Comparative Study of Knowledge Transfer during Technology Pull in Complex Production Environments

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Employed by the Department of Defense (United States Air Force) since 1988 in several capacities.

- 2 years  – Lead Project Engineer of Air Command and Control Systems
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Employed by Sikorsky Aircraft since 1972 in several capacities.

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CHAPTER 1
Introduction and Background

INTRODUCTION

Companies have long been seeking ways to improve the transference of technological knowledge within and between organizations in the hope of reducing costs associated with a product, such as research, product development, and lifecycle costs. They have also sought to facilitate the easier coordination of effort for product innovation. In order to improve technology transfer, companies and researchers are exploring the ways that information is pulled through an organization. Among the best ways known to initiate technology transfers are:

1. Use of cross-functional teams;

2. Collocation of cross-functional team members;

3. Recognition and utilization of individuals who act as gatekeepers and boundary spanners; and

4. The exploitation of boundary objects as a means to develop a common interpretive translator between individuals of diverse, cross-functional organizations.

In our research, the accumulated data suggests that the combination of all four mechanisms will increase the likelihood that a project will be successful in sharing technological knowledge within and between organizations. The challenge for any organization is to determine to what extent these mechanisms can be put in place so that an environment conducive for pulling technological knowledge through research and development and into production can be created. The Sikorsky Growth Blade project, which is presented in Chapter 4, is a prime example of such an environment.
CROSS FUNCTIONAL TEAMS

A good deal of literature has been written describing the various mechanisms which companies have employed in transferring technology from research and development (R&D) to production. In writing about the use of cross-functional teams, researchers Katzenbach and Smith (1993) identified several reasons why cross-functional teams work well: "First, they bring together complementary skills and experiences that, by definition, exceed those of any individual on the team. Second, in jointly developing clear goals and approaches, cross-functional teams establish communications that support real-time problem solving and initiative. Third, teams provide a unique social dimension that enhances the economic and administrative aspects of work. Finally, cross-functional teams have more fun. This is not a trivial point because the kind of fun they have is integral to their performance."¹ Cross-functional teams are for many organizations the most effective means by which to incorporate their technically diverse functions and expertise into one productive unit. Cross-functional teams not only bring together the skills of many functions under one team, but they also bring about a structure that promotes the ability to listen carefully to the customer, understand his needs, and respond more effectively to the customer's requirements. As a result, the team is able to improve product cycle time.

According to Peter Block (1993), "As the marketplace places the premium on cycle time, adaptability, and giving a unique response to the customer, the advantages of the functional organization no longer hold. The alternative is to create multifunctional units organized around customers. You create teams responsible for doing the whole task, dedicated to a certain customer. What you lose in control and predictability [in a cross-functional team versus a functional team], you make up in response time and a widespread intimacy with the customer. Also, if we want

to breed ownership and responsibility close to the work, teams [cross-functional teams] being responsible for whole tasks is one way to do it."^2

**COLLOCATION**

Tom Allen saw the advantages to cross-functional teams in pulling technological knowledge through a project, but he also noted that cross-functional teams that are collocated communicate more effectively than those that are not collocated. Specifically, Allen (1971) reported that in order to influence communication within an organization, that organization must take into account the physical configuration of the facilities in which a project team is located. According to him, "...the proportion of people with whom an individual communicates decays with the square of the distance outward from the focal person."^3 What is amazing about this statement is that the probability of effective communication is close to zero for people located beyond 25 yards from one another. However, Allen’s research was done over 25 years ago, before the advent of electronic information systems such as electronic mail and video-conferencing systems, which are becoming commonplace in today’s organizations. These electronic systems promote communication within and between organizations, so close physical proximity to another person does not appear to be as crucial a factor for the success of a project as it once was. In fact, researcher Michael Schrage (1995) downplayed the importance of physical presence when he stated, “While video conferencing and other high-bandwidth communication technologies are available but not pervasive, it’s clear that the existing telecommunications infrastructure is acquiring a collaborative overtone. While there is no substitute for face-to-face contact, these technologies render physical presence a useful but not necessary part of a successful collaborative experience.”^4

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Another argument against the need for physical collocation of team members is the economic reality that many people are assigned to multiple projects at the same time. Companies are often faced with financial constraints which make collocation impossible. Therefore, the question then becomes “How does one effectively communicate with other individuals between and within organizations without necessarily being physically collocated?” Our analysis leads us to the use of boundary management techniques, such as gatekeepers, boundary spanners, and boundary objects, as the prominent mechanisms in pulling technological knowledge within and between organizations.

INDIVIDUALS

Many researchers have pointed out that the process of technology transfer can be facilitated by the presence of special liaison agents, or gatekeepers, operating either individually or as part of a group, who span the boundary between different organizational units. According to Nochur and Allen (1992), “The gatekeeper is a high technical performer who connects an organization with outside sources of technology. He keeps up with new technical developments outside the organization by reading more technically sophisticated literature and by communicating with external experts. Further, because of his proven technical competence, he is frequently consulted on technical matters. As a result, the gatekeeper is a very effective channel for transferring technical information into an organization from external sources.”\textsuperscript{5} De Meyer (1991) also noted in his studies that boundary-spanning roles (gatekeepers, liaisons, and sponsors) serve as key components to an effective communication network within an organization. For instance, the emergence of gatekeepers as aids in technology transfer allows engineers to initiate contacts between different organizations. De Meyer believes gatekeepers generally need a combination of good technical skills, as well as good listening and integrating skills, to be effective within an organization.

Other proponents of boundary management techniques like gatekeepers and boundary spanners include researchers Deborah Ancona and David Caldwell. According to Ancona and Caldwell (1992), “If teams are to fulfill their promise of shortening the product development cycle, they must develop the ability to collect information and resources from a variety of sources – inside and outside the organization – and interact with others in the organization to negotiate deadlines and specifications, coordinate workflow, obtain support for the product idea, and smoothly transfer the product to those groups that will ultimately manufacture, sell, and service it.”

Ancona and Caldwell observed the patterns of boundary activities that product development teams undertake to manage the transfer of technology with other teams. Ancona and Caldwell divide these patterns of boundary activities into three dimensions: (1) Ambassador; (2) Task Coordination; and (3) Scouting. Ambassador activities are activities designed to protect the team from outside interference. An example of an ambassador activity would be assigning someone the task of persuading other individuals that the team’s activities are too important to be overloaded with too much information from outsiders. Task Coordination activities involve coordinating with other functions to deliver a product that meets the expectations of other functional groups. One task coordination activity might be having design engineers resolve design problems with other groups, such as product engineers and marketing personnel. Scouting activities include searching for ideas or information about a competitor or technology.

Ancona and Caldwell discovered that the ways in which teams manage their boundaries are strongly related to their performance. However, these relationships are dependent upon both the frequency of specific activities and when performances are evaluated. For example, when teams are engaged in task coordination activities, the relationship between the frequency of these activities and the team’s success is much stronger when the evaluation is prepared after the team completes its assignment versus making the evaluation while the team is still

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working on the assignment. In addition, the teams that combine task coordination and ambassador activities are the highest performing teams. These teams are more innovative than other teams using other strategies for technology transfer.

An important factor found by Ancona and Caldwell about team management of technology transfer is that frequent communication with outsiders is necessary but not sufficient in building cross-functional relationships for product innovations. What is necessary is that teams not rely upon extensive external communication by all members, but rather, use gatekeepers to collect and interpret the information from outside sources. In a separate study done by Ancona (1991) relating to boundary management, she describes the changing role of teams in organizations. Specifically, Ancona describes the creation of new teams in today’s organizations as open systems, entailing complex interactions with people beyond their borders. Ancona points out that teams, which implement a probing strategy, are rated as the highest performers. According to Ancona (1991), “Probing teams actively engage outsiders and revise their knowledge of the environment through external contact, initiate programs with outsiders and promote their team’s achievements within their organization.”7 In addition, Ancona found that as probing team members interview outsiders and test ideas, their internal processes become smoother, i.e., clearer goals, better shared information, etc.

Tushman (1977) extends Tom Allen’s gatekeeper concept by showing that there are individuals who span boundaries within an organization. These individuals perform the very important role of integrating differentiated functional and departmental units. Later research by Allen further points out the significance of boundary management through the use of boundary spanners. According to Allen (1990), “To overcome the boundary impedance within organizations, a variety of strategies must be employed. There are, first, individuals, who play a role similar to that of the gatekeeper. They mediate and translate between organizational

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units. These ‘boundary spanners’, as they have become to be known, are different from gatekeepers. They are not necessarily the exceptionally high performers that gatekeepers usually are. They are often people who have been transferred between units and who therefore understand how the different systems function and why they function differently. ⁸ Boundary spanners help to fill the gap between knowledge known in one organization and knowledge known in another organization. However, the best “gap-filler” for knowledge transfer within and between multiple organizations can be seen in the last managerial mechanism to be discussed, i.e., boundary objects.

