination of the value stream of Figure 4.1 reveals a number of critical observations. First, the majority of interfaces within the engineering department are focused in two places, Airframe and Electrical. Consideration of the attendant responsibilities of these two organizations would appear to substantiate this finding. It is intuitively obvious that the airframe structure acts as the installation platform for all other components of the aircraft. Therefore, it is apparent that the airframe interface is a fundamental element within the subsystem design requirements for most of the other engineering constituents. Examination of the roles and responsibilities of the Electrical functions likewise discloses an inherent necessity for most other disciplines to execute coordinated interface activities. The design and installation of all aircraft system wiring must incorporate the requirements of all other disciplines. The installation of most electrical and electronic equipment and the design of the various subsystem control and monitoring functions also falls within the realm of the electrical discipline. Ultimately, the electrical activities are manifested within the airframe product, and this reality is illustrated by the strong relationship mapping defined by the heavyweight arrows and high iteration score.

Another interesting observation is the degree of iteration and the strength of the relationships between the six tightly linked airframe-based activities in the upper left corner of the value stream map. Based on the recognition of this high degree of interaction, these disciplines have traditionally been co-located within the organizational structure as indicated by their grouping on the value stream map. What is interesting to observe is that the equally intensive relationship between the Avionics and Electrical functions in the lower left corner and lower center portions of the map do not exhibit the same degree of integration. In contrast, these subgroups exhibit considerable segregation within the traditional organization structure, as indicated by the

physical separation on the map. The authors feel that such discrepancies are illustrative of the *muda*-inducing organizational fragmentation that has been postulated.

Finally, it is of extreme importance to realize that, as illustrated by the value stream map of Figure 4.1, the technical disciplines that have traditionally been considered as core competencies are not necessarily the focus of activity within the organization. Examination of Figure 4.1 reveals the core competency areas represented with shaded boxes are relatively insignificant contributors to the creation of customer value. Despite this, these disciplines have typically received preferential resource consideration during development programs. This fact, which is frequently not appreciated, results from evolutionary organizational fragmentation and the lack of a holistic perspective during organizational and process design activities. This failure to accurately identify functional roles and responsibilities during organizational change initiatives such as the lean enterprise transformation, typically results in improper resource allocations, poorly conceived organizational structures and ultimately the failure of the initiative itself.

Once again, it is important to note that the value stream maps illustrated by Figures 3.1 and 4.1 are representative of a derivative development effort based on a mature product platform. In the case of a new platform development program, significantly greater emphasis would be required for the core technology areas. The basic concepts invoked herein are equally effective in mapping such an activity. However, as previously stated, the majority of design activity at Sikorsky Aircraft, and many other corporations, is based upon incremental improvements or customer peculiar customization of an established baseline platform. Based on this rationale, the

derivative-based value streams have been utilized to exemplify the techniques advanced by this treatise.

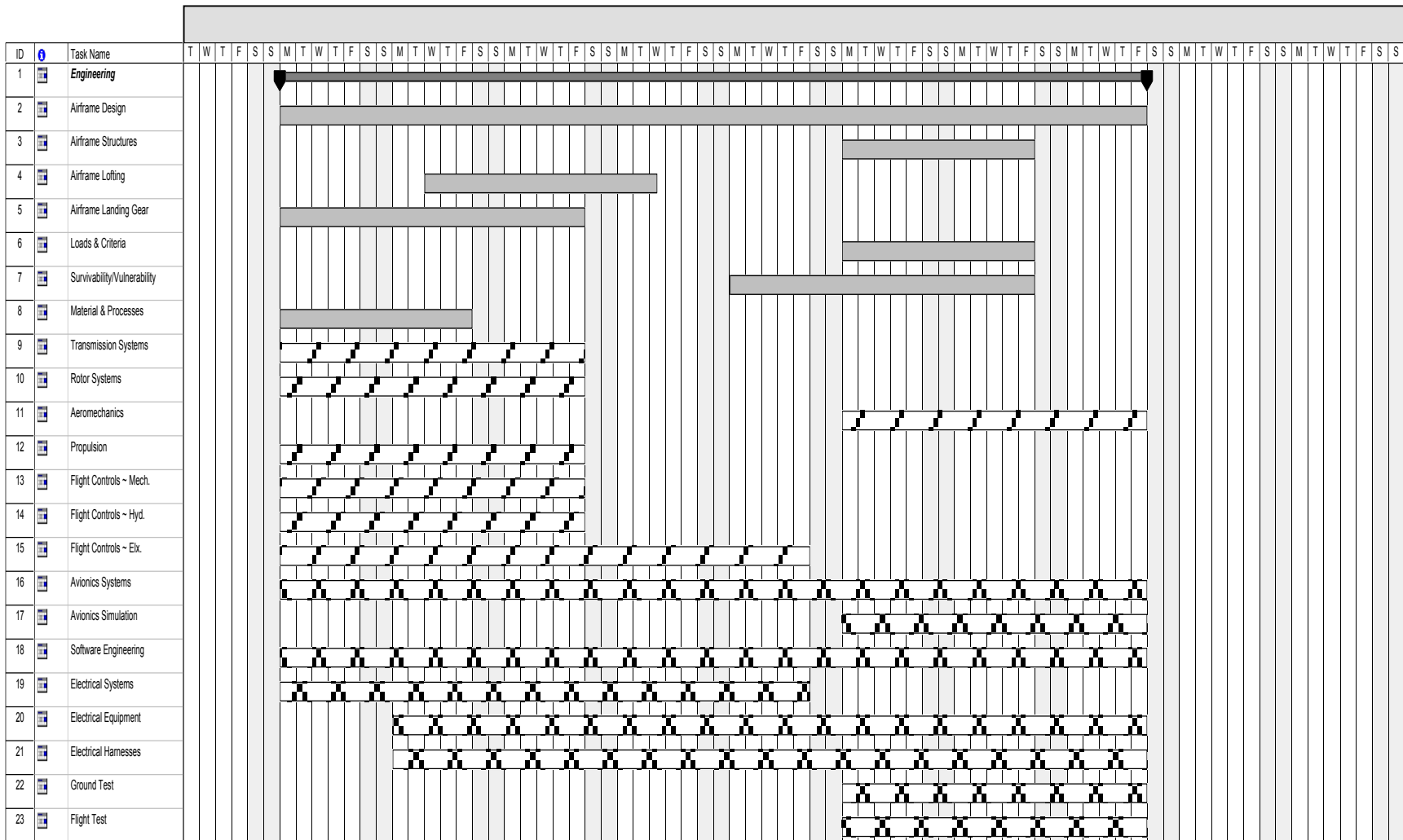
#### **4.2 Engineering Process Timeline**

The generation of the engineering-specific, sublevel value stream map of Figure 4.1 enables the extraction of a similarly focused process timeline map. This timeline provides a greater degree of resolution than the timeline presented as Figure 3.1 in the previous section. To provide the highest possible resolution for our ensuing analysis, the engineering activities illustrated by the original comprehensive process timeline of Figure 3.1 has been segregated into pre- and post contract award phases. The two resultant engineering process timelines are illustrated in Figures 4.2 and 4.3 that follow. Figure 4.2 depicts the process timeline prior to contract award, while Figure 4.3 represents the post award activity.

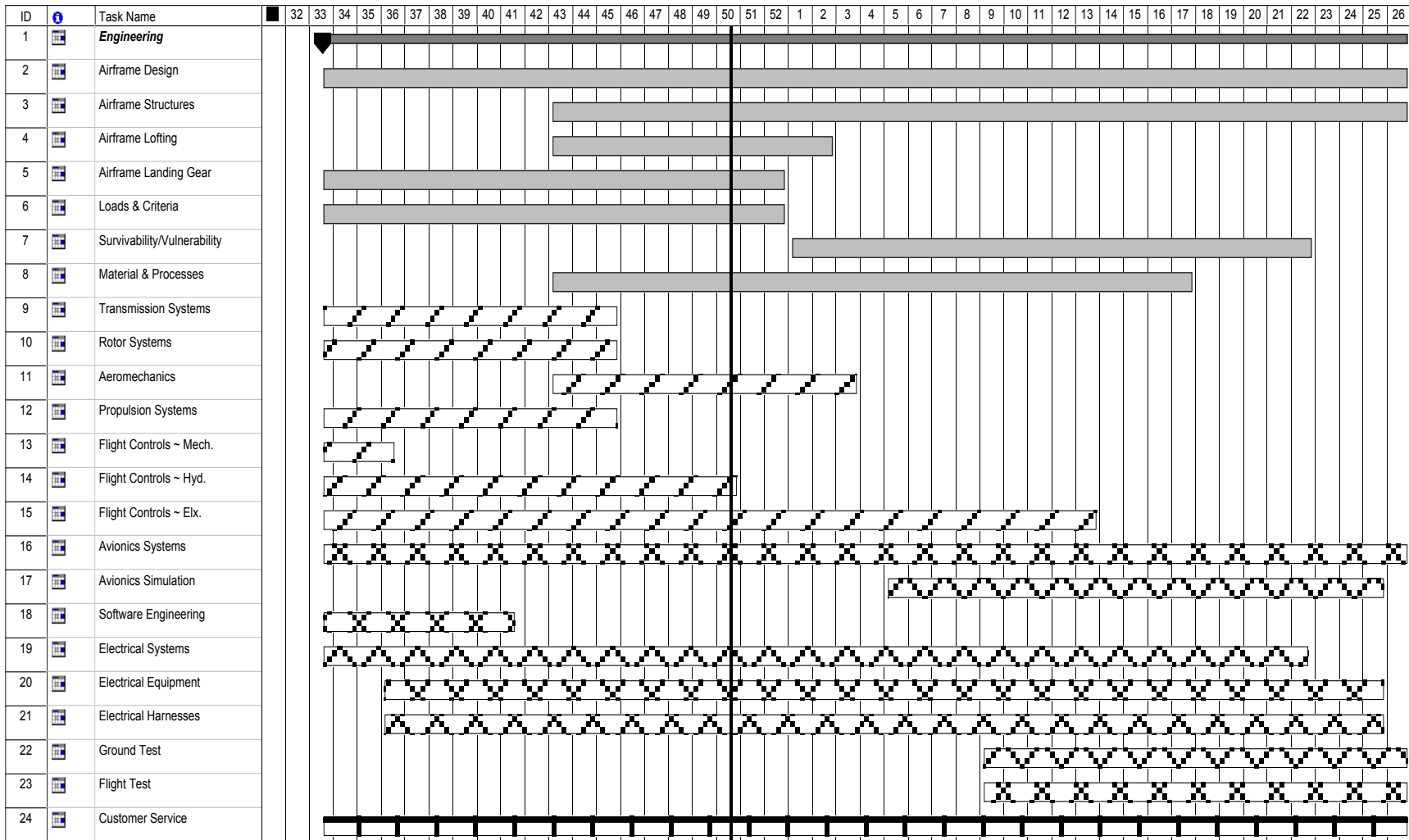
Examination of the process timelines of both figures tends to validate the findings of the preceding value stream analysis. The pre-contract activity related to proposal preparation discloses that the core technologies, as indicated by the diagonally cross-hatched task bars are not the principal tasks in terms of process duration. Further, the timeline of Figure 4.2 emphasizes the fact that Airframe and Electrical related activities are the primary resource consumers during the pre-contract phase.

The timeline of Figure 4.3 provides even greater insight into possible organizational inefficiencies as it represents the major period of engineering-based customer value generation. Analysis of this post-contract timeline offers further substantiation of the value chain derived

findings. Once again, it is readily apparent that the principal activities are focused within the Airframe and Electrical arenas, not the normally emphasized core technology areas. Additionally, it is relevant to note the high degree of concurrency exhibited within the process timeline of Figure 4.3. When considered in conjunction with the dependency data obtained from the value stream analysis, the timeline reveals additional areas of organizational and process discontinuities. Due to the dependent relationships that exist between many of the individual engineering disciplines, it would appear that the concurrency of the present process invites unnecessary rework and inefficient resource allocations due to suboptimal scheduling of project tasks. The authors contend that this exigency is primarily the result of the structural fragmentation and the general lack of appreciation for the interrelationships that exist within complex organizational systems throughout industry and is a major impediment to many change initiatives. As a result of these organizational structure issues and lack of cognition, poor process design and inefficient resource allocations occur, which in turn support the original organizational inadequacies. In this manner, a self-perpetuating cycle is initiated. While the organization/process relationship is closely coupled, the causal relationship established herein is supported by the repeatedly demonstrated inability of corporations to invoke substantive process reinvention without the enabling effect of a preceding organizational change initiative. The systems engineering tools to be proposed in the following sections shall provide a solution to this common dilemma.



**Figure 4.2: The Pre-contract Engineering Process Timeline**



**Figure 4.3: The Post-contract Engineering Process Timeline**

### **4.3 Technology Clockspeeds**

An examination of the technology clockspeeds for each discipline represented in the Engineering Value Stream Map of Figure 4.1 provides an additional perspective for the organizational analysis. One would anticipate that the high clockspeed technologies would experience the highest rate of change and would therefore require the greatest allocation of resources. If functional interactions are utilized as an indicator of technology clockspeed, the value stream map of Figure 4.1 would appear to indicate that Airframe and Electrical/Avionics have the highest clockspeeds, while the core technology areas have the lowest. While this at first seems counterintuitive, careful consideration reveals otherwise. Recalling that our value stream map is for a derivative aircraft and recognizing that the product lifecycle is typically measured in decades partially supports these findings. Once designed, the core technology components of the aircraft are generally not affected by derivative design activities, as these items are as their origin implies, core components. Such components generally originate internally, are resource intensive and have significant costs associated with their initial design, test and certification. For this reason, changes in these areas are generally constrained to incremental process improvements intended to enhance producibility and reduce costs. Consequently, fundamental changes in the core technologies area generally do not occur during the individual product lifecycle, resulting in a relatively slow technology clockspeed. As in the discussions of the previous paragraphs, the clockspeed analysis indicates that the core technologies are not the proper focus.

Conversely, the Avionics and Electrical technologies are influenced by a number of internal and external sources. As has been previously noted, and as illustrated by the value stream map,



changes originating with any of the other functional disciplines will invariably impact the design of the electrical subsystems. Additionally, changes in the areas of avionics and electronics are driven by a significant number of external entities. The presence of a much greater number of change initiators results in a much higher rate of technological change and a significantly faster technology clockspeed.

From a clockspeed perspective, the Airframe mapping at first appears contradictory. Few will argue against the fact that airframe structure is inherently a slow clockspeed technology, with little in the way of substantial changes from one airframe to another. The intense nature of the intra-organizational relationships would tend to invalidate the clockspeed perspective and cast doubt upon the value stream mapping technique in general. However, when the aforementioned role of the airframe structure as the installation platform for all other system and subsystem components is factored in, the correlation becomes apparent. Due to the fact that any significant subsystem change, regardless of its technological origin, will likely necessitate a corresponding structural change, the normally slow clockspeed of the airframe technology is affected. The resultant effect is that the technological clockspeed of the airframe structure is artificially accelerated to enable incorporation of evolving requirements driven from the high clockspeed electrical and avionics technologies. The fact that the avionics to electrical and electrical to airframe connections possess the highest iteration figures of merit supports the contention that these technologies are the source of the airframe clockspeed acceleration.

#### **4.4 Engineering Analysis Conclusions**

The sub-level analysis of the Engineering Organization reveals the muda-inducing effects of the fragmentation that occurs as a result of the evolutionary nature of the organizational structures

that exist throughout industries today. The three perspective analyses (Value Stream Analysis, Process Timeline Analysis and Clockspeed Analysis) conducted in the previous paragraphs indicate that significant improvements are possible within the organizational structure of the Engineering Department. Considered with respect to the findings of the analyses conducted above, the current organizational structure exhibits a high degree of fragmentation and inefficient resource allocations resulting from the lack of a systemic understanding of the organizational complexities with regard to customer value generation.

The utility of traditional systems engineering methodologies to support the lean enterprise transformation shall be advanced in the subsequent sections of this thesis. It is believed that the benefits of these techniques will be twofold. They shall be used to validate the findings of the relatively new lean analysis techniques and to demonstrate the viability of systems engineering precepts in the design of complex organizational structures.

## **5. Systems Engineering Methodologies**

The application of systems engineering methodologies in the context of organizational design is not entirely unprecedented. However, it is believed that the combinatorial application of QFD and DSM has not been demonstrated as proposed herein. In the proposed context, the QFD shall be utilized to examine customer needs relative to the organizational activities required to satisfy the exposed needs. As employed here, the focus of the QFD shall be the identification of the required design process participants in relationship to the satisfaction of customer needs, rather than the traditional needs versus design attributes determination. The QFD shall be constructed for the purpose of establishing a *Figure of Merit* for each organizational constituent such that the relative importance of each subgroup in generating customer value may be quantified. The DSM shall then be employed to examine the relationships extant within the organization from three different perspectives and to illustrate the discontinuities, inefficiencies and fragmentation that has been hypothesized within the commentary of this work. Manipulation of the DSM will be performed in conjunction with the QFD derived Figures of Merit to propose an optimized and aligned organizational structure. In this context, the unique combined application of QFD and DSM to perform organizational design from a systems inclination shall serve as significant enabler of the lean enterprise transformation. In addition, the DSM analysis will provide confirmation of the conclusions of the relatively new lean enterprise value stream mapping and process timeline analytical tools. In this manner the well established DSM and QFD systems engineering methodologies shall provide invaluable validation of these fundamental lean enterprise concepts.

## 5.1 Quality Function Deployment

### 5.1.1 Origins of QFD

In today's marketplace, customers are becoming increasingly used to getting products with very high quality even in their initial phases.<sup>8,9</sup> At the same time old markets are decreasing and new markets are emerging to replace them. With these new markets come new customer needs. The quality arena could be considered one of the primary drivers to the aforementioned changes in the competitive environment.<sup>10</sup>

Quality itself is a difficult word to define as it means different things to different entities. For instance, Crosby describes quality as *"conformance to requirements"*,<sup>11</sup> Juran and Gryna as *"fitness for use"*<sup>12</sup> while Taguchi and Wu describe quality as *"the losses to society caused by the product after its delivery."*<sup>13</sup> Due to this ambiguity, numerous methods and processes commonly associated with the quality arena. Examples of these are: Reliability Analysis, Design of Experiments, Robust Design, Statistical Process Control, Seven Quality Control Tools, Capability Studies, Seven Management Tools, Process Management and various forms of company self-assessments.<sup>14</sup>

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<sup>8</sup> Andreasen, M. M. "Design Methodology." *Journal of Engineering Design* 2(4): 321-335, 1991.

<sup>9</sup> Cooper, R. G. *Winning at New Products – Accelerating the Process from Idea to Launch*; 2<sup>nd</sup> edition. New York, NY; Addison Wesley Publishing Company, 1993.

<sup>10</sup> Womack, J. P., Jones, D. T. and Roos, D. *The Machine that Changed the World*. New York, NY; Rawson Associates, 1990.

<sup>11</sup> Crosby, P. B. *Quality is Free: The Art of Making Quality Certain*. New York, NY; New American Library, 1979.

<sup>12</sup> Juran, J. M. and Gryna, F.M. J. *Quality Control Handbook*; 4<sup>th</sup> edition. New York, NY; McGraw-Hill, 1988.

<sup>13</sup> Taguchi, G. and Wu, Y. *Introduction to Offline Quality Control*. Tokyo, Japan; Central Japan Quality Control Association, 1979.

<sup>14</sup> Bergman, B. and Klefsjo, B. *Quality from Customer Needs to Customer Satisfaction*. New York, NY; McGraw-Hill, 1994.

Traditionally, quality has been the practice of monitoring results of processes. More recently, however, greater emphasis is being put on the activities prior to manufacturing; in fact well before, as in the case of studying customer needs and adapting processes to those specific needs.<sup>14</sup> This shift in focus from “inspecting in” quality to building it in through targeted processes and design activities results in interpretations. Perhaps the best definition of quality therefore becomes ***“The ability to satisfy the needs and expectations of the customer.”***<sup>14</sup> This last definition can affect the way an organization works more than the former definitions, as there is an overarching principle of customer satisfaction regardless of the process in question. In this way the quality process is moving from a basically internal process to an external, customer-focused process. Therefore these new methods need to be developed.<sup>15</sup>

***QFD***, or Quality Function Deployment, is a comprehensive technique whereby cause-and-effect relationships may be visualized, originating with the specific customer needs, continuing through the production processes and culminating with end-item delivery. A continuous technique of this nature assures that the Voice of the Customer is “heard” throughout the entire Product Development Process (PDP). With an understanding of the underlying principles, the objectives of QFD<sup>16</sup> may be summarized as follows:

1. Convert user’s needs (or customer’s demands) for product benefits into substitute quality characteristics at the design stage

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<sup>15</sup> Gustafsson, N. *Comprehensive Quality Function Deployment – A Structured Approach for Design for Quality*. Linköping University, Linköping, Sweden; LiU-Tek-Lic, 1995.

<sup>16</sup> ReVelle, J. B., Moran, J. W. and Cox, C. A. *The QFD Handbook*. New York, NY; John Wiley and Sons, 1998.

2. To deploy the substitute quality characteristics identified at the design stage to the production activities, thereby establishing the necessary control points and check points *prior* to production start-up.

If these two objectives are met, the result is a product, designed *and* produced, such that it meets the user's needs and the customer's demands for product benefits.

QFD is a technique initiated in Japan in the mid-1960s with two motives in mind. One was to better determine designed quality, and the other was to determine in advance key manufacturing operations.<sup>17</sup> The QFD process was first used with some success in the late 1970s by the Toyota Corporation;<sup>18</sup> it then spread to the West with the automotive industry as the early adopters. For example, between 1987 and 1991 over 5,000 Ford Motor Company employees had completed QFD training and approximately 400 QFD projects were underway.<sup>19</sup> It is now an integrated approach when designing new cars.<sup>20</sup>

Almost all companies are in some way listening to what the customer has to say; the competitive advantage is in the interpretation and the way the information is used. As stated previously, QFD is a system that clearly exposes cause-and-effect relationships, and this can be used to translate the Voice of the Customer into company language.<sup>21</sup> The main purpose of QFD is

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<sup>17</sup> Akao, Y. *History of Quality Function Deployment in Japan: The Best on Quality*. International Academy for Quality Book Series, Vol. 3. Hanser Publishing, 1990.

<sup>18</sup> Sullivan, L. P. *Quality Function Deployment*. Quality Progress, 1986.

<sup>19</sup> Anderson, R. E. *HRD's Role in Concurrent Engineering*. Training and Development Journal 47 (6), 1993.

<sup>20</sup> Dika, R. J. *QFD Implementation at Chrysler - The First Seven Years*. The Fifth Symposium on Quality Function Deployment, Novi, Detroit, ASI and GOAL/QPC, 1993.

<sup>21</sup> Ohfuji, T. *Development Management and Quality Function Deployment*. Tokyo, Japan; International Symposium on Quality Function Deployment, ISQFD '95, Union of Japanese Scientists and Engineers, 1995.

quality assurance during new product development.<sup>22</sup> This helps to identify critical parts and processes, creating a focus on targeted improvement areas. This is extremely important as it allows for the effective allocation of constrained resources. QFD therefore can be said to be a process to ensure satisfied customers and long-term corporate survival.

Mizuno and Akao<sup>22</sup> describe the tenets of QFD as follows:

#### Quality Deployment

To convert the user quality requirements into counterpart characteristics to determine design quality for the finished product, and, based on the counterpart characteristics, systematically deploy the correlations among the quality of each functional component and that of the individual parts as well as each of the process elements.

#### Function Deployment

To deploy, in detail, the jobs or business functions that are concerned with building quality into an end-means system, step-by-step.

#### Quality Function Deployment

Interpreted in the broadest sense, Quality Function Deployment is Quality Deployment and Function Deployment combined as illustrated by Figure 5.1.

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<sup>22</sup> Mizuno, S. and Akao, Y. *QFD The Customer-Driven Approach to Quality Planning and Development*. Tokyo, Japan; Asian Productivity Center, 1994.