**BOUNDARY OBJECTS**

Lastly, we believe the most effective boundary management technique available in pulling technological knowledge within and between organizations which will assist an individual in understanding a technological problem is the use of boundary objects. According to Marcie Tyre and Eric Von Hippel (1993), “The ability to understand and resolve problems is only partly located in experts’ heads. It is also located in the experts’ ability to recognize and to enact clues about the problem or its solution. Thus, to understand and resolve problems, experts need to make use of practices, occurrences, beliefs, and artifacts available in specific concrete settings.” ⁹ Another researcher, Paul Carlile, has been exploring how boundary objects redefine and enlarge the knowledge boundaries between functions and, in turn, create common investments across multiple functions. Boundary objects embody a certain aspect of knowledge-in-practice, but also have a common character across different functions, which makes them very practical for problem solving. According to Carlile (1997), “Use of a boundary object, like a drawing or prototype part, often results in the concrete exchange and negotiation of knowledge between functions, dislodging old knowledge and creating new knowledge (i.e., compromises, solutions, work-arounds, innovations, etc.). A

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boundary object facilitates the application of different functional knowledge in transforming the current state of designing and implementing the product; thus, transforming the current embodiment of cross-functional knowledge.”\(^{10}\) Carlile professes that when problems become more concrete through the use of a boundary object, individuals from one function such as manufacturing are better able to apply their knowledge and transfer that knowledge to another function, e.g. design, in order to fix the problem.

An example of a boundary object that would fit well into Carlile's philosophy is the computer-aided design (CAD) system. In fact, Robertson and Allen (1990) made the following statement after reviewing ten manufacturing companies that used CAD systems: “CAD systems, when used as an aid to conversation, create a common language or set of references. This common language allows differentiated and interdependent groups to effectively communicate about design-related issues. The combination of a face-to-face meeting and the availability of a rich and flexible representation of the design leads to a medium of communication that is both unique and powerful.”\(^{11}\) Robertson and Allen saw that engineers would use CAD systems to coordinate with others by accessing others’ designs directly. As a result, many design errors were detected and corrected earlier than usual had CAD systems not been used. Perhaps the best way to close our discussion on boundary objects is to read the words of an engineer who was involved in the Robertson and Allen study: “With CAD, you can create different views for different tasks. This cuts the drawing time – you don’t have to recreate the design each time. Also, CAD is better than drawings. It takes a lot of practice to understand someone else’s drawing. Drawings get pretty complex, there’s a lot of lines, and you can get optical reversals and other problems...You can also shade the CAD model if you do surfaces, which makes it look a lot more realistic.”\(^{12}\)


\(^{12}\) Ibid., pg. 11.
In summary, we have researched literature on several managerial mechanisms used to pull technological knowledge within and between organizations, e.g., manufacturing and design engineers using a CAD system as a boundary object. Collectively, all of the managerial mechanisms are beneficial to promote throughout a project. From a senior manager's viewpoint, researchers Steven C. Wheelwright and Kim B. Clark would support the premise of adapting all of the management techniques to enhance project success during development. In fact, Wheelwright and Clark identified pivotal activities that senior managers must perform if project teams are to work effectively. According to Wheelwright and Clark (1995), "These activities include:

(1) Defining project boundaries, missions, and charters;

(2) Picking the right kinds of teams (or, more precisely, matching the project type to team type);

(3) Ensuring that functions build capabilities so that teams have the right knowledge, tools, and other resources to achieve their objectives;

(4) Ensuring that upon completion, there is a seamless transition of responsibility to the operating organization."\(^{13}\)

In the upcoming chapters, we will analyze four projects from complex production environments to examine the influence of the managerial mechanisms (Cross-functional teams, Collocation, Gatekeepers/Boundary-Spanners, and Boundary Objects) in pulling technological knowledge within and between an organization.

CHAPTER 2
Theory Development and Propositions

OVERVIEW

During any design and development project, the ultimate product goal is to meet or exceed the customer's operational needs or requirements. Usually, these requirements, whether formal or informal, are expressed in the form of satisfaction or dissatisfaction with an existing or previous product. Given this customer 'first hand' product information, any design organization intent on improving the existing product must translate the expressed and perceived issues into a substantive design configuration that will successfully benefit the customer's long term requirements. Therefore, a company with new projects will most likely create a list of projected performance targets that will assist the design and manufacturing organizations in meeting the intent of those customer needs.

Having stated this, it is impossible for any one-customer representative or any one-company representative to define every possible need or use of a product. Therefore, as a product development program begins and progresses into production, it becomes necessary for many functional representatives to evaluate the development process for potential customer requirements that were not initially expressed during concept development. Also, as the design and manufacturing process continues it is helpful to have several different individuals of varying perspectives provide critical assessment of the product as it reaches production. This critical evaluation approach is considered to be the standard review process for complex structures, such as aircraft systems.

Once a company initiates a project, it is essential to develop a creative environment that sponsors a success-oriented process for its workers and which encompasses concept development through integrated product development. This success-oriented process for projects attempts to involve many diverse non-design
organizations, through teaming, in the creative design process. Thus, teaming early during concept development provides an opportunity to express and interact with the design and manufacturing organizations while the design ideas are still being formed. A successful introduction of experiences and knowledge by all functional groups into the design and production manufacturing process creates that collaborative, motivated involvement of people and ultimately results in benefits to the final product.

**BACKGROUND**

Searches of the literature on the subject of successful integrated product development teams confirm the premise that highly motivated, well-informed people will be the most successful in meeting the final product goals. As has been studied concerning those teams, there are several specific personnel, as well as structural and organizational approaches which, when employed, will increase the probability of success for the development team. Team strategies such as choosing team members for their experience and collocating team members improve the likelihood of effective technical communication. In addition, employees informally known as gatekeepers and boundary spanners can be used within groups to assist in the coordination of the information process flow. These strategies create organizational environments that sponsor improved communication and increase the likelihood of successful dialogue between non-design functional groups outside of design as well as within design organizations during the development process.

However, even after an organization improves the likelihood of communication by structuring the project teams, it must still recognize and deal with the natural tendency for individuals to oppose change to their existing environment. This is especially true when the change affects the person, ‘designer’ who created this new, imaginative idea and feels a great sense of personal ownership toward the concept. In order to force a designer to stop, listen and apply alterations,
alternatives, or new ideas to a concept under development, it is essential that the individual proposing a new idea have the ability to sell the designer on the need, merit, and effectiveness of the change. This selling activity is usually done through face-to-face negotiation where one person must convince another of the rightness of the idea and the benefit of the idea to the design as well as the customer. This process of selling and negotiation constantly occurs during all stages of the product development process. It takes place both within the design and manufacturing organization as well as those acting from outside the design community.

The negotiation process generates a conflict or friction between both of the involved people, groups or organizations. This friction is usually resolved by convincingly expressing and demonstrating one’s expertise and knowledge about a topic or need. The negotiation process persuades the opponent that change meets the customer requirements as well as the design requirements of form, fit and function. If the opposing individual is unable to convert technical knowledge of a subject into a design oriented discussion, the designer or parent organization will most likely dismiss any idea that does not conform to the designer’s way of thinking or the previous knowledge of a topic or requirement. In a similar way, manufacturing also experiences conflict negotiations during process development. Ultimately, if customer issues are not resolved early in the negotiation process, costly redesigning will result because of contractual commitments to production tools and parts. Finally, this generally leads to lengthy production delays as changes become more complex and, therefore, more difficult to adapt into the production process.

Improving the ability to communicate among individuals within groups, as well as across group boundaries, represents one of the most difficult processes to master, especially while a complex development project focuses on meeting a completion date. The focus of our thesis is to reveal those events or characteristics in a project that enhance an individual’s ability to transfer their knowledge of a technology and effectively apply, or pull, that knowledge into the design or manufacturing process.
under development. In other words, how can the product knowledge retained by various non-design, cross-functional organizations be seriously considered and innovatively pulled into the design or manufacturing development process?

Communication between people is enhanced when there is a common understanding of the language being used. Just as individuals need a common vocabulary in order to be able to share ideas, organizations and groups must also have a shared “language” which all members must be able to speak fluently if real communication is to occur. When communicating ideas related to the design and manufacture of a product, that common language flows from a shared understanding of the physical product, including its form, its properties such as shape, strength, and the relationship of parts within an assembly. This communication process extends to the representatives who understand the customer needs and how those needs are reflected in the final product via the design and manufacturing process.

TEAM

It is desirable that all participants in a development project have the ability to influence the design as it is being formulated. Each functional member of a project imagines how the desired state of the product will ultimately exist. This is based one’s personal expertise, functional understanding, and expected customer requirements or constraints. Therefore, the effectiveness of each individual is dependent upon the ability to communicate concepts in a language that the designer recognizes as meaningful to the product or manufacturing process.

There are a variety of ways in which alterations to the design may occur. It is possible, but unlikely, that political forces within an organization may dictate the final design without group consensus. However, it is more common that the design is usually modified as a result of regular communication and negotiations among the organizations which have a vested interest in the customer’s requirements, yet may not have control over the design configuration itself. In order to create a more
balanced negotiation process, the various groups must have a persuasive method of presenting their case to the designer and more effectively respond to counter-arguments.

**Boundary Spanners & Gate Keepers**

- One possible way to accomplish this is to have the “non-design organization” retain equivalent design capability and product knowledge, by means of a concept designer. That means that the non-design organizations must retain a duplicate expert in all technical fields that are involved in the design process. The knowledge equivalency approach requires group members to possess a unique expertise in many technical areas and to receive continuous training in order to be able to debate issues on an equal technical basis. In addition, if any brand-new technical ideas are to develop, the group then needs to hire a member of another organization who is expert in that field of interest. Such a scenario is unlikely, since companies of the 1990’s have downsized in order to meet the efficiency needs of the company’s leaders and the shareholders.

**Collocation**

- Another method of improving the likelihood of the persuasive influence of an outside group or individual upon the design concept is to build an organizational group around the design organization, which monitors the design process on a daily basis. This is best described as a collocated, multi-functional project team. In this scenario, each outside functional source would have regular access to the designer. As the designer creates new drawings, the outside individual could critique and influence each design detail as it is produced. Collocation enhances the communication process by increasing the likelihood of contact between diverse but required functional groups.

Two potential difficulties exist, when applying collocation as an organizational communication structure. First, as functional groups lose people to long term
projects, expertise and functional knowledge slowly degrade. If collocation were to exist for more than a two-year period, research indicates that multi-functional teams would decrease in effectiveness as time progresses and ultimately lose current knowledge with respect to the industry. Second, multi-national or global companies cannot practically construct single collocated projects. Various design practices are based on culture; multi-national customers, costly transportation and housing costs, etc. conspire to force all but the smallest companies to abandon the idea of collocation. They must either do business across long distances or meet in one location to discuss issues on a less frequent basis. Neither option maximizes the quality of communication.

BOUNDARY OBJECTS

An enhancement to the above communication approaches is to represent the design in such a way that all organizations can express their concerns regarding the design via a physical representation. Since many organizations do not understand how to read a drawing or create a design, poor communication is very likely to take place. Often it is difficult to verbalize a change issue or a new idea to the design organization. Converting a verbal idea into a visual design concept is a complex process. The fundamental reason for this complexity relates to the drawing itself. The designer imagines the part in three dimensions and draws the part in a geometric code, which is represented as a part in two dimensions. This conversion process creates a knowledge barrier, which effectively limits non-design organizations in implementing many constructive design changes into the design and development process.

However, these same non-design organizations regularly interact with the physical components that their customers utilize every day. Many of these operational parts or subsystems normally experience functional problems many times a year. This means that the non-design organizations understand actual part functions and their related problems in the course of participating in problem analysis and
implementing corrective action while the part is in service. Thus, these non-design organizations have great knowledge regarding how, when, and where the customer uses the product, maintains it, and what it costs to operate it. They understand the product as a real three-dimensional, operational component with known system problems and complaints.

The question that remains is, ‘How does a non-design organization intelligently negotiate known operational issues with the design organization?’ In general, the most effective way for these non-design organizations to communicate their understanding of a particular issue is through the use of a physical representation of the part or assembly. The non-design person uses the 3-D physical representation as a translation tool in order to communicate one's physical understanding of an issue back to the designer. Thus, the representation itself acts as a communication interface or ‘object’ that is used by the non-design person to relate a specific problem and convert it back into the designer’s communication domain. Once understood, the designer can ultimately represent the negotiation issue back into the detail form, be it a paper or electronic drawing, or a model of the part in the production process.

To be effective, the design group should be able to convert a design into a realistic 3-D representation of the final configuration prior to actually producing the part. The non-design community will then have an easier time communicating issues and potential solution of problems to the designer. The physical design representation acts as a common link or ‘object’ that is utilized by the two negotiating organizations to span the boundary of understanding and knowledge. This communication tool or ‘boundary object’ is the common interpretive tool for communicating each group’s understanding of the issue and the need for change.
PROPOSITIONS

1. Early involvement of a multi-disciplined team is essential for successful, time efficient projects.

2. Teams require cross-trained, multi-functional people in order to transform technical knowledge into practical team information that enhances team performance.

3. Collocation of team members enhances communication between individuals.

4. The more concrete a boundary object, the more effective the communication process, therefore the easier the transition of technological knowledge between individuals.
CHAPTER 3
Research Methodology

INTRODUCTION

In the spring of 1998, the authors performed interviews at two major aerospace firms and a major automotive firm within the United States. The aerospace firms were the Boeing Company and Sikorsky Aircraft Company, and the automotive firm was Ford Motor Company. Each of these firms was selected based upon the following criteria:

(a.) Each firm designs and manufactures many of its own products;

(b.) Each firm is a significant player in the aerospace or automotive industry; and

(c.) Each firm is a large multi-functional company that produces complex products requiring integration of a wide array of technologies and systems.

Boeing is the major producer of fixed wing commercial and military aircraft for the world. Boeing, which recently merged with McDonnell Douglas Corporation, now owns several divisional facilities distributed around the country. One series of interviews was performed at the Aircraft & Missiles Division of the Boeing Company in Long Beach, California. This is where the C-17 Globemaster III was designed by McDonnell Douglas and is now being produced as part of the Boeing Company. Another series of interviews took place in Saint Louis, Missouri, where the F-15 Eagle and F-18 Super Hornet production facility is located. Over 1,000 aircraft have been produced for both production type aircraft. Currently, the advanced F-18 E/F is just now being started as a production aircraft.

Sikorsky Aircraft Corporation’s major facility is located in Stratford, Connecticut. Sikorsky is the number one producer of medium and heavy lift helicopters in the
free world. Interviews concentrated on design projects that were incorporated into the Blackhawk helicopter.

Equally interesting was our visit to the Ford Motor Company in Dearborn, Michigan, where we performed interviews on topics related to advanced automotive development projects. We reviewed topics concerning innovative designs that were incorporated into today’s production vehicles.

METHODOLOGY

Of the dozens of interviews that we completed over the days that we visited these facilities, four projects were chosen specifically for their completeness and richness of information during and through the complete concept to production development time span. These projects were the:

1) Sikorsky Blackhawk Growth Blade,
2) Sikorsky Blackhawk Tip Cap,
3) Boeing F-15 Speed Brake, and the
4) Boeing C-17 Pre-Coated Rivets/Fasteners.

The projects are presented in the order given above.

In general, these projects represent a cross section of technology insertions that advance customer, manufacturing, and design capabilities. These projects required improvements to existing products, well after the product was initially developed and produced. For each project, the interviews attempted to pick a representative cross section of the team, consisting of three or more people, which included design, stress and/or manufacturing responsibility. The number and type of individuals were chosen so that confirmation of reported project elements or characteristics could be corroborated by at least two sources of verification.
Finally, each interview attempted to evaluate the particular project motivation, the technology innovation adapted, the team organization, type of people involved, the significance of collocation, and how communication amongst differing team functions took place and how it might have been enhanced. Upon completion of the interviews, we tabulated the results on the strength of influence each of the managerial mechanisms (Cross-functional teams, Collocation, Gatekeeper / Boundary-Spanners, and Boundary Objects) played in pulling technological knowledge through a project. Each project’s use of a managerial mechanism had a potential to achieve a score of 3 (Strong), 2 (Moderate), 1 (Weak) and 0 (Not Existent). The results are shown in Chapter 5.
CHAPTER 4
Presentation and Analysis of Data

The following four projects represent the primary interviews of this thesis\textsuperscript{14}.

They are:

1) Sikorsky Blackhawk Growth Blade,\textsuperscript{15}

2) Sikorsky Blackhawk Tip Cap,\textsuperscript{16}

3) Boeing F-15 Speed Brake,\textsuperscript{17}

4) Boeing C-17 Coated Rivet.\textsuperscript{18}

The projects are presented in the order given above.