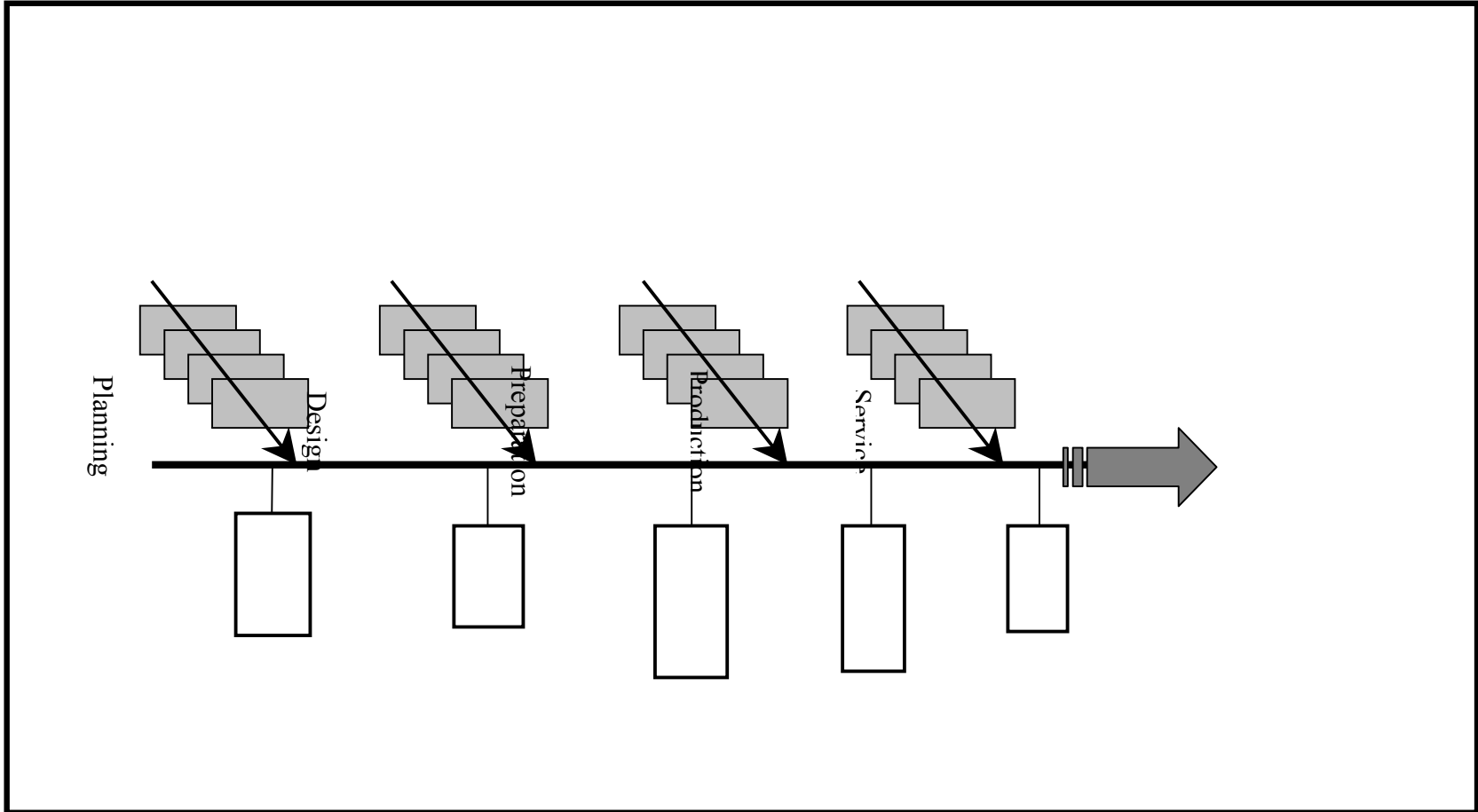


Figure 5.1: Definition of QFD in the Broad Sense



### **5.1.2 Lean Enterprise Applications**

The first step in QFD is the generation of a House of Quality (HoQ) shown in Figure 5.2 below. This is a list of objectives; in product development these are customer needs. The “Voice of the Customer” (VOC), is gathered by qualitative customer contact, survey or by observation. It is interesting to note that 20-30 customers interviewed (either in focus groups or individually) are said to identify 90% or more of customer needs in a relatively homogenous customer segment.<sup>23</sup> The HoQ is used to understand the voice of the customer and translate it into technical terms understandable to the engineer. These customer needs are weighted in terms of importance, which helps to lend the QFD process focus.

The basic structure of the QFD House of Quality is defined in Figure 5.2. In the traditional HoQ, the Customer Needs are elicited and listed in the left hand column. These needs are considered as the “Whats” of the ensuing design process. Adjacent to the needs column is an “Importance” column. This column is populated with a ranking factor intended to provide insight into the relative importance of each need from the customer perspective. The design attributes necessary to satisfy these needs are then determined and added horizontally in the rows shown at the top of the HoQ. These attributes represent the “Hows” of the process and are the technical implementations necessary to satisfy the customer needs or “Whats.” The main center portion of the house is a matrix construct that provides correlation of the needs and attributes. When completed, this matrix establishes the contribution of each attribute relative to each need.

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<sup>23</sup> Griffin, A. and Hauser, J. R. *The Voice of the Customer*. Marketing Science 12 (1): 1-27, 1993.

Typically, a numeric value indicative of relative importance is entered into each of the matrix cells. Across the bottom of the HoQ, are additional cells that contain specific technical target values related to the design attributes arranged across the top of the central relationship matrix. The upper portion or “Roof” of the HoQ provides gross identification of interrelationships or conflicts between the various design attributes.

**Figure 5.2: House of Quality**

As discussed, QFD can be employed to elicit customer needs and to generate a list of weighted customer specific requirements. These attributes can then be utilized to identify the necessary modifications to the product platform required to satisfy specific customer requirements. The application prescribed herein introduces an innovative approach to the House of Quality whereby organizational requirements necessary to satisfy customer needs will be determined. This technique is intended to either validate the organization as it now exists or to illustrate the need for realignment enabling effective resource allocation. In either case, the HoQ generated should match the previously described Value Stream Map.

To permit this shift in focus, several minor modifications to the HoQ are mandated. The required modifications are illustrated in Figure 5.3. Note that the HoQ remains essentially unaltered with the exception of the upper and lower regions normally occupied by the Design Attributes and Target Values fields. In the upper portion of the HoQ, the design attributes have been replaced by a listing of the various Functional Disciplines comprising the design community. In this context, the “Hows” have been replaced by the “Whos.” For this particular example, these cells will contain the engineering disciplines that are the focus of the Sikorsky Aircraft analysis. However, the organization-based contents of these cells may be customized on a case by case basis, and may be as broadly or narrowly focused as a specific situation may necessitate. The central matrix portion of the HoQ remains relatively unchanged except that the value entered in each cell is a numerical value proportional to the contribution of the specific group relative to the customer need located in the intersecting row. At the bottom of the HoQ, the Raw Score and Figure of Merit fields have supplanted the Target Value fields. The raw score consists of the sum of the products of the customer derived importance factor for each need and

the contribution factor located in the central matrix. These values are summed vertically to generate a raw score for each functional discipline. Below the raw scores, a row of cells contains a normalized value for each group to facilitate future data manipulations. These normalized scores result in a relative ranking, on a 1-to-10 scale, for each of the functional disciplines represented in the HoQ.

**Figure 5.3: Modified House of Quality**

### **5.1.3 QFD Analysis**

A House of Quality for a typical derivative aircraft program at Sikorsky Aircraft has been generated and is presented as Figure 5.4. The House of Quality shown was derived from a diverse sampling of customers and is representative of a typical derivative aircraft program. The importance weightings contained in the HoQ are extracted from actual customer generated proposal data and superimposed onto this model. The values in the central relationship matrix have been based on a combination of the data obtained from the lean methodologies of Sections 3 and 4, as well as the authors' knowledge of the tasks required to provide the required functionality. The intent of this QFD exercise is to determine the relative importance of the various functional groups in terms of the customer value generated through satisfaction of the customer needs attributable to a number of aircraft options of a typical derivative development program. The importance of each group will then be utilized to perform an analysis of the existing organization in an effort to either validate the current structure or elucidate improvement opportunities. In addition, it is hoped that scrutiny of the modified QFD will provide valuable insight into the organization-based obstacles preventing successful lean transformation initiatives and validation of the lean analytical tools, Value Stream Mapping and Process Timeline analysis.

Examination of the QFD of Figure 5.4 reveals a number of observations that tend to support the findings of the preceding lean analysis. As shown by the value stream map of Figure 4.1 and the process timelines of Figures 4.2 and 4.3, a number of disciplines forming the nucleus of the development activity become apparent, with other functional groups being somewhat peripheral. Furthermore, the QFD analysis supports the previous findings that these high-value disciplines are not necessarily those functions traditionally identified as core technology areas.

The high-value disciplines identified in the QFD analysis are those possessing a normalized score of nine or ten. Per the QFD of Figure 5.4, the high-value disciplines are those listed below.

- **Airframe**
- **Electrical Systems Design**
- **Electrical ~ Harness Design**
- **Electrical ~ Equipment Installation**
- **Avionics Systems**

As was shown by the Value Stream Map of Figure 4.1, customer value generation appears to be focused in the Airframe and Electrical arenas. Based on the essentially identical results of the two methodologies, the QFD analysis appears to provide valuable confirmation of the lean analysis.

The application of this modified QFD methodology will reduce *muda* by emphasizing the generation of customer value by eliminating much of the ambiguity and the multiple iterations characteristic of the current requirements definition processes. This methodology could further be used to more accurately determine resource allocations and to optimize organizational structures by targeting typical customer need areas identified by the HoQ. By linking the resource requirements *by discipline* directly to the customer requirements, and designing the organizational structure accordingly, planning and execution of the proposed product development will be matched to the actual customer needs. The resultant streamlining of the value chain is a crucial step in the transition to the lean enterprise.

OFD *Fiour*

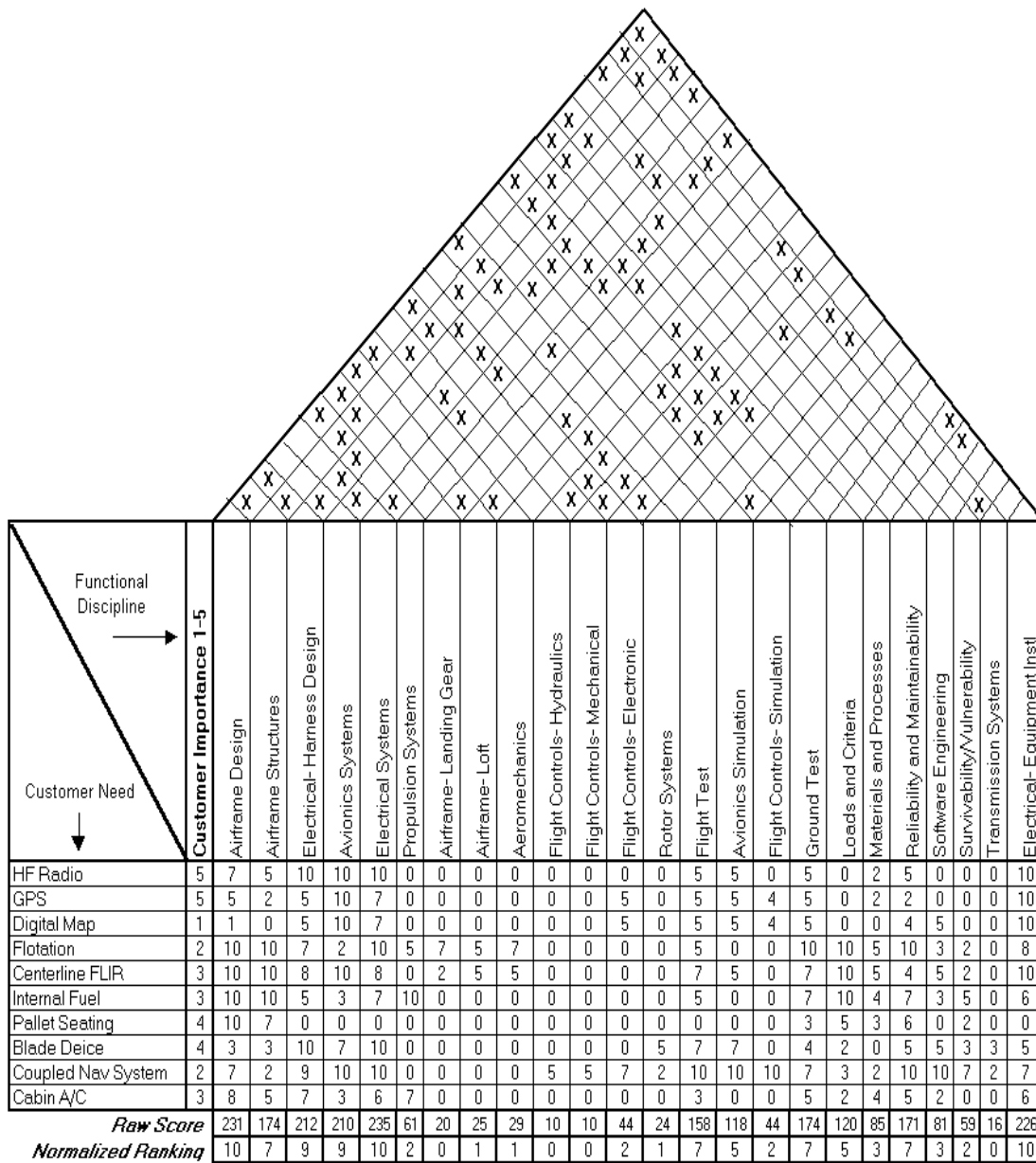


Figure 5.4: Derivative Program House of Quality

Once again it is important to remember that this analysis is for a derivative aircraft program and that these findings are not necessarily valid for a new aircraft program, as the involvement of these peripheral groups would necessarily increase. The authors contend, however, that the modified QFD methodology would still in fact be valid for a new aircraft development program, as the customer needs and therefore the normalized departmental rankings would be significantly different. Similarly, the correlation to the lean tools would remain positive, as the basis for these analytical methods would change in unison. Furthermore, the principles presented herein are deemed sufficiently robust and flexible that they invite universal application across the industrial spectrum.