\textsuperscript{14} The interviews conducted herein represent the perspective of the technical professionals participating in the projects. Their views may differ somewhat from the actual events experienced within the company.

\textsuperscript{15} Meetings attended at Sikorsky Aircraft Corporation in Stratford, CT from 17 to 19 December 1997 and 6 January 1998. Several cases were reviewed, but most information was accumulated for the Blackhawk Growth Blade and Tip Cap. Interviews were held with designers, structural analysts, manufacturing, N/C programmers, and shop support engineer. Interviews are unpublished documents. Interviews were conducted as part of International Center for Research on the Management of Technology (ICRMOT), located at the MIT Sloan School of Management for the Lean Technology program. Individuals interviewed have not been disclosed due to the proprietary nature of the topics covered.

\textsuperscript{16} Ibid., at Sikorsky Aircraft Corporation in Stratford, CT from 17 to 19 December 1997 and 6 January 1998.

\textsuperscript{17} Meetings attended at the Aircraft & Missiles Division of the Boeing Company in St. Louis, MO on 16 & 17 February 1998. Interviews were held with lead designer, N/C programmer, and supervisor. Travel and interviews were sponsored by the International Center for Research on the Management of Technology (ICRMOT), located at the MIT Sloan School of Management, in support of the Boeing Company and its contract with the U.S. Air Force to study Lean Technology. Individuals interviewed have not been disclosed due to the proprietary nature of the topics covered.

\textsuperscript{18} Meetings attended at the Aircraft & Missiles Division of the Boeing Company in Long Beach, CA, on 29 January 1998. Interviews were held with two manufacturing engineers. Travel and interviews sponsored by the International Center for Research on the Management of Technology (ICRMOT), located at the MIT Sloan School of Management, in support of the Boeing Company and its contract with the U.S. Air Force to study Lean Technology. Individuals interviewed have not been disclosed due to the proprietary nature of the topics covered.
CHAPTER 4
Presentation and Analysis of Data

CASE 1
GROWTH BLADE

INTRODUCTION

This case discusses the process used by Sikorsky to develop and manufacture its rotor blades, as well as those factors management employed in this process. An account of the integrated product manufacturing development process is given, along with a description of the problems encountered during its implementation. Chapter 5 will present the analysis of the strengths and weaknesses of the integrated product development manufacturing process used in the H-60 blade project. We will also highlight some of the successful communication methods that were utilized during this project. Chapter 6 will offer conclusions and suggestions for future investigation.

PROJECT BACKGROUND

In 1991, Sikorsky Aircraft embarked upon a new development and manufacturing project which represented a significant shift in manufacturing policy. The H-60 rotor blade project marked the first time that an integrated product development manufacturing IPD process was utilized by Sikorsky to produce a blade to very exact specifications in a shorter time and at a lower cost than had ever been accomplished before. The H-60 blade project provided an ideal opportunity for Sikorsky to incorporate an entirely different approach to development and manufacture of a new product. If successful, the project could serve as a model for future endeavors.

The original titanium rotor blade used on the H-60 helicopter had been designed approximately twenty years ago, when the H-60 helicopter was being developed. The rotor blades were capable of lifting in excess of 21,500 pounds. The design and manufacturing process used by Sikorsky was a traditional one in which the
Preliminary design was sequentially reviewed and revised by various groups within the company until the blade was deemed ready for production. The typical scenario was as follows:

- Research and Development gave basic data about the blade to Design Engineering, which drew up the initial plans and specifications.

- Manufacturing Engineering reviewed the work of the designers and made changes based upon the realities of the manufacturing process.

- The Tooling group was next to receive the project. This group recommended changes which would better accommodate the tools and shop equipment used in the blade’s production.

- The project could be returned to the Design group and Tooling group a number of times until all groups were satisfied with the design.

- A blade was produced and tested. If alterations needed to be made, expensive re-tooling had to take place.

Each of these steps was done in sequence, with relatively little ongoing interaction between the internal and external groups working on the project. As a result, several negative consequences occurred:

- Overall time from inception of the project to production was lengthy. The average time to develop and manufacture a blade was five to six years.

- Costs rose each time adjustments were made to the blade. This negatively affected the company’s profit and the cost to the customer.

- Manufacturing had to build the blade with all its inherent problems and then modify the process on the shop floor to make the various parts fit together properly. It was very difficult to duplicate the two-dimensional design in the actual manufacturing process.

- The formal manufacturing procedure made it difficult to maintain ongoing communication with suppliers. This communication problem led to production delays and higher costs.

- Production processes required constant ‘tinkering’ and adjustments by Manufacturing in order to maintain process control.
segments of the community, including Finance, Facilities, Environment, Customers, Marketing, Logistics, Suppliers, and Safety.

INNOVATIONS

In addition to the use of the latest design technology, the Core Team utilized advanced composite materials, derived from the new all-composite Comanche helicopter. The growth blade represented the first application of this new material process in blade production, thus advancing manufacturing capability and increasing the strength and durability of the new blade. The composite blade, unlike its titanium predecessor, was significantly lighter, yet it was stronger and more resistant to variations in the blade's airfoil contour. By controlling the contour and weight distribution, the team was successful in significantly reducing undesirable aircraft vibration while at the same time improving the performance of the aircraft. This new high-reliability blade would also decrease the incidence of breakdowns and repairs, thus lowering operating costs to the customer and raising customer satisfaction.

From the manufacturing point of view, the blade assembly process was a simple and very successful one.20 However, there were several problems with respect to the detail parts that influenced the cost, repeatability, and ease of manufacturing. It was decided that manufacturing's charter was to simplify the process and improve the quality of the blade detail parts, as required. In particular, this meant that the manufacturing process for the new composite spar had to resolve the field problems of fit and distortion that aggravated the present titanium spar. By developing a simpler process for making precise production grade tools, manufacturing as well as design believed that the composite spar would be a superior design to the 20-year-old production design. This belief stemmed from the fact that the spar was the primary structure of the blade and the part that controlled

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20 Interview at Sikorsky Aircraft Corporation in Stratford, CT on 18 December 1997
• The growth blade design and manufacturing team had simplified the manufacturing process in all locations except the tip section of the blade. Unfortunately, the manufacturing of the tip end of the blade could not be produced with simple, uniform plies laid in regular layers. Because of the advanced aerodynamic requirements of the blade, the tip had a bend and a droop, which was located within 6 inches of each other. The aerodynamic loads, along with the complex shape, caused the structures engineers to add extra, complex ply orientations for most of the tip composite layers. The manufacturing engineers were forced to develop an assembly process that manually placed each layer of composite in the tip mold in very specific locations. Each layer within the tip changed in shape and position as the stress engineers analyzed and designed the optimum pattern for ply orientation and placement.

• Through the use of a computer, the 'Laser Alignment Tool' (LAT) could be programmed with the exact shape and position of each composite layer. As each layer was sequenced through the manual assembly process, the laser, which was positioned several feet over the tool, would draw and outline the subject layer on the tool for the technician to see. This permitted the technician to place the ply in the proper orientation with respect to the tool. In addition, an added quality check occurred by comparing the shape of the outline to the shape of the ply that was being placed in the tool. If the ply did not match then there was an error in the sequence placement of the composites. The LAT proved to be extremely useful to manufacturing when it came to demonstrating the quality and repeatability of the production assembly process of the composite tip section. The new tool and process were successfully demonstrated to the FAA. Subsequently, the 'Laser Alignment Tool' has been applied to other composite assembly processes.
experiencing. If this discussion was related to a physical understanding of a problem, several reactions might happen.

- Meet at someone’s desk in order to define the issue more precisely
- Evaluate the 3-D CATIA model for accurate contour definition
- Get other people involved to expand the definition and impact of the problem
- Go to the shop floor and evaluate the problem on a tool or part
- Create a small experiment to better understand risk and reduce the potential problem

**DESIGN TOOLS AS BOUNDARY OBJECTS**

A tool that permitted the team to realize a production process early in the design phase was 3-D CATIA. CATIA is a computer base, 3-D surface modeling design package that permits quality definition of components prior to producing a physical part. In this blade project it was used to define every detail part into a 3-dimensional computer database. As the 3-D parts were completed, they in turn were electronically assembled, so that design and manufacturing could evaluate the likelihood of assembly success, dimensional variability and quality.

Likewise, with the parts electronically documented, manufacturing engineering now had the opportunity to evaluate possible process methods and decide upon the method of manufacturing. Alternative ideas could also be evaluated by modifying the process via the 3-D electronic design method. The 3-D design and development process represented a new way to simulate the real world prior to committing to the final production process. The growth main rotor blade was the first Sikorsky project to use a complete 3-D-design process that fully documented the design in such a way that a complete transfer of the design data could be directly forwarded to tooling and manufacturing.
CHAPTER 4
Presentation and Analysis of Data

CASE 2
COMPOSITE TIP CAP

INTRODUCTION

This case discusses the rapid development and prototyping process used by Sikorsky to create and manufacture a replacement composite tip cap within 6 months of project go ahead. An account of the integrated product development process, along with a description of the tools used to communicate project issues, such as, 3-dimensional modeling, finite element analysis, production tooling, and field service parts. This case details some of the potentially successful communication methods that were utilized during this project.

DESIGN BACKGROUND

In January of 1996, an analyst was funded to evaluate a proper ply orientation and thickness for the new tip cap skin configuration. As this design process was moving forward, external events took place which caused the customer to show new interest in the tip cap problem. The Coast Guard suffered a tip cap incident involving one of their aircraft in April 1996. A tip cap broke loose from the aircraft, and in the act of failing it caused significant blade damage to the tip cap attachment to the blade and the adjacent skin. The failure and resulting damage initiated a significant vibration during flight that caused the pilots to immediately land the aircraft onto a local beach. This incident heightened the customer’s awareness of the general problems and the potential safety implication if this should happen again. Immediately, the company and the customer created a program that would design and qualify a new composite tip cap for the H-60 aircraft. The program management funded an integrated project team which included a designer, an analyst, representatives from manufacturing tooling and manufacturing operations, and a lead shop supervisor. Because the customer had expressed a great sense of
urgency, the company's upper level management was also highly motivated to provide a rapid turnaround of a new design introduction into the naval fleet.

TEAM STRUCTURE

The urgency of the tip cap problem defined the need to bring together an experienced group of engineers who were completely familiar with the configuration and related problems of the tip cap. The team representatives included a lead designer, structural analyst, manufacturing engineer, and shop foreman. All but the structural analyst had worked for several years on solving both tip cap production process problems, as well as fleet operational problems. Each team member had worked with each other previously, thus immediately creating a cohesive, highly motivated, cross-functioning team.

To round off this team, there were two supervisors who represented the design and manufacturing functions, respectively. They were also very familiar with the history of the tip cap, as well as the design, analysis, and processing of composites as they existed at Sikorsky. As the project continued, these supervisors continuously verified that the applied concepts met the design and manufacturing goals of low risk and high quality in the replacement tip cap. They, along with the head of the Rotor design group (Chief), acted as the upper management communication voice for the team as it progressed through the project.

The lead designer communicated with certain individuals who were not normally considered part of a design process. The head of the training school within the company was notified that the design group was fixing a field problem by designing a composite replacement part. The training school became involved by evaluating the repairability of the composite structure. These repair concepts were later put to the test during the qualification of the part. The training school experience

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23 Interview at Sikorsky Aircraft Corporation in Stratford, CT on 19 December 1997
product. Overall, this process was extremely successful due to the significant flexibility that it provided to the team.

COMMUNICATION AND COLLOCATION

As reported in the Growth Blade project, the team was not co-located as a project. The whole group maintained their functional location within their organizations. These locations placed them within the same, large building, but spaced them as much as 300 meters apart. A great deal of the dialogue regarding day-to-day problems occurred over the telephone, on the shop floor where the problems developed, or often at someone’s desk. Most of these discussions were conducted as required during the day. Each session would highlight an issue that one of the team members was experiencing. If this discussion related to a physical process or design understanding of the part, one or several reactions might happen.

- Meet at someone’s desk in order to define the issue more precisely
- Get other people involved to expand the definition and impact of the problem
- Go to the shop floor and evaluate the problem on a tool or part
- Create a small experiment to better understand risk and reduce the potential problem

A formal, once a week meeting was held in the manufacturing group area. This allowed the whole team to become familiar with the latest configuration and problem solving issues that still required resolution. In general, this formal meeting was considered to be of secondary importance compared to the informal daily meetings which were ongoing, but it served an information-gathering purpose for the supervisors, who conducted more formal upper management meetings during the week.
COMMUNICATION TO MANAGEMENT

After the formation of the team, upper management did not directly participate in the day-to-day operations of the project. Status information concerning the project was regularly provided to upper management on an impromptu basis or at their regular scheduled meetings that were held on a weekly basis, such as a Thursday safety review meeting. When this occurred, the head of Rotor design facilitated the information exchange. Other program meetings were attended by either or both of the functional supervisors.

Customer interest was very high throughout the entire development and production process. Customer information requests were met by frequent phone calls made by the program office or the Chief of the Rotor design group. At least one formal meeting was held at the Coast Guard facility in Mobile, Alabama. The Rotor Chief gave a formal engineering status briefing, which reviewed the cause of the original failure and outlined the status of the tip cap development project at that point in time. Throughout the project, the supervisors' primary role was to serve as the communication network for the team. This permitted the core team to concentrate on the daily activities and the success of the project.

EXAMPLE: COMMUNICATIONS USING BOUNDARY OBJECTS

After the single rib configuration was created and the process validated, the rib experienced a structural problem. Two counterweights, which mount to the inboard wall of the rib, caused the rib walls to bend because of excess load. This bending was noticeable when finger pressure was applied to the rib wall. Manufacturing attempted to modify and stiffen the proposed rib. This modification included the addition of small bridge ribs that would support the rib wall adjacent to the counterweight. It was thought that this change would result in the more even distribution of the counterweight loads. This judgement was only an opinion from manufacturing and not based upon structural analysis. However, this idea had an additional fatal flaw. Production-manufacturing engineering evaluated this concept
and believed that there were far too many detail pieces within the rib that needed to be assembled during the manufacturing process. These extra parts required excessive labor hours to construct the final configuration. Such a design alteration conflicted with the design and manufacturing team goals of 'ease of manufacturing' and 'lowest cost'.

Over a one-week period, the team met in the shop, trying to resolve the problem. The team proposed a design solution to correct the soft rib wall by adding a 'bead' to the offending bonded rib surface. A bead is a ¼ inch curved shape, oriented perpendicular to the length of the bonded surface. Several beads were added to the rib bond design, thus correcting the warping problem and also eliminating the complex rib configuration.

To prove the bead would correct the warp, the manufacturing group, along with a production assembly technician, made a trial piece (Boundary Object). This trial part permitted the manufacturing group to evaluate the production process along with the physical stiffness properties of the bead. The part was constructed because of the difficulty in analyzing these physical characteristics using the computer modeling tools. The construction of this trial part validated the manufacturing process improvements and the ease of production. Once this part was produced it was passed around to the different organizations of design, programs and the customer in order to explain the issue and the corrective actions that were designed into the part.

However, the other structural problem regarding the support of the counterweights still existed. The structures engineer suggested that material be locally added to the rib in order to support the counterweight flight loads. However, the manufacturing organization resisted this recommendation because it added an additional detail piece to the construction process of the tip cap assembly. The lead M.E. had to negotiate between organizations, design and manufacturing, in order

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25 Interview at Sikorsky Aircraft Corporation in Stratford, CT on 19 December 1997
to understand and resolve the need for this added complication. In the end, the added piece proved to be structurally necessary, based on the 3-D finite element stress analysis (Boundary Object), which showed that the design would not meet the required stress allowable for the rib material. Consequently, it was concluded that a two-piece rib was unavoidable.

While this negotiation process was continuing, another manufacturing engineer independently proposed an idea to change the now two-piece rib back to a single-piece rib through the use of a tooling concept that he had learned in another development project. The ME supervisor considered this idea to be high risk and was not convinced that the rib could be manufactured as one piece. The supervisor opposed the change due to uncertainty of success. However, convinced his idea was possible, the second M.E. went to the shop and made a trial piece that demonstrated the ease of construction of the one-piece rib (Boundary Object). Because of the success of this demonstration part, the manufacturing supervisor agreed to allow the change in process and include the one-piece rib in the final design. Ultimately, the one-piece rib was incorporated into the ‘Lead-the-Fleet’ tip caps, about half way through the first 50 production run. No problems were encountered during the transition of the one piece rib.
CHAPTER 4
Presentation and Analysis of Data

CASE 3
SPEED BRAKE

INTRODUCTION

This case reviews the process used to develop and manufacture the speed brake for the F-15 by Aircraft & Missiles Division of the Boeing Company, St. Louis division. This case implemented the use of the integrated product development (IPD) manufacturing process as part of the introduction of the high speed machining process into a newly developed F-15 speed brake configuration.