As previously discussed, the upper portion, or “roof” of the HoQ shows relationships between segments of the “design attributes” section of the HoQ, or in our modified case the relationships between “functional disciplines.” This portion of the QFD is helpful in identifying the interaction between groups, but does not adequately show the strength or “direction” of that relationship. As can be seen in the HoQ of Figure 5.4, interactions between functional entities has been indicated by an “X” in the relationship matrix.

Examination of the HoQ defined departmental relationships is a validation of what is seen in the Engineering Value Stream Map. That is, that no matter what the derivative option (specific customer requirement) is, the organizational relationship remains somewhat constant. The strength and “direction” of the relationship, however, is still not clear from the HoQ. To enable a comprehensive evaluation of the organizational structure requires the additional resolution made possible by the Design Structure Matrix.



## 5.2 **Design Structure Matrix**

The rationale for utilizing Design Structure Matrix (DSM) has been defined as follows:

*For complex design projects... the best design project steps and step sequencing might not be apparent when the project is initiated. In these cases, design process design becomes an important first step. This provides a rational basis for 1) starting the project and having all team members understand the steps and 2) quickly reacting to project events or discoveries that require the process to adapt.*<sup>24</sup>

Taking this thought a step further, this argument can be extended to the design organization itself, the engineering arm of the corporation. If the organization were aligned in such a way to facilitate the design process and information flow that was best suited to satisfaction of customer needs, it would seem obvious that there would be substantial benefit through a reduction of iteration and unnecessary handoffs. Many engineering systems are large and multidisciplinary, and require a complex design cycle. In such an environment, the implications of organizational or process fragmentation are significant. The DSM makes it possible to determine the couplings between the various design processes and groups before the design cycle begins. Once this is achieved, the optimal organization and process structures may be resolved.

The earlier QFD effort has shown the relative strength of the various engineering disciplines and the relationships between these groups, both as they correlate to desired customer needs. With the greater detail provided by the Design Structure Matrices analysis of the existing organization,

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<sup>24</sup> Boppe, Charles. *Systems Engineering Lecture Notes*. Unpublished Paper, Course 16.880; Massachusetts Institute of Technology, Cambridge, MA, 1997.

the strength and “direction” of these relationships may be considered, enabling the disclosure of opportunities for enhanced organizational alignment.

The Design Structure Matrix is, as its name implies, a matrix construct that enables identification of the interactions that occur between the various required elements of a design process. In this regard the DSM is superior to the “roof” of the QFD, as it provides additional valuable information in the form of the identification of the strength and directional characteristics of the relationship. More specifically, the DSM allows the interaction to be identified as feed-forward or feedback. Feed-forward interactions indicate that the output of a specific process step is passed forward for utilization in a future step. Feedback relationships, on the other hand, are those in which the output of a particular process step is passed back to a preceding stage. It should be obvious that feed-forward relationships are far more desirable than are those of a feedback nature. Feed-forward interactions enable a logical, sequential progression towards the process goal. The feedback relationship however is indicative of iteration, rework and waste. While it is true that feedback driven iteration is often necessary to allow design convergence, it is frequently encountered in excessive quantities due to organizational or process discontinuities. In those cases where feedback is necessary, every effort must be made to minimize the length of the feedback loop. The primary advantage of DSM over other methodologies such as PERT or process flow charts is the ability to group and display the iterative subcycles commonly found in the larger design cycle. Once these iterative subcycles are identified, their processes can be ordered in such a way as to produce the best design in the least time and at minimum cost.<sup>25</sup>

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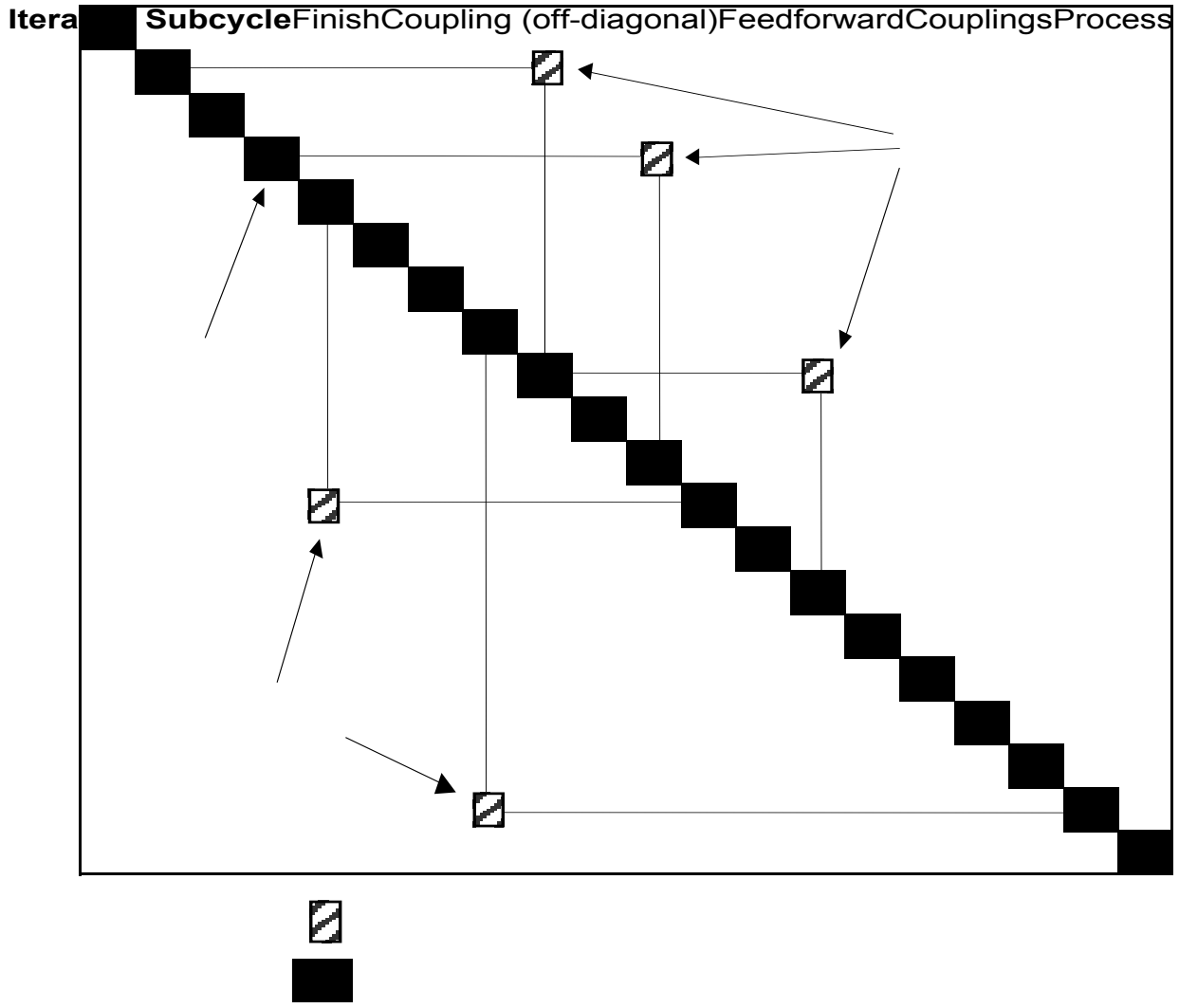
<sup>25</sup> Rogers, J.L., et al. *A Knowledge-Based Tool for Multi-Level Decomposition of a Complex Design Problem*. NASA TP-2903, 1989.

The Design Structure Matrix is constructed by listing the process steps to be examined in a square matrix as illustrated by Figure 5.5. The processes are listed one per row vertically, on the left side of the matrix and one per column across the top of the matrix. The horizontal and vertical sequences must be identical. The matrix cells where like subject rows and columns intersect forms a diagonal extending from the upper left corner to the lower right corner of the square matrix. These elements along the diagonal represent the flow of the process. Each process step receives an input from the left and generates an output to the right. For each process step, its relationship to other process steps is charted by moving across the row occupied by the process step and placing an indicator in the appropriate column. These off-diagonal elements indicate the couplings between any two processes. Figure 5.6 in the following section provides an illustration of a fully completed DSM matrix.

Activities in these various design processes form a system. These activities can be structured to maximize the forward flow of information. If these activities are poorly structured, additional effort in the form of multiple iterations will be required to attain a given degree of convergence.<sup>26</sup> Simply put, a well-structured process simplifies the identification of concurrent tasking and reduces the level of iteration, reducing time-to-market. Process step sequence and

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<sup>26</sup> Steward, D.V. *Systems Analysis and Management*. Petrocelli Books, Inc. 1981.



**Figure 5.5: Design Structure Matrix**

convergence criteria will determine how many times organizational entity boundaries are crossed. Each time an entity boundary is crossed an overhead time/cost penalty is incurred. This may be attributed to *muda* such as supervisory check-offs and other non-value-added processing of the entity's information transfer. If reducing time-to-market is a key organizational goal, the corporate focus can be redirected from perhaps product performance enhancing activities to those which have the greatest impact on reducing process time based upon the optimized structuring provided by the DSM.

### **5.2.1 DSM Analysis**

Our application proposes to utilize the DSM to extend the purview of the preceding QFD analysis. A modified Design Structure Matrix shall be utilized to examine the complex interactions that exist between the individual functional groups that comprise a corporate organization. This approach shall examine the strength and directional characteristics of the intra-organizational relationships and attempt to optimize the organizational structure through matrix manipulation intended to reduce feedback loops and to identify logical subgroups. In addition, the QFD derived Figures of Merit for each functional discipline shall be factored into the DSM such that feedback loops that can not be eliminated are limited to organizational entities with low customer value generation attributes. Finally, as was the case with the QFD analysis, the structured DSM approach shall be employed to confirm the findings of the earlier lean enterprise methodologies.

Once the importance of each functional discipline, as it relates to typical customer needs, has been determined through the use of the QFD methodology, the Design Structure Matrix (DSM) analysis may be undertaken. The serial application of QFD and DSM provides a structured approach enabling a detailed investigation of the interactions that occur between different functional organizations. The QFD derived rankings for each functional discipline are incorporated into the DSM as the organizational interrelationships are examined from three distinct perspectives. The construction of multiple DSM matrices, each with a specific focus, will significantly increase the utility and robustness of the proposed methodology. To this end, we will focus in on these interdisciplinary interactions through three lenses: organizational relationships, process relationships and information-flow relationships.

It is felt that by understanding the nature of these relationships from the three perspectives, using an objective medium such as DSM, the enterprise will be able to plan its organization in accordance with its true customer needs based requirements. It is believed that the DSMs illustrating the three distinct perspectives will reveal the organizational and process discontinuities, fragmentation and inefficiencies that generate waste and result in the failure of lean enterprise transitions. What will be shown is that the structure of the organization can be streamlined from its present configuration utilizing the combination of QFD and DSM techniques to calculate optimized functional relationships. In addition, the DSM analysis will provide confirmation of the conclusions of the relatively new lean enterprise value stream mapping and process timeline analytical tools. In this manner the well established DSM and QFD systems engineering methodologies shall provide invaluable validation of these fundamental lean enterprise concepts.

In the paragraphs that follow, DSM matrices representing the current conditions within the organization will be constructed. These matrices shall be analyzed and compared to one another, and the organizational misalignments and discontinuities identified. Each matrix will then be optimized using the rankings obtained from the QFD results of the previous paragraphs. The optimized matrices shall be compared to the original DSMs to illustrate the advantages of the proposed systems-based structures.