PROJECT BACKGROUND

The speed brake on the F-15 is a large composite structure, roughly 10 feet by 3 feet, that is integrated into the top of the F-15 fuselage behind the cockpit. When the F-15 lands, the rear end of the speed brake is lifted by hydraulic pressure, creating a large surface area that causes air resistance and assists the slowing of the aircraft. The composite air brake was installed on over 1,000 F-15s. The new all-aluminum brake represented a major shift in priorities to affordability, where price was the driving consideration. After a 3-year process of discovery, design, and implementation, the first new brake was installed on a production aircraft in February 1998.

Over the long history of the composite speed brake, there had been difficulty with the complex assembly of the brake. In addition, there were also numerous field reliability problems associated with this part. Because of these problems and the continued need for cost reductions, the F-15 program office asked Engineering to evaluate the brake for improvement and re-design of the brake. The original speed brake was built of composites, with a carbon epoxy skin and 483 integrated detail pieces, 8 machine parts and 372 fasteners. The original design criteria were driven by a need to reduce weight; hence, the composite brake only weighed 92 pounds.
as low a weight as composites. It was inevitable that the weight of the part would increase. The importance of this initial assumption is hard to overstate. When the design engineer looked at alternatives, he was free to look beyond composites and alter the design weight if a significant production cost reduction could be realized. The decision to allow an increase to the brake weight was made easier by the fact that the brake is right at the aircraft's center of gravity. Thus, a few pounds would not have an effect on the aircraft balance or dynamics.

Second, the F-15 program Office decided to have one person, the lead designer from Phantom Works, follow the project all the way through, from concept and design development to production. This person possessed the expertise in the production high speed machining process for aluminum, and the communications skills to see the project to a successful conclusion.

TEAM STRUCTURE – People, Integrated Product Development & Collocation

Beginning around 1993, management started to promote team concepts. Initially they supported co-location during an F-18 project that was working on a new equipment shelf. This early equipment shelf project in the F-15 nose was the first IPD application experience. The initial idea was to make the shelf more manufacturable by building it from fewer parts through the process of machining the parts by low cost conventional means. This project sparked the idea to create monolithic machined parts, which became a general trend for new parts to follow, such as the speed brake.

The key N/C person for the speed brake production development was among 2 or 3 people who had been assigned to manufacturing engineering in the F-15 shelf program. An important first step for the brake was that the project manager called a meeting to have the numerical control (N/C) group talk about product issues to design engineers on the F-15 project. The goal was to experiment with an IPD (Integrated Product Development) approach. There was a strong sense from the project manager that he wanted to make the IPD concept work. The N/C lead
engineer was initially nervous about the feasibility of the idea, but once he first saw the concept he said, "Wow, what a neat part." He was convinced that the speed brake could be a success. At this point in the development phase, the lead N/C engineer thought that the design was only 40-50% complete, almost rudimentary in places. He saw an ideal opportunity to use his previous F-15 shelf experiences with high speed machining and apply them to the brake. A high velocity mill had just been purchased by McDonnell-Douglas, but the concern was that the equipment had not yet been used to make any production parts.

Because of the IPD process, the design and manufacturing people were brought together early in the program development. Fortunately, people were open to new ideas, and, as the N/C engineer said, "...it was very unusual to tap into the middle of a design and development program." He found both designers to be good at trying to accommodate N/C requirements. He remembered telling them, "You're the designer, and your word is final." By acknowledging their power, he believed that the engineers would feel "soothed" and supported, even when he was forced to argue with them for what he needed. He distinguished between those things he had to have and those things he thought would improve the product. The lead N/C engineer reported that there was a "tug of war" and a "strong discussion" between them, with both sides pushing for what they thought was best. The lead N/C engineer says he felt that what was done on the speed brake simply could not have been done in the McDonnell Douglas culture before this time, due to the prior inability to weigh and consider opposing viewpoints in an open atmosphere.

By November 1995, it was thought that the design was ready to go. However, the team found that it had to back off and go through another Conceptual Layout stage for about another 2 to 2.5 months, because the team did not include a structural analyst early in the design phase. The F-15 Program judged that the structures

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27 Interview at the Boeing Company in St. Louis, MO on 17 February 1998
28 Interview at the Boeing Company in St. Louis, MO on 17 February 1998
29 Interview at the Boeing Company in St. Louis, MO on 17 February 1998
engineer could have saved "about half the (extra) development time"\textsuperscript{30} [a month or more] if he had been involved earlier. The structural analyst determined that the 110-pound conceptual design did not provide enough stiffness to the brake. Initially, engineers had expected the natural frequency of the brake to occur at greater than 30-hertz, but found through analysis that the natural frequency of only 20-hertz was the actual reading. Therefore, 30 pounds of aluminum was strategically included within the part to augment the stiffness. Historical test and structural data had also been re-analyzed in order to validate the final structure. Although limited resources might have been the cause for slow team building during the speed brake project, it was also thought that the project would have experienced even greater delays without the lead designer transferring from Phantom Works and then co-locating within the F-15 Program group. According to the N/C engineer, the IPD team "... would have been in a world of hurt"\textsuperscript{31} without the lead designer's production experience, which made the crucial difference in the outcome of the project.

INNOVATIONS

1. Technology Insertion: High speed machining was first implemented in simple structures, like the equipment shelf in the F-18 fighter program. However, the lead N/C manufacturing engineer felt that the speed brake team was pursuing unexplored territory, full of risk. They had no actual production experience, and there was no experience in producing reliable large compound curved surfaces using high-speed machining. Though the research developers made some effort to be helpful in resolving some smaller issues, they had no understanding regarding how to solve machining 'the complex' curved surfaces that were found on the speed brake. From the point of view of production manufacturing, it was thought that the research area was a controlled environment, isolated

\textsuperscript{30} Interview at the Boeing Company in St. Louis, MO on 17 February 1998
\textsuperscript{31} Interview at the Boeing Company in St. Louis, MO on 17 February 1998
from the practical experience of the shop floor. The team determined that it had to go significantly beyond the existing limits of the known experience of high speed machining to produce a practical manufacturing process.

- To solve this problem the manufacturing team evaluated the processes of cutting aluminum. It was determined that if a standard cutter was used during the machining process it would take countless parallel cuts to achieve a smooth curved surface contour for the brake. This made for a time-consuming and expensive cutting process. The team evaluated several cutter concepts and came up with a hybrid cutter, a cross between a ball nose and flat cutter that could cut more material. Though a good cutter concept, there was a major concern that the non-rotating center of the cutter would drag and damage the part as it was surfacing the skin. The team asked research for help with this problem, but after repeated requests the response was deemed inadequate. Research was unable to offer any resolution to the problem of the quality of the machined surface. The team felt it was left out on its own.

- One key to finding a solution was the lead N/C engineer's continued dialogue with other N/C programmers. They provided advice on ways to cut curved surfaces. Several people offered suggestions about ways to program the cutter on the machine rather than design a new cutter. These proposed techniques had been used for conventional cutting of other parts. A half dozen techniques were non-standard, apparently part of the tribal knowledge of the N/C community that had been used for curved surfaces in the past. A novel idea emerged which solved this issue by moving the cutter so as to "rock the tool".\textsuperscript{32} This change, once incorporated into the machine, eliminated the possibility of a stagnant rotation point. The entire tool was placed in constant motion during the cutting process.

\textsuperscript{32} Interview at the Boeing Company in St. Louis, MO on 17 February 1998

The team feels that without this innovation and other N/C techniques the milling of the speed brake would have failed. The lead N/C engineer's actions as a boundary spanner, in the area of machine tools, led to a breakthrough in processing high speed machining for curved surfaces.

COMMUNICATION

During the transition of the company to IPD teams, the N/C programmers stressed that only a portion of their job involved the actual programming of machines for manufacturing processing, such as writing the code that guides the tool path. Much of their day-to-day concerns centered around the problems of how to hold the part in the machine, how to define the tools for drilled holes and manage the other processes up through final inspection. Because engineering drawings are often ambiguous, the N/C programmer had to interpret the configuration, define the manufacturing process and substantiate why it should be inspected in a certain way. Often it led to changes in drawings. The N/C results were a more complete representation of the part, not only because they showed changes to the original drawings, but also because they included the production process tooling and manufacturing approach. Each drawing could represent "thousands and thousands of dimensions on a complex part," and making changes due to N/C implementations could prove to be a "long bureaucratic nightmare", fraught with numerous communication difficulties.

Early Communication Experience: The N/C lead engineer's first opportunity to talk to design engineers early in the design phase took place in Long Beach, California. In 1991/92 there were limited design resources at McDonnell Douglas, St Louis. The Manager decided to have his N/C people to get to know the comparable group in Long Beach. According to him, at the time there was "a new concept floating around" that looked like IPD. IPD was supposedly being used on the NASA space station, another McDonnell project. When the St. Louis designers

\[33\] Interview at the Boeing Company in St. Louis, MO on 17 February 1998

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asked for a meeting, the N/C lead engineer and other group members quickly agreed. These joint meetings resulted in good progress on these small initial projects, since N/C was actually able to make input regarding design. A fellow N/C group member told him, while "...you can't tell them what to do"\textsuperscript{34} it was beneficial to be able to dialogue with the design engineers.