Finally, the results of the QFD/DSM analysis and optimization activities shall be compared to the value stream and process timeline data obtained in Sections 3 and 4. The systems engineering methodology data shall be used to validate the lean enterprise techniques. The data obtained from the two methodologies shall then be combined to form the basis of an organizational restructuring proposal.

### **5.2.2 Organizational Analysis**

The Design Structure Matrix of Figure 5.6 presents a graphical representation of the organizational interactions that exist between the various functional constituents comprising the engineering division within Sikorsky Aircraft. The numbers in each square provide an indication of the relative importance of each interaction occurring within the context of the derivative program. The numbers 1 through 3 have been employed to define the relative strength of each

DSM- Organizational Relationships

		Existing Affiliation →																						
Existing Affiliation ↓	Functional Group →	A	A	A	A	A	B	B	B	C	C	C	D	B	B	E	E	F	E	E	G	H	A	G
	Functional Group ↓	Airframe Design	Airframe Structures	Airframe- Loft	Loads and Criteria	Airframe- Landing Gear	Transmission Systems	Rotor Systems	Propulsion Systems	Electrical Systems	Electrical- Harness Design	Electrical- Equipment Instl	Aeromechanics	Flight Controls- Hydraulics	Flight Controls- Mechanical	Flight Controls- Electronic	Avionics Systems	Materials and Processes	Software Engineering	Avionics Simulation	Ground Test	Reliability and Maintainability	Survivability/Vulnerability	Flight Test
A	Airframe Design	1	1	1	1	1	3	3	3		1	1	3	3	3		3				3	3	3	3
A	Airframe Structures	1	1	1	1	1	2	2	2		2	3	1	3	3		3				2	3	3	3
A	Airframe- Loft	2	3		3	3		3	3			3											3	
A	Loads and Criteria	2	2			2	2	2	2			3	2	3	3	3		2			3		3	1
A	Airframe- Landing Gear	1	1	1	2				2	3	2	3	3			2				3	3	2	3	
B	Transmission Systems	2	2		2		1	1	2	2			2	2	3	3	3			2	2	2	1	
B	Rotor Systems		2	3	3		1		3	2	3	3	2	2	2	3		3		3	2	2	1	
B	Propulsion Systems	3	3	2	2		1	3		2	3	2	3	3	3	3	3	3	3		2	3	2	1
C	Electrical Systems				2	2	3	2		1	1		2	2	1	1		2	2	2	3	2	2	
C	Electrical- Harness Design	1	2		3	3	3	3	1		1		3	3	1	1	3		3	3	3	3	3	
C	Electrical- Equipment Instl	1	1		3	2	3	3	2	1	1		3		1	1	3				3	3	3	
D	Aeromechanics	2	2	2	2	2	3	2	2						2	3			3	3		2	1	
B	Flight Controls- Hydraulics	2	2		2	3	3	2		2				1	1		3			2	2	2	3	
B	Flight Controls- Mechanical	2	2		2		3	2		3	3		3	1	1		3			2	2	2	2	
E	Flight Controls- Electronic			3		3	3		3	2	2	3	1	1		2		1	1	3	3	2	1	
E	Avionics Systems					3		3	1	1	1				2		1	1	2	3			1	
F	Materials and Processes	2	2		2	2	2	2		3	3		2	2							3	2		
E	Software Engineering								2						1	1			2	3	3		2	
E	Avionics Simulation							3	2				3	3	1	1		2			3		3	
G	Ground Test	3	2			3	2	2	3	2			1	1	3	2		3			3		2	
H	Reliability and Maintainability	3	3			3	2	2	2	3	3	3		3	3	2	3	2		2			2	
A	Survivability/ Vulnerability	3	2			3	3	3	3	2	2	2	3	3	3	2	2	3	3		2	3		
G	Flight Test		2		2	3	3	3	2	2	2	2	3	3	3	1	1		2	3	1			

**Legend:**

- 1 = 1st Degree Relationship: Intensive Daily Technical Interaction, High COI, Critical Performance Interfaces
- 2 = 2nd Degree Relationship: Weekly Technical Interaction, Medium COI
- 3 = 3rd Degree Relationship: Limited Technical Interaction, Low COI, Primarily Management Interactions

**Figure 5.6: Organizational Design Structure Matrix**



interaction. We have defined a first-degree interaction as intensive, occurring on a near daily basis. Such interactions tend to be necessary for the transmission of critical design information. Feedback relationships within this category typically result in additional iterations, increased rework, and delays of design completion. *Muda*, when manifested in these interactions, has significant negative implications for lean enterprise objectives. First-degree interactions are the most important in terms of customer value maximization and are indicated by the shaded numeral 1 in the matrix of Figure 5.6.

Second-degree interactions, depicted as the numeral 2 in the DSM, are of medium importance. These interactions are less frequent, occurring on an approximately weekly basis and are somewhat less important to fulfillment of design objectives. While the second-degree interaction remains important, it does not possess the urgency of the first-degree interaction. Relationships of this type are inherently less time sensitive, providing some alleviation for inefficiencies and discontinuities. Consequently, feedback relationships of a second-degree nature have less iterative and rework impact.

Finally, the least important interactions, defined as third-degree, have been annotated with the number 3 in the design structure matrix. These relationships tend to be characterized by less formality, very little time sensitivity and a lack of critical design information. Often, these interactions occur exclusively at management levels and are purely informative in nature. Third-degree relationships are typically very casual and offer only minimal potential for significant enterprise benefits relative to improvement costs and customer value.

Another feature incorporated into the DSM illustrated in Figure 5.6 is the alpha-coding of the individual engineering technical disciplines, which has been labeled as “Existing Affiliation.” This alpha-coding identifies the functional groupings that currently exist within Sikorsky Aircraft. When combined with the first, second and third-degree interaction rankings, this coding is intended to assist with the identification of inefficiencies that occur due to poor organizational design and fragmentation. The sequence of the groups as shown within the DSM of Figure 5.6 is indicative of their actual sequence of involvement on a typical derivative program.

An examination of the DSM reveals the high degree of fragmentation that exists within the engineering organization. Additionally, Figure 5.6 illustrates the inefficiencies and discontinuities that exist within the current structure. The scattered nature of the first-degree data suggests that the current sequence of involvement, which is to a large degree determined by the organizational structure, is undesirable. The presence of essentially equivalent numbers of feed-forward and feedback interactions is indicative of an inefficient, waste inducing organizational structure. The poor organizational structure also results in very little correlation between the importance of individual relationships and the length of the feedback and feed-forward interactions. Clearly, great potential exists for significant organizational improvements.

Utilizing the QFD derived figures of merit for each engineering discipline and the interaction rankings contained within the DSM, the organizational structure may be improved through consolidation of closely related disciplines and logical re-sequencing. By placing tightly linked groups in close proximity to one another and arranging them in the proper sequence, feedback

loops may be minimized or reduced. Such improvements result in reduced durations through reduction of feedback induced rework. To facilitate the optimization of the DSM, the organization-based matrix of Figure 5.6 has been filtered to eliminate the third-degree interactions and the QFD Figures of Merit for each discipline have been added as shown in Figure 5.7. The novel addition of the customer value generation based rankings, as obtained from the preceding Quality Function Deployment, enables an additional level of resolution during the impending Design Structure Matrix execution. The matrix has then undergone iterative manipulation intended to minimize both the quantity and the length of the organizational feedback interconnections. During this process, priority has been given to the first-degree relationships with high QFD derived Figures of Merit. Due to their aforementioned critical nature and their importance to customer value generation, improvements within these areas offer the greatest return on improvement investment. Figure 5.7 provides an illustration of the organization-based DSM after optimization has been performed. When compared to Figure 5.6, it is apparent that the highly dispersed nature of the first-degree interactions has been significantly reduced. Also, note the significant reduction in the number and length of first-degree feedback loops. It must be realized of course that the complete elimination of feedback loops is not possible. However, the addition of the QFD derived Figure of Merit enables the optimization of the DSM to contemplate a third dimension, customer value. Note that as illustrated by Figure 5.7, the remaining ungrouped feedback loops are all associated with low customer value entities. The post optimization matrix of Figure 5.7 is characterized by much tighter relationships and significantly less organizational fragmentation.

DSM- Organizational Relationships

		Existing Affiliation →																								
		A	A	A	C	C	C	E	E	E	G	A	A	B	B	G	E	D	B	B	B	F	H	A		
Existing Affiliation ↓	Functional Group →	QFD Figure of Merit	Airframe Design	Airframe Structures	Airframe- Landing Gear	Electrical- Equipment Instl	Electrical- Harness Design	Electrical Systems	Avionics Systems	Software Engineering	Avionics Simulation	Flight Test	Airframe- Loft	Loads and Criteria	Flight Controls- Mechanical	Flight Controls- Hydraulics	Ground Test	Flight Controls- Electronic	Aeromechanics	Transmission Systems	Rotor Systems	Propulsion Systems	Materials and Processes	Reliability and Maintainability	Survivability/Vulnerability	
	A	Airframe Design	10		1	1	1	1						1	1											
A	Airframe Structures	7	1		1		2						1	1			2		1	2	2	2				
A	Airframe- Landing Gear	0	1	1		2		2					1	2									2		2	
C	Electrical- Equipment Instl	10	1	1	2		1	1	1									1				2				
C	Electrical- Harness Design	9	1	2		1		1	1									1								
C	Electrical Systems	10			2	1	1		1	2	2	2			2	2	2	1		2		2			2	
E	Avionics Systems	9				1	1	1		1	1	1					2	2								
E	Software Engineering	3					2	1			2	2						1								
E	Avionics Simulation	5					2	1	2									1								
G	Flight Test	7		2		2	2	2	1	2				2			1	1				2				
A	Airframe- Loft	1	2																							
A	Loads and Criteria	5	2	2	2							1							2	2	2	2	2			
B	Flight Controls- Mechanical	0	2	2								2		2		1	2	1			2				2	2
B	Flight Controls- Hydraulics	0	2	2			2							2	1		2	1			2				2	2
G	Ground Test	7		2			2	2			2				1	1				2	2					
E	Flight Controls- Electronic	2				2	2	2	1	1	1				1	1										2
D	Aeromechanics	1	2	2	2							1	2	2				2			2	2				2
B	Transmission Systems	0	2	2			2	2				1		2	2	2	2					1	1		2	2
B	Rotor Systems	1		2			2					1			2	2			2	1					2	2
B	Propulsion Systems	2				2	2					1	2	2			2			1						2
F	Materials and Processes	3	2	2	2									2	2	2				2	2	2				2
H	Reliability and Maintainability	7										2					2	2		2	2	2	2			
A	Survivability/ Vulnerability	2		2		2	2	2	2								2	2								

Legend:

- 1 = 1st Degree Relationship: Intensive Daily Technical Interaction, High COI, Critical Performance Interfaces
- 2 = 2nd Degree Relationship: Weekly Technical Interaction, Medium COI
- 3 = Filtered

Figure 5.7: Optimized Organizational Design Structure Matrix

While additional manipulation of the DSM may be possible, especially if software packages are employed, the arrangement presented as Figure 5.7 clearly illustrates the potential for improvement. Also, the use of software packages would undoubtedly make it feasible to perform a primary optimization of the first-degree interactions and a secondary optimization of the second-degree relationships. Such a process would provide even greater organizational alignment through further reductions in fragmentation.

The individual disciplines have been reorganized such that the first-degree interactions associated with high customer value entities have been consolidated into tightly bunched groups. To enable comparison, Figure 5.7 retains the alpha-coding from Figure 5.6 representing the current functional subgroups within the engineering organization. In contrast, the bold boxes added along the diagonal within the field of the DSM matrix define the improved organizational groupings. These boxes indicate that the groups corresponding to the boxed interactions may yield organizational improvements when treated as a functional entity within the organizational structure. In today's team based organizations, these arrangements may be considered as Integrated Product Teams (IPT). Consolidations of this type facilitate communication, information flow and other critical interactions, minimizing waste, rework and design iterations through a systems-based approach to organizational design. Combined, these benefits yield significant competitive advantages in terms of improved quality, shortened time to market and increased customer satisfaction. In this context, the applicability of this technique as a lean transformation catalyst becomes obvious.

It is interesting to note that several functional disciplines have not been incorporated into any of the DSM groupings. This suggests that the subject entities are not strongly linked to any particular specialty and that they serve a supporting role for a number of constituents. Closer examination of the DSM and QFD data for these functional entities supports this contention. Organizational assignments for such activities tend to be somewhat flexible.

Returning to Section 4 for an examination of Figures 4.1 through 4.3 reveals a number of parallels. Observe that the groups identified as highly resource consumptive in the earlier lean analysis also appear as highly interactive in our DSM analysis, as indicated by the presence of first-degree annotations. Additionally, these same groups are characterized by high QFD Figures of Merit. Furthermore, the traditional core competency groups are once again shown to be less important within the greater system and customer value contexts. However, it is important to recall that these analyses have been performed for a derivative development program, which is the subject corporation's dominant business case. Were the analysis to be performed for a new product platform, the results would undoubtedly place greater emphasis on these core technology disciplines.

The following sections will apply the combined DSM and QFD methodology introduced here to the organization from the perspective of process and information flow. The three-stage analysis is intended to provide a robust solution through a series of checks and balances.

### **5.2.3 Process Analysis**

The second phase of our DSM analysis provides an analysis from the process perspective. Figure 5.8 illustrates the current organizational structure with the matrix entries attributable to the current product Development Process (PDP). Similar to the organizational matrices of Figures 5.6 and 5.7, the Design Structure Matrix of Figure 5.8 presents a graphical representation of the process flows that exist between the various functional constituents comprising the engineering division within Sikorsky Aircraft. Likewise, the numbers in each square provide an indication of the relative importance of each interaction with respect to process execution and accomplishment. To maintain commonality and allow correlation between the organizational and process DSMs, the same 1 to 3 scale has been applied to the process interactions defined in Figure 5.8. The alpha-coding of the following matrices is also consistent with the previous matrices; identifying the existing functional groupings at Sikorsky Aircraft.

As previously illustrated in Figure 5.6, the process DSM of Figure 5.8 reveals an equally substantial amount of fragmentation with regard to process flow; as evidenced by the large, random feed forward and feedback loops and a large amount of scatter. The process flow DSM again exhibits very little correlation between the importance of individual relationships and the length of the feedback and feed-forward interactions. The resultant effect of process discontinuities as indicated by Figure 5.8 is a PDP characterized by excessive cycles of iteration. In an attempt to compensate, corporations frequently incorrectly employ concurrency, resulting in waste, rework and inefficiency. Figure 5.8 suggests that there is significant opportunity for process flow improvements, in addition to the aforementioned organizational opportunities.

DSM- Process Flow

		Existing Affiliation →																						
Existing Affiliation ↓	Functional Group	A	A	A	A	A	B	B	B	C	C	C	D	B	B	E	E	F	E	E	G	H	A	G
	Functional Group	Airframe Design	Airframe Structures	Airframe- Loft	Loads and Criteria	Airframe- Landing Gear	Transmission Systems	Rotor Systems	Propulsion Systems	Electrical Systems	Electrical- Harness Design	Electrical- Equipment Instl	Aeromechanics	Flight Controls- Hydraulics	Flight Controls- Mechanical	Flight Controls- Electronic	Avionics Systems	Materials and Processes	Software Engineering	Avionics Simulation	Ground Test	Reliability and Maintainability	Survivability/Vulnerability	Flight Test
A	Airframe Design	■	1	1	2	1	2		2		1	1	3					3			3	1	3	3
A	Airframe Structures	1	■	3	1	1	2	3	1		3	3	2	3	3						3			1
A	Airframe- Loft	1	2	■	1	3		3	2			1											1	
A	Loads and Criteria	2	1	3	■	1			3			1											1	3
A	Airframe- Landing Gear	1	1	3	3	■				3	3							2			2	1	2	2
B	Transmission Systems	2	2		1		■	2	2	3	3			3	2	3		1			3	1		2
B	Rotor Systems	3	3	1	2		1	■		3	2		1	1	1	3		1			2	1	2	1
B	Propulsion Systems	2	2	3	3		1		■	3	3							2	3		2	1	3	2
C	Electrical Systems							3	3	■	1	1		3		3	1		2	1	1	1	3	1
C	Electrical- Harness Design	2	3					3	3	1	■	1		3		3	2		3	3	1	1	3	1
C	Electrical- Equipment Instl	2	2					3	1	1	■					3	2	2	3		2	1		2
D	Aeromechanics	2	1	1	1		1	1	3			■	1	1	1									1
B	Flight Controls- Hydraulics	2	2		1		2	2	3				2	■	2	2		1			2	1	2	1
B	Flight Controls- Mechanical	2	2		1			2					2	1	■	1		1			2	1	2	1
E	Flight Controls- Electronic				2			3		2	2		2	2	2	■		1	1		2	1	2	1
E	Avionics Systems								3	1	1	1		3	3	2	■		1	1	1	2	3	1
F	Materials and Processes	1	1		3	2	3	2	1					3	3			■						
E	Software Engineering							2		2							2		■	1	2	3		
E	Avionics Simulation									2	3	3					2		2	■	3			3
G	Ground Test	3	3		3			2	1	3	3		3	2	2	1		2		2	■	2		2
H	Reliability and Maintainability	2				3	2	3	2	3	2	2		3	3	3	3	3	3					3
A	Survivability/ Vulnerability	2	3		2	2		3	3	3	3			3	3	3	3							
G	Flight Test	3	3		1		2	3	1	1	3		1	2	2	2	1		2	2	3	1		

**Legend:**

1 = 1st Degree Relationship: Intensive Daily Technical Interaction, High COI, Critical Performance Interfaces

2 = 2nd Degree Relationship: Weekly Technical Interaction, Medium COI

3 = 3rd Degree Relationship: Limited Technical Interaction, Low COI, Primarily Management Interactions

**Figure 5.8: Process Design Structure Matrix**



Using this modified DSM methodology, we can optimize the organizational structure in an attempt to reduce the iteration. The optimized structure seeks to shorten the iterative loops and attempts to minimize the feedback cycles as much as practicable. Such improvements will result in reduced process flow duration and reductions in concurrency as feedback induced rework is reduced or eliminated. To remain consistent with the organizational DSM, the process-flow-based matrix of Figure 5.8 has been filtered to eliminate the third-degree interactions, and the QFD Figures of Merit for each discipline have been added.

The process DSM, following optimization is illustrated by Figure 5.9. As can be seen, the optimized matrix is characterized by significant reductions in both feedback loops and interaction scatter. Additionally, the post optimization matrix of is distinguished by much tighter functional relationships and significantly less process flow inefficiency. Note that while a number of feedback loops remain outside the optimized functional groupings, they are all associated with low Figure of Merit organizational entities. The functional coupling suggested by the optimized process DSM is identified by the bold outlined boxes along the diagonal within the central matrix. Once again, when compared to the current alpha-coded arrangement, significant differences are apparent. However, when correlated to the preceding organizational DSM a striking degree of similarity is disclosed.

The functional groupings suggested by the two DSMs are nearly identical. The variations that are noted between the two DSMs are predominantly isolated to low Figure of Merit entities that were observed to be unallocated during the previous organizational analysis. It was suggested at

DSM- Process Flow

		Existing Affiliation →																							
Existing Affiliation ↓	Functional Group																								
	QFD Figure of Merit	A	A	A	A	G	C	C	C	E	G	E	E	A	B	B	E	D	B	B	B	F	H	A	
		Airframe Design	Airframe Structures	Airframe- Landing Gear	Loads and Criteria	Flight Test	Electrical- Equipment Instl	Electrical- Harness Design	Electrical Systems	Avionics Systems	Ground Test	Software Engineering	Avionics Simulation	Airframe- Loft	Flight Controls- Mechanical	Flight Controls- Hydraulics	Flight Controls- Electronic	Aeromechanics	Transmission Systems	Rotor Systems	Propulsion Systems	Materials and Processes	Reliability and Maintainability	Survivability/Vulnerability	
A	Airframe Design	10		1	1	2		1	1					1					2		2		1		
A	Airframe Structures	7	1		1	1	1											2	2		1				
A	Airframe- Landing Gear	0	1	1							2											2	1	2	
A	Loads and Criteria	5	2	1	1													1						1	
G	Flight Test	7				1				1	1		2	2		2	2	2	1	2		1		1	
C	Electrical- Equipment Instl	10	2	2			2		1	1	2	2											2	1	
C	Electrical- Harness Design	9	2				1	1		1	2	1												1	
C	Electrical Systems	10					1	1	1		1	1	2	1										1	
E	Avionics Systems	9					1	1	1	1		1	1	1			2							2	
G	Ground Test	7					2			1	1				2		2				2			2	
E	Software Engineering	3								2	2	2		1							2				
E	Avionics Simulation	5								2	2		2												
A	Airframe- Loft	1	1	2		1												1			2			1	
B	Flight Controls- Mechanical	0	2	2		1	1					2				1	1	2		2		1	1	2	
B	Flight Controls- Hydraulics	0	2	2		1	1				2				2		2	2	2	2		1	1	2	
E	Flight Controls- Electronic	2				2	1		2	2		2	1		2	2		2					1	1	2
D	Aeromechanics	1	2	1		1	1								1	1	1	1		1	1				
B	Transmission Systems	0	2	2		1	2								2					2	2		1	1	
B	Rotor Systems	1				2	1		2			2			1	1	1		1	1		1	1	2	
B	Propulsion Systems	2	2	2			2				2								1				2	1	
F	Materials and Processes	3	1	1	2																2	1			
H	Reliability and Maintainability	7	2					2	2											2		2			
A	Survivability/ Vulnerability	2	2		2	2																			

Legend:

- 1 = 1st Degree Relationship: Intensive Daily Technical Interaction, High COI, Critical Performance Interfaces
- 2 = 2nd Degree Relationship: Weekly Technical Interaction, Medium COI
- 3 = Filtered

Figure 5.9: Optimized Process Design Structure Matrix

that time that the placement of these entities within the organizational structure was less critical than the high customer value disciplines. The resequencing of these functions in the process analysis supports this earlier conclusion. The only variation of functional disciplines with high QFD Figures of Merit involves Flight and Ground Test. While the process DSM optimization has modified their placement somewhat, it is apparent that the change is relatively insignificant. By observation, the slight excursion from the optimized sequence necessary to reconcile these differences would have minimal impact on the characteristics of the organizational and process interactions. This slight shift in resource placement can be justified through a thorough understanding of the affected disciplines. Both groups tend to occupy a peripheral position from which they are required to support across the larger organization. Although strong interactive ties exist with other disciplines, neither group can be inexorably constrained to a specific partner. By their very nature, these functions are forced to maintain a somewhat ambiguous relationship with the other members of the engineering community.

This optimized process sequencing when analyzed in comparison to Section 4 shows again that the earlier value stream map identification of groups as highly interactive is validated by the process DSM analysis. Additionally, the process DSM clearly supports the conclusions of the previously performed organizational analysis, in that the suggested structure withstands the process-focused scrutiny.

#### **5.2.4 Information Flow Analysis**

The third and final phase of our DSM analysis provides an analysis from the information flow perspective. Figure 5.10 again illustrates the current organizational structure of the Engineering department at Sikorsky Aircraft. Similar to the previous matrices of Figures 5.6 through 5.9, the Design Structure Matrix of Figure 5.10 presents yet another representation of the relationships that presently exist between these various functional groups. In this example, the numbers in each square provide a indication of the relative importance of each interaction with respect to information flow between the groups. Once again in this DSM the same 1 to 3 scale has been applied to the process interactions defined in Figure 5.10. The alpha-coding of the matrices in Figures 5.10 and 5.11 is also consistent with the previous matrices, with the differing letters identifying the existing functional groupings at Sikorsky Aircraft.

The Information Flow perspective DSM of Figure 5.10 also indicates the existence of considerable fragmentation in the PDP. As previously discussed, this is denoted by the widely dispersed placement of first-degree feed-forward and feedback cycles. As noted in the previous Organizational and Process deliberations, there is very little correlation between the importance of the informational relationships and the length of the feedback and feed-forward interactions. Such information systems are significant sources of *muda* as a result of the excessive process durations and iterations that they cause. Furthermore, inefficient information flow as illustrated by Figure 5.10 may be manifested within the PDP in the form of unknown rework, resulting in additional delays and design iterations as corrective actions are implemented.