- In one case the design people had conceived of a 20-foot long part that also had tolerance requirements of 3/1000ths. When the difficulties of producing such a part were identified, they told the N/C engineer to simply move the piece to a different tool and cut it again. N/C people proceeded to explain to a "roomful of design engineers"\textsuperscript{35} the realities of producing tight tolerance parts within the production shop environment. The meeting proved useful because N/C felt that after the dialogue it became much easier to work with design engineering on produceability issues that existed in the shop. After working on projects together and building a liaison with the shop over a 7 or 8 month period in Long Beach, N/C found that it was able to "slip in new production ideas" to the St Louis production facility. This first merge into IPD communication networking proved to be the model for the speed brake process to follow.

**EXAMPLE: COMMUNICATIONS USING BOUNDARY OBJECTS**

**EXAMPLE 1:** The lead designer often walked to the production facility to talk to the shop floor technicians who installed the bushings in the F-15 speed brake. He used this opportunity to understand how the brake was put together and installed while proceeding through production. Whenever he talked to an installer, he would bring a **sketch** or drawing which would describe the configuration of the brake. The original design drawing was without an access hole in the exterior surface. When talking to the installer, he noted that it would be nice if "I had a hole to allow adjustment of the stop."\textsuperscript{36} This would permit him to see inside the part and make

\textsuperscript{34} Interview at the Boeing Company in St. Louis, MO on 17 February 1998

\textsuperscript{35} Interview at the Boeing Company in St. Louis, MO on 17 February 1998

\textsuperscript{36} Interview at the Boeing Company in St. Louis, MO on 17 February 1998
the necessary adjustments. The installer was describing a nut and bolt hard-stop that required an adjustment after the brake was installed onto the aircraft.

On the old brake, there existed no exterior access to this adjustment, and so it was necessary for the installer to install the brake, actuate the hydraulic servo to close the brake, measure the adjustment gap, remove the brake, make an adjustment, then reinstall, and finally verify the installation adjustment. Such a process proved to be time-consuming and costly to the company. Eliminating the many steps of this process became a primary goal of the team.

Beyond learning about the adjustment, the lead designer realized that there was an additional benefit to having access to this area. There was also a need to drill a transverse hole into the clevis that attaches the servo to the brake. The designer chose to enlarge one of the two-adjustment access holes in order to permit easy drill manufacturing access into the clevis. This simplified the drilling process and reduced the set-up time and cost of machining the brake.

In a boundary-spanning role, the lead designer used a sketch as the boundary object for communication. The shop personnel were able to translate this sketch into a visual representation, then develop an idea that could change the sketch and improve the process of the brake installation. The shop individuals also used boundary objects when the conversation focused on the tooling and installation of the part on the aircraft. This process was a successful information exchange between diverse organizations.

**Example 2:** After producing the new speed brake, it was noted upon the first installation into the aircraft-mounting hole that there was interference within the aircraft mount. The installation of the brake was skewed slightly to one side when closed. When the problem was investigated, it was determined that the tool, which was manufactured for the original composite brake in the early 1970's, included this assembly bias as originally designed and produced. It seemed that the original installer 'graybeard' had compensated for this error and had made some
adjustment in the assembly process. However, there appeared to be no effort to correct the tool drawing problem; instead, the production process was altered to compensate for the error. This alteration brought everything back into alignment, but the tool design problem was never reported back to the engineering community or incorporated into the drawings at that time.

Since the new brake was designed to use the old assembly tool, the new brake could not be properly installed according to the aircraft’s assembly requirements. A temporary fix was to file off a clearance cut onto the new speed brake arm until a modification of the tool could be incorporated. This was an interim measure, however, for the engineers modified the tool drawing and corrected the alignment problem.

The designers were able to use both the original tool and the original part produced by the tool as boundary objects. Communication with the shop floor was enhanced by direct contact with the assembly tool and aircraft, which demonstrated the mounting process and problems thereof. Ultimately, these boundary objects enabled the team to understand the design problems, correct them, and produce a speed brake that could be properly mounted to the aircraft.
CHAPTER 4
Presentation and Analysis of Data

Case 4
Pre-Coated Fasteners and Rivets

INTRODUCTION

McDonnell-Douglas's Military Transport Aircraft Division located in Long Beach, California, was acquired this past year by The Boeing Company. The Military Transport Aircraft Division is responsible for the manufacturing of the C-17 Globemaster III cargo aircraft and is one of the world's largest manufacturers of military transport aircraft. Production of the C-17 Globemaster III cargo aircraft has been ongoing since the early 1990's. Thirty-two C-17 cargo aircraft had been built prior to the transition to the use of the technologically innovative "pre-coated fasteners". According to the General Manager of the C-17 Project, "Our goal is to build 500 plus variants in Long Beach, California for the next 30 years." Presently, the C-17 has a production run of 120 cargo aircraft for the United States Air Force. Aircraft & Missiles Division of the Boeing Company expects that a commercial version of the C-17 will become available within the next few years.

The impetus for the use of pre-coated fasteners came through an affordability program started by McDonnell-Douglas after the customer, United States Air Force, complained about the high cost of producing a C-17 cargo aircraft (over $260 million). Since the project was a firm-fixed type contract, the United States Air Force demanded that McDonnell-Douglas reduce its costs to produce a C-17 cargo aircraft by 25% or it would cancel the existing orders for the out years. Reacting to the pressure to comply with the customer's request, McDonnell-Douglas (The Military Transport Aircraft Division) began the Affordability Assessment Program, designed to identify parts and processes used in manufacturing the C-17 cargo aircraft that might be candidates for technological innovations. Thus, the Pre-Coated Fastener and Rivets project became a reality.

37 C-17 Globemaster III Military Transport Aircraft Directory, 1996
due to the fact that the process of installing fasteners and rivets using the wet-sealing application process was a major problem in manufacturing the C-17 cargo aircraft because it was messy, time consuming, of poor quality, and costly.

Two of the gentlemen interviewed on the C-17 Cargo Aircraft Project were instrumental in bringing this innovative technology of pre-coated fasteners and rivets to fruition. Specifically, we spoke to the project manager and the senior manager.

INNOVATION

The United States Air Force is calling the use of pre-coated fasteners and rivets a revolutionary change in manufacturing aircraft. McDonnell-Douglas accountants are calling it an innovation that will save $2.2 million as each new C-17 Globemaster III comes off the assembly line.\(^\text{38}\) It is a new kind of rivet or more precisely a new kind of rivet coating. The Pre-Coated Fasteners and Rivets Project replaced the wet-sealing application to titanium fasteners and aluminum rivets with a pre-coated dry sealant application to titanium fasteners and aluminum rivets.

Wet sealing application involves a series of steps such as:

1. Refrigerate sealant
2. Thaw sealant
3. Clean surface of aircraft
4. Apply sealant
5. Put in fastener or rivet into pre-drilled hole
6. Install fastener or expand rivet with Impact Gun
7. Squeeze out excess sealant

\(^{38}\) McDonnell-Douglas Press Release 97-51
8. Clean surface with toxic substance

9. Inspect each hole given the variance of the process.

On the other hand, the process for a pre-coated fastener or rivet has fewer steps as follows:

1. Vendor applies dry-sealant to fastener or rivet

2. Vendor delivers the pre-coated fastener or rivet to McDonnell-Douglas in Long Beach and

3. Assembler screws in fastener or drills rivet in the aircraft...end of job!

As one can see, the number of steps are far fewer for pre-coated fasteners and rivets than the wet sealing application.

The pre-coated dry sealant allows mechanics to work faster and cleaner — and do better work. According to the project manager, "The Military Transport Aircraft Division of McDonnell-Douglas is at the cutting edge in fastener technology, introducing along with two suppliers, Hi-Shear Corporation and Aerospace Rivet Manufacturing Corporation, a major leap forward that will cut costs and reduce rework dramatically, while improving airframe quality and preventing fatigue."³⁹ The senior manager noted that each C-17 aircraft has a total of over 1.4 million fasteners and rivets which had been costly to install using the wet application due largely to the cost of disposing of its hazardous materials. According to the senior manager, "Introducing the pre-coated fasteners saves a lot of money, and it improves the quality of work life for our mechanics."⁴⁰ Even the team leader in the Drivmatic area reported that, "We get a better squeeze on the fastener and avoid problems where rivets don't fill the hole tightly. Also, on the titanium pins, if you have to remove any, they don't seize up because there is more lubricity."⁴¹ The old wet sealant used to clog up the Drivmatics.