DSM - Information Flow Between Functional Disciplines

		Existing Affiliation →																						
		A	A	A	A	A	B	B	B	C	C	C	D	B	B	E	E	F	F	F	G	H	A	G
Existing Affiliation ↓	Functional Group																							
	Functional Group	Airframe Design	Airframe Structures	Airframe- Loft	Loads and Criteria	Airframe- Landing Gear	Transmission Systems	Rotor Systems	Propulsion Systems	Electrical Systems	Electrical- Harness Design	Electrical- Equipment Instl	Aeromechanics	Flight Controls- Hydraulics	Flight Controls- Mechanical	Flight Controls- Electronic	Avionics Systems	Materials and Processes	Software Engineering	Avionics Simulation	Ground Test	Reliability and Maintainability	Survivability/Vulnerability	Flight Test
A	Airframe Design		1	3	3	2	2		2		1	1	3					2			3	2	3	3
A	Airframe Structures	1			3	2	2	3	2		3	3	3	3	3						3			1
A	Airframe- Loft	1			1			3	2				1										1	
A	Loads and Criteria	2	1			1	2		3												3		1	3
A	Airframe- Landing Gear	1	2		3					3	3			2				2			2	3	2	2
B	Transmission Systems	2	2		3									3	2	3		3			3	2		2
B	Rotor Systems	3	3	2	2		2		1	3	2		3	2	2	3		2			2	1	2	1
B	Propulsion Systems	2	3	3	3		1			1	3	2					3	2	3		2	2	1	2
C	Electrical Systems						3	3		1	1			3		2	1		2	3	1	2	3	1
C	Electrical- Harness Design	1	2				3	3	3		2			3		3	2		3	3	3	3	3	2
C	Electrical- Equipment Instl	1	2					3	2	2						3	3	2	3		2	3	3	2
D	Aeromechanics	1	2	3	1		3	1	3					2	2	1								1
B	Flight Controls- Hydraulics	2	2		2		2	2	3	2			2		2	2		3			2	2	2	2
B	Flight Controls- Mechanical	2	2		2		2	2					2	1		1		3			2	2	2	2
E	Flight Controls- Electronic				2		3		1	2	2	2	2	2	2		2		1	1	2	1	2	1
E	Avionics Systems							3	1	1	1								1	1	1	2	3	1
F	Materials and Processes	2	2		3	3	3	2	1					3	3									
E	Software Engineering						2		3								1			1	2	3		2
E	Avionics Simulation								2	3	3						1		1		3			3
G	Ground Test	3	3			3			2	1	3	3		3	2	2	1		2			2		2
H	Reliability and Maintainability	2				3	2	3	2	3	2	2		3	3	3	3	3	3				3	
A	Survivability/ Vulnerability	2	3		2	2		3	3	3	3			3	3	3	3							
G	Flight Test	3	3		2	3		3	1	2	3	3	1	2	2	1	1		2	2	3	1		

**Legend:**

1 = 1st Degree Relationship: Intensive Daily Technical Interaction, High COI, Critical Performance Interfaces

2 = 2nd Degree Relationship: Weekly Technical Interaction, Medium COI

3 = 3rd Degree Relationship: Limited Technical Interaction, Low COI, Primarily Management Interactions

Figure 5.10: Information Flow Design Structure Matrix

Historically, inefficiencies as illustrated here spawn deeply entrenched informal networks that ultimately become the norm for doing business. Significantly, this condition necessitates that employees deviate from the prescribed “system” to accomplish their assigned tasks. Informal network reliance of this type fosters organizational fragmentation as individual stakeholders may be disenfranchised through lack of information accessibility, leading to increased potential for dropped information hand-offs and missed opportunities to decrease the aforementioned iteration and unnecessary rework. These informal networks tend to be constructed through years of personal interaction on an individual basis and are somewhat precarious in nature. The potential destructive impact of transformation initiatives results in a resistance to change, as the informal networks are threatened. This desire to maintain the status quo represents a serious impediment to any change initiative and must be taken into account prior to change implementation.

The Information Flow DSM of Figure 5.11 has undergone the same matrix manipulation as the previous DSMs, whereby the matrix has been manipulated to minimize or eliminate feedback loops with attention to the QFD derived Figure of Merit. As in the previous matrices, the third degree interactions have been filtered out and the optimization efforts have concentrated on the first-order interactions as they provide the most value-for-effort. Once again, a marked reduction in feedback loops and overall scatter characterize the matrix of Figure 5.11. The improved Information Flow DSM is indicative of increased efficiency and suggests a lower overall iterative nature. The bold outlined rectangles along the diagonal represent the optimized grouping of the functional entities necessary to facilitate information flow. When compared to Figure 5.10, a substantial deviation from the existing information network is apparent. However,

DSM - Information Flow Between Funtional Disciplines

		Existing Affiliation																								
		A	A	A	A	C	C	C	G	E	E	E	G	A	B	B	E	D	B	B	B	F	H	A		
Existing Affiliation	Functional Group	Functional Group																								
	QFD Figure of Merit	Airframe Design	Airframe Structures	Airframe- Landing Gear	Loads and Criteria	Electrical- Equipment Instl	Electrical- Harness Design	Electrical Systems	Ground Test	Avionics Systems	Software Engineering	Avionics Simulation	Flight Test	Airframe- Loft	Flight Controls- Hydraulics	Flight Controls- Mechanical	Flight Controls- Electronic	Aeromechanics	Transmission Systems	Rotor Systems	Propulsion Systems	Materials and Processes	Reliability and Maintainability	Survivability/Vulnerability		
A	Airframe Design	10		1	2		1	1											2		2	2	2			
A	Airframe Structures	7	1		2								1						2		2					
A	Airframe- Landing Gear	0	1	2					2				2	2								2		2		
A	Loads and Criteria	5	2	1	1													2						1		
C	Electrical- Equipment Instl	10	1	2				2	2	2												2				
C	Electrical- Harness Design	9	1	2			2			2			2													
C	Electrical Systems	10				1	1		1	1	2		1				2						2			
G	Ground Test	7						1		1	2		2			2	2				2		2			
E	Avionics Systems	9				1	1	1	1		1	1	1				2						2			
E	Software Engineering	3							2	1		1	2							2						
E	Avionics Simulation	5						2		1	1															
G	Flight Test	7			2			2		1	2	2			2	2	1	1			1		1			
A	Airframe- Loft	1	1		1													1			2			1		
B	Flight Controls- Hydraulics	0	2	2		2			2	2			2			2	2	2	2	2			2	2		
B	Flight Controls- Mechanical	0	2	2		2			2				2		1		1	2	2	2			2	2		
E	Flight Controls- Electronic	2			2	2	2	1	2	2	1	1	1		2	2		2					1	2		
D	Aeromechanics	1	1	2		1							1		2	2	1			1						
B	Transmission Systems	0	2	2									2			2				2	2		2			
B	Rotor Systems	1			2		2		2				1	2	2	2			2		1	2	1	2		
B	Propulsion Systems	2	2			2		1	2				2						1			2	2	1		
F	Materials and Processes	3	2	2																2	1					
H	Reliability and Maintainability	7	2			2	2																			
A	Survivability/ Vulnerability	2	2		2	2													2		2					

Legend:

- 1 = 1st Degree Relationship: Intensive Daily Technical Interaction, High COI, Critical Performance Interfaces
- 2 = 2nd Degree Relationship: Weekly Technical Interaction, Medium COI
- 3 = Filtered

Figure 5.11: Optimized Information Flow Design Structure Matrix

when compared to the previous optimized DSMs for Process Flow and Organizational Structure, a high degree of correlation is revealed. Compared to the functional groupings previously suggested in the optimized Process Flow and Organizational Structure DSMs, the Informational Flow DSM is divergent only in the sequence of low Figure of Merit entities. This again suggests that these lower Figure of Merit entities are less critical in their position in the organizational, process and/or informational hierarchy with regard to ultimate customer value.

When analyzed in comparison to section 4, we see similar results in terms of the expected amount of interaction between subgroups in our DSM and the earlier Value Stream Map. This Information Flow DSM additionally supports the earlier stated conclusions from the Organizational Structure DSM analysis, as the suggested structure also withstands an Information Flow scrutiny.

### **5.3 Organizational Design Conclusions**

Throughout this thesis, the ability to utilize QFD and DSM methodologies to perform a systems-based organizational analysis has been clearly demonstrated. A comparison of the optimized Organizational, Process and Information Flow DSMs displays a great deal of similarity to the Value Stream Map and the Process Timelines of Figures 4.1 through 4.3, providing corroboration of the lean analysis.

Intuitively, one would think that the DSMs for Organization, Process and Information Flow would be largely redundant as the linkages between disciplines is virtually matched in all three instances. However, as can be seen in the three initial DSM matrices of Figures 5.6, 5.8 and 5.10



which represent the existing organization, the organization, process and information flows have quite different linkages with differing strengths. While the existing process flow (Figure 5.8) and information flow matrices (Figure 5.10) are quite similar, a large discrepancy is apparent when compared to the existing organization matrix of Figure 5.6. The commonality between all of these matrices is the inherent inefficiencies that they indicate exists within the corporation.

The three stage DSM-based analysis performed during this work supports the hypothesis that much of the difficulty experienced during change initiatives is a result of organizational and process discontinuities. A major contributor to this condition is the lack of alignment across the information, process and organization continuum. The combination of QFD and DSM as applied herein suggests that the application of these tools within a lean conceptual framework can explicate the organization's value generation components from the evolutionary confusion. The technique advanced by this work precludes the fragmented approach to restructuring that is frequently witnessed. The proposed Systems Engineering based methodology, as demonstrated here on a limited scale, clearly provides a structured, comprehensive organizational design solution. The addition of the QFD derived Figure of Merit enables consideration of fundamental lean principle of customer value maximization. This approach suggests that the functional groupings illustrated in the organizational DSM of Figure 5.7 provide the optimal organizational structure for the example employed. The subsequent process and information based DSM constructions substantiate this conclusion. It is believed that a precursory organizational design undertaken in the manner prescribed represents a significant enabler of the lean transformation.

## **6. Lean Enterprise Transformation**

### **6.1 The Need for Change**

While preparing this study we have examined numerous instances of successful lean transformation. Several common characteristics have been observed in all cases. The first is the existence of motivational impetus in the form of organizational crisis. In all cases, the company embarking on the transition to lean was experiencing life-threatening crises. All of the companies were experiencing serious difficulties that made recognition of the need for change intuitively obvious and created an environment where change was embraced as the only alternative. In this thesis we have shown the situation at Sikorsky Aircraft to be in this category, with the loss of regular, domestic high-compensation military contracts and the subsequent need for increasingly international commercial work. The second major factor is the presence of a highly placed change agent within the upper echelon of the organization. These individuals displayed unwavering commitment to the lean transition and possessed the ability to motivate and recruit disciples to the cause. The final commonality is the understanding that the transformation is more a journey than it is a destination. With this realization, a progressive implementation effort that establishes achievable sequential goals is prescribed. In *Becoming Lean*<sup>27</sup>, the importance of the first two factors and the need for a coordinated effort expanding from a pilot implementation is typical of all successful transformations.

Although recent changes at Sikorsky suggest that the need for change has been realized, to date the implementation efforts have been fragmented and poorly orchestrated. A subject of considerable concern, is the current haphazard utilization of *kaizen* (incremental improvement)

events and other fragments of the Toyota Production System (TPS). At present, Sikorsky frequently invokes portions of the TPS without consideration of the greater contextual imperatives. The execution of uncoordinated *kaizen* activities, Quality Circles, product teams, TQM (Total Quality Management) and most recently 5S, are classic examples of what Mike Rother describes as “superficial lean”<sup>28</sup> and are symptomatic of the fragmentation we seek to eliminate. In fact, in several well-intentioned instances, the reorganization that is supposed to eliminate the discontinuities of the organization does exactly the opposite, as informal networks are changed or destroyed. Sikorsky and all other companies contemplating the transition to lean practices, must gain a holistic understanding of the TPS and the associated lean concepts to enable the successful transformation. It is believed that effective organizational design, utilizing the systems-based techniques presented in this treatise, will be a key enabler of the successful lean transformation through recognition and elimination of the current fragmented structure.

The following paragraphs identify significant issues that must be addressed prior to or simultaneously with the initiation of the lean transition effort. Failure to resolve these fundamental issues will result in a high probability of change initiative failure.

### **6.1.1 Communicating the Vision**

Many of the classic problems associated with organizational change have been encountered during the research and writing of this report. Breakdowns in communication, misalignment of goals and incentives, and the erosion of functional expertise are the most serious. Employees in

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<sup>27</sup> Liker, Jeffrey K. et al. *Becoming Lean: Inside Stories of U.S. Manufacturers*. Portland, Oregon: Productivity Press, 1998.

general seem to understand that the need for organizational change as a “necessary response to competitive realities.” As there are dramatic changes to the employee’s existing cultural and mental models, however, this is typically a time of great uncertainty for employees.

The transformation of an enterprise such as Sikorsky, heretofore based on traditional mass production to one based upon lean principles and practices requires a major comprehensive change in behavior throughout the organization. A large-scale change such as this involves examining and redefining the organization’s core processes and information and technology enablers; affecting each and every system within the company. Not only is this change behaviorally challenging, overcoming “muscle memory” if you will, but will most likely cause cultural and political upheaval if not handled delicately. A change initiative of this size and scale must be led from the “top” of the organization, specifically the Chief Executive Officer (CEO) and senior management. Successful implementation of the principles and practices of “lean” will depend strongly upon the personal involvement, understanding, and leadership of top management within the organization. When heretofore successful organizations undergo radical change, it is often the cultural and political upheaval that is their undoing rather than the change itself. Much of this has to do with the disturbance of the status quo; the change in “comfort level” for long-time employees at all levels. With good communication from the change agents, much of this can be mitigated and in fact can be avoided altogether. Employees as stakeholders need to be kept aware of the reason for the change and their specific place in the overall scheme

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<sup>28</sup> Rother, Mike. “Crossroads: Which Way Will You Turn on the Road to Lean,” *Becoming Lean: Inside Stories of U.S. Manufacturers*, edited by Jeffrey K. Liker. Portland, Oregon: Productivity Press, 1998.

of the reorganization effort. To date this has not occurred in the Subject Company, with the attendant confusion and anxiety that the impending uncertainty fosters.

To that end, the realignment of the organization as described will facilitate useful communication between business units and serve to more easily align these same business units to the corporate mission statement. By utilizing the objective DSM matrices as previously described, we are able to clearly see the process, informational and organizational flows that will optimize that alignment, as all facets of the organization can be represented with their attendant feed-forward and feedback requirements. This alone, however, will not guarantee success. It is the author's belief that without the aforementioned change agent, well respected and highly placed in the Subject Company to literally over-communicate the vision and substance of the change to the rank and file, there will be little chance for success. Employees need to feel valued as an integral part of the organization. Again, with the HoQ and DSM analyses, it is much easier for the employee to see his or her fit in the organization.

### **6.1.2 Customer Value**

By realigning the organization and optimizing the overall throughput as described, customer value will assuredly be increased, as overall corporate efficiency will be enhanced. The HoQ as described directly relates the organizational structure to customer needs. In this way the Voice of the Customer (VOC) is "heard" throughout the value stream, enhancing customer satisfaction. The subsequent utilization of DSM to generate an optimal, customer value focused organizational and process structures facilitates customer satisfaction.

## **6.2 Process Design**

Throughout this treatise we have primarily dealt with organizational issues, purposely sidestepping specific process issues. It is the opinion of the authors that prior to addressing the myriad of complex processes within a large-scale manufacturing facility, one must first address the organizational structures and the process flows will necessarily follow. It is interesting to note that although much *muda* can be found throughout specific process steps, to tackle singular processes in an attempt to create a “lean” organization is a prime example of the fragmentary approaches now underway at Sikorsky. One must view the processes themselves holistically as part of the organizational whole. Without looking at the organization as a *system* and instead treating processes as singular entities, the previously discussed alignment requirements and the feed-forward/feedback relationships required for success are often overlooked.

## **6.3 Metrics**

The basic premise of lean endeavor, whether it is at the manufacturing, organization or enterprise level, is to maximize the generation of customer value. When understood from this perspective, it becomes apparent that many of today’s measurements are not only meaningless, they are detrimental in that they drive behavior in sub-optimal directions. “Lean metrics” aimed at optimizing value production and determining customer satisfaction will be the basis for the success of the lean organization and subsequently the lean enterprise. The benefits of the adoption of “lean metrics” will be twofold. First, the elimination of “*muda-metrics*”, those metrics with no real connection to customer value, which often promote local optimization at the expense of enterprise objectives, exacerbating fragmentation. The transition to lean metrics will allow the reassignment of skilled employees to value added positions. Second, the development

and application of the new metrics will truly enhance overall enterprise performance. Additionally, the accurate measurement of true performance variables will illustrate the advantages of lean and build support for the transition effort.

While it is not the intention of this work to provide a list of "ready to use" metrics for the transition, some high level guidelines are provided below:

- Localized metrics which attempt to measure individual or group performance without consideration of the true enterprise objectives must be eliminated. Misaligned metrics of this type foster organizational fragmentation and are a major component in the development of the inefficient structures we seek to eliminate through the applications presented in this discourse.
- The performance of the Integrated Product Teams should be mainly evaluated as their name clearly states, as a TEAM. If measurements based on the performance of individual team members are utilized, behaviors detrimental to the team objectives will begin to appear. The resultant loss of alignment with the vision will confuse and further erode the team.
- Metrics that encourage teams to be creative in finding ways to cut costs/improve processes/get rid of *muda*, etc. will be implemented with focus on customer value-added improvements. Plans have to be made in order to reward this new way of working. The goal is to make everyone in the organization aware of the necessity of being more efficient. This kind of metric can be applied throughout the organization, for the different Integrated Product Teams as well as the different core functional departments.

- The suppliers, part of the stakeholders that the company intends to satisfy, play a key role in the long-term success of the enterprise. In this regard, Sikorsky should redefine their supplier relationships by establishing metrics that focus on supplier performance in terms of life-cycle costs. Also, a commitment to the principle of mutual success must be demonstrated very early in the transition. This behavior will show Sikorsky's commitment to the success not only of their own programs, but of the members of the extended enterprise as well.

The new paradigm introduces many self-perpetuating principles. Maximized customer value will result in increased customer satisfaction, which equates to increased sales and accordingly increased gross revenues. Implementation of lean philosophies reduces operating expenses and the Cost of Goods Sold by eliminating waste. Decreased expenses enable the realization of greater net revenues and profits, which are the high-order metrics most important to corporate management, shareholders and all other stakeholders.

#### **6.4 Lean Implementation**

As has been previously stated, implementation of the lean concepts represents the most difficult phase of the transition process. Before initiating the transition to lean, the nature of the undertaking must be understood. The implementation of lean is complex and difficult, making the occurrence of setbacks inevitable. No universal approach exists for all companies or situations, necessitating a trial and error approach. Numerous failures will be experienced and redirections will be required as experience is gained. A true appreciation of the long-term benefits and a dedicated commitment to the transition are mandatory for success. Finally, it must be recognized that the lean transition is a process not a destination.



A carefully orchestrated pilot implementation is recommended. The need for early success with clearly observable improvements is important to gain employee support and build momentum. Analysis of the successful transitions detailed in *Becoming Lean*<sup>29</sup> and strategies identified in *Lean Thinking*<sup>30</sup> appear to support this approach. It is believed that one of the primary causes of implementation failure is organizational and process fragmentation and discontinuities. The resultant inefficiencies frequently represent insurmountable challenges to the corporation attempting to undergo the lean transformation. In this regard, the utility of the modified QFD and DSM methodologies becomes apparent. The capability to verify lean analysis findings and establish optimized organizational and process structures increases the likelihood of success.

## **6.5 Barriers to Lean**

The greatest obstacle to change is employee resistance. This resistance will be manifested in several different forms. The first will be political, as power shifts from the functional organizations to the IPT leaders. The second will be cultural in nature as employees will naturally oppose change and attempt to maintain the status quo. The third form of resistance will be based on the common perception of lean as requiring more with less and the accompanying fear of loss of employment. The importance of communication in overcoming these impediments cannot be overemphasized. The presence of a strong change leader and continuous communication of the need for change and the revised roles of individual employees is

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<sup>29</sup> Liker, Jeffrey K. *Becoming Lean: Inside Stories of U.S. Manufacturers*. Portland, Oregon; Productivity Press, 1998.

<sup>30</sup> Womack, James P. and Jones, Daniel T. *Lean Thinking: Banish Waste and Create Wealth in Your Corporation*. New York, NY; Simon & Schuster, 1996.

absolutely critical to success. The trust of the employees must be established through understanding and assurances that the lean transition will not mean lost jobs as productivity increases. It must be understood that lean is an enabler for growth rather than a means of reducing the workforce. To this end, communication may take the form of training as all employees are introduced to the lean principles. The familiarity achieved by these training programs will in itself provide significant assistance in overcoming the aforementioned barriers to implementation. To facilitate this, the establishment of a clear effective organization is of paramount importance. Attempts to implement lean principles without eliminating the existing fragmentation and discontinuities will encounter the full effect of the aforementioned barriers. It is believed that the preliminary organizational restructuring presented herein will enable successful enterprise transformation by allowing employees to experience the benefits in the form of improved communication and process flow. In addition, the improved organizational will permit reductions in concurrency, lead-times and rework. The realization of these benefits, made possible through effective organization, will generate internal support for the lean transformation and be a major factor to its success.

## 7. Summary and Conclusions

The evolutionary nature of organizational development within industry is seen as a principal determinant in the failure of many organizational and process change initiatives, including Lean Enterprise Transformation. Within the corporate environment, this evolutionary dynamic is frequently unacknowledged, resulting in organizational and process fragmentation and discontinuities. The effective resolution of the many complexities associated with organizational structures represents a significant enabler for lean transition.

The primary objective of this thesis has been to demonstrate the effective application of two common Systems Engineering methodologies within the context of organization structural design. The recognition and treatment of the corporate organizational structure as a complex system invites such an approach. The role of the proposed methodologies has been twofold. First, the ability to successfully modify the QFD and DSM techniques to model and analyze the organization with regard to the underlying lean principle of customer value maximization. And second, to provide independent validation of the lean analytical tools, Value Stream Mapping and Process Timeline Analysis.

It is the opinion of the authors that this thesis has achieved the objectives set forth at the outset. The QFD-based analysis of Section 5.1 clearly demonstrates the effectiveness of a modified QFD technique to determine organizational requirements relative to the underlying lean concept of customer value generation. This quantification of customer value results in the generation of what we have generically referred to as the QFD Figure of Merit. This value serves as an indicator of the contribution of each organizational constituent with regards to customer value

and is incorporated into the subsequent DSM analysis. While the example employed to demonstrate the application is admittedly limited in scope and customer specific, the proposed procedure is sufficiently flexible to permit effective utilization irrespective of industrial peculiarities or scale.

The serial employment of DSM to examine organizational relationships provides a greater degree of resolution, in that both the strength and the directional characteristics of the individual interactions may be examined. The addition of the QFD Figure of Merit to the DSM methodology enables a more meaningful “lean” perspective to the subsequent optimization activity. In an effort to obtain a more robust solution, the DSM analysis was conducted from three separate perspectives. This approach intended to demonstrate that the optimal organizational structure would demonstrate alignment from the three individual analyses. The results presented herein substantially support this hypothesis. However, the authors recognize that the intertwined nature of the three perspectives lends significant difficulty to attempts to impartially determine the appropriate relationship weightings independent of the other factors. Despite this difficulty, the DSM analysis performed in conjunction with the added QFD Figure of Merit achieved the objective of an organizational structure based on customer value.

Additionally, when compared to the Value Stream Map and the Process Timeline, the unique sequential application of the modified Quality Function Deployment (QFD) and Design Structure Matrix (DSM) methodologies clearly support the initial lean analysis. The benefits of the modified Systems Engineering methodologies, however, is not limited to verification. Based on the results of the analysis contained herein, the combination of QFD and DSM are strong

complimentary tools for corporations contemplating the transition to lean practices, in that they enable an increased understanding of the organizational complexities which represent the major contributor to failure of the initiative.

### **7.1 Recommendations for Future Study**

While the work performed during the preparation of this thesis demonstrates the viability of the proposed methodologies, additional study is indicated. One particular area of concern is the presence of a significant number of second-degree interactions as defined by the three DSMs. The manual DSM manipulation utilized during this effort is understandably limited in the capability to optimize the structure with regard to multiple interaction variables. It is recommended that future activities in this realm explore the utilization of DSM optimization software such as NASA's DeMAID (**D**esign **M**anagers **A**id for **I**ntelligent **D**ecomposition). A second recommendation is that the three perspectives incorporated in the DSM analysis receive additional scrutiny. Due to the highly interdependent nature of the three organizational components, the development of a single objective evaluation criteria would benefit the proposed procedure through simplification. Finally, as previously stated, the case study incorporated within this work is limited in scope. Additional work on a larger scale and across diverse organizations is necessary to establish the robustness of the proposed methodology. Despite these limitations, the authors believe that work represents a viable foundation for additional research into this unique application of System Engineering methodologies.

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