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³⁹ Meeting at McDonnell-Douglas in Long Beach, CA on 29 January 1998.
⁴¹ McDonnell-Douglas Press Release 97-51
The new pre-coated dry sealant also reduced the process variability factor in installing 590,000 titanium fasteners and 733,000 aluminum rivets. In addition, the coating provided corrosion protection in each hole. According to the project manager, "We're expecting a 1.1 million-hour savings in Phase 2 of implementation that will begin shortly." Phase 1, which began with P-33 aircraft and Phase 2 combined are expected to save 2.3 million labor hours on P-33 aircraft through P-120 aircraft. The project manager expects that other military and commercial programs will eventually adopt this technology.

TEAM STRUCTURE

The team consisted primarily of the project manager, the senior manager from the staff, a test engineer from Phantom Works, and two vendors (Hi-Shear Corporation and Aerospace Rivet Manufacturing Corporation). The team had a strong technical capability and experienced individuals, such as the project manager and senior manager, who were familiar with manufacturing processes associated with the wet application of fasteners and rivets. Also, one of the vendors had prior experience in applying the pre-coated fastener to commercial aircraft. The other vendor had experience in manufacturing rivets, but lacked experience with coating them. The test engineer from Phantom Works brought forth the technical capability to assist the rivet vendor in manufacturing a pre-coated rivet. The test engineer holds the process patent for dry-coating a rivet.

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42 Meeting at McDonnell-Douglas in Long Beach, CA on 29 January 1998

57
INDIVIDUALS

The project manager played a strong role as the gatekeeper between McDonnell-Douglas and Hi-Shear Corporation. The project manager, an industrial engineer by trade, was familiar with the technical problems associated with wet-seal application to fasteners and rivets. According to the project manager, "It was a problem looking for a solution." \(^{43}\) The project manager initiated contact with Hi-Shear Corporation back in 1992 and discovered that Hi-Shear had applied pre-coated fasteners to commercial aircraft. Hi-Shear explained to the project manager the benefits of this innovation, such as durability, reliability, and practicality in using pre-coated fasteners in the commercial aircraft sector.

The project manager can be classified as a gatekeeper, for he was a high technical performer who connected the organization with an outside source of technology. The senior manager can be characterized as a powerful “boundary-spanner”. The senior manager was a gentleman who had specific experience in operations and manufacturing and had been transferred to senior staff to enhance his abilities in networking between program management and manufacturing. According to the senior manager, “I co-led the Integrated Product Team (IPT) with the project manager for the first half of the project. You see, good networking was critical to the success of this program. I had credibility with the folks on the floor, since I had prior experience on the floor, and also, I would routinely go down there to find out what was going on. I was able to convince them [mechanics] that this was a good idea and would save them a lot of grief.” \(^{44}\) The senior manager fits Torn Allen’s definition of a boundary spanner to the tee, for the senior manager was a person who well understood the functions in manufacturing and operations. He could effectively translate their concerns to program management regarding the existing process on wet-sealing applications.

\(^{43}\) Meeting at McDonnell-Douglas in Long Beach, CA on 29 January 1998
\(^{44}\) Meeting at McDonnell-Douglas in Long Beach, CA on 30 January 1998
COLLOCATION

No collocation existed in the physical sense, as Tom Allen would describe collocation. The rational explanation for the lack of collocation stems from the fact that the key members of the IPT were working on other projects that demanded their time. Also, it was the responsibility of the vendors to produce the pre-coated fasteners and rivets at their respective manufacturing facilities.

COMMUNICATION

The IPT had weekly meetings and telephone conferences with all members. The meetings outlined a two-phased approach to getting pre-coated fasteners and rivets installed in the C-17 cargo aircraft. A two-phased approach was decided upon since the IPT felt it would be easier to first tackle the testing and installation of pre-coated fasteners, since they already existed in a commercial form. On the other hand, the pre-coated rivets would require a new process technology similar to that of coating a pill before it could be tested and installed. Also, the IPT had to overcome the problem of dry-coating aluminum rivets, given that aluminum does not withstand high temperature heating as well as titanium.

BOUNDARY OBJECTS

One of the first boundary objects utilized in this project was the feasibility study conducted by the project manager. The project manager used a feasibility study comprised of financial spreadsheets to first persuade the general manager that switching to dry-coat sealing rather than wet-sealing fasteners would be cost effective in both labor and materials. In this case, the project manager transferred his knowledge of replacing the process of wet-sealing fasteners with the process of dry-coat sealing. He then transformed that knowledge into cost figures so the general manager could understand what the project manager was conveying to him about the benefits of this technological innovation.
Another example of a boundary object was when the IPT showed test results to the customer, United States Air Force, on the dry-coated titanium fastener and rivet. The test results, which took 12 to 18 months to collect, showed that the pre-coated fastener and rivet could withstand environmental conditions like salt water without corroding or becoming porous. Again, one can see how concrete problems like risk of fatigue, porosity or corrosion were quelled by evidence of the merits of the dry-seal process which enabled another individual, such as a customer, to clearly understand the benefits of the new fastener and rivet. Although the use of the test results is seen as a boundary object, the fact that it took between 1 to 1-1/2 years to transfer that knowledge to the customer makes this particular boundary object only moderately effective.

Lastly, the use of boundary objects was considered to be moderately effective because of the original transformation of the existing commercial understanding of pre-coated fasteners to a military version of both a pre-coated fastener and rivet. The commercial pre-coated fasteners met Federal Aviation Administration (FAA) specifications, but not military specifications. According to the project manager, “The U.S. Air Force wanted us to test this pre-coated fastener to 10,000 specs.”  In addition, the vendor for the pre-coated rivet had never dry-coated an entire rivet before. Therefore, a new process technology had to be developed to be able to uniformly cover an aluminum rivet with aluminum pigmented resin and corrosion inhibitors. As mentioned earlier in this case, aluminum does not withstand high temperature heating as well as titanium. The test engineer from Phantom Works was able to develop a process for coating an entire rivet, but this process took over a year to develop.

**CUSTOMER SUPPORT**

The customer in this case study was weak in supporting the efforts to get the pre-coated fastener and rivets into production cargo aircraft. The customer was the

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45 Meeting at McDonnell Douglas in Long Beach, CA on 29 January 1998
original developer of the wet-sealing application and felt comfortable in its use as a corrosive protector. The project manager, who felt disgusted by the lack of enthusiasm on the part of the customer, said to the customer, "So what's it going to be, the propeller or jet engine?" Afterwards, the customer requested that the pre-coated fastener and rivet meet numerous specifications, which prolonged the time required to implement this innovative technology. Unfortunately, the customer did not offer any support up front to assist the IPT in seeking ways to expedite the implementation of this technological innovation. The customer was unwilling to reduce the level of testing performed even though commercial test data was available. Consequently, it took over 5 years to make this technological innovation a reality.

**MANAGEMENT SUPPORT**

Internal management support was weak. The project manager tried to convince Internal Research and Development (IR&D) management that this innovative technology was worth funding. IR&D management responded in a bureaucratic fashion, stating that they could not fund projects that only benefited a single project and were not universally beneficial to the other projects\(^{46}\). Even after the success of this project, the project manager requested sharing this technology with its sister division in St. Louis, Missouri. However, upper management refused to grant the project manager's request, because there were no travel funds available to allow him to travel and spread the news on this innovative technology.

\( ^{46} \) U.S. Government rules regarding IR&D uses, strictly forbid application of funds to be applied to a single aircraft product.
Chapter 5
Comparative Summary of the Case Studies

This chapter summarizes the results of the case studies presented in the last chapter. The literature research, which is outlined in Chapter 1, represents the comparative context for this investigation.

This study sought to identify how information [knowledge] is successfully transferred in a complex production environment using well-known managerial mechanisms, such as cross-functional teams, collocation, gatekeeper or boundary spanner individuals, and boundary objects. In addition, the study sought to determine if these project mechanisms could create timesavings for a project as they pull technical knowledge through the development process. The framework for this chapter will correspond to the four managerial mechanisms discussed in Chapter 1.

CROSS-FUNCTIONAL TEAMS

Cross-functional teams played an important role in the success of all four aerospace projects that we studied. In each case, careful attention was paid to the membership of the team, the prior experience of each member, and the breadth of cumulative knowledge possessed by each member. The primary core team for each of the projects we studied consisted of representatives from design, structures, and manufacturing. These people, in turn, were able to access individuals from program management, material support, and finance to assist them in completing the development tasks of the project. Although the number of team members varied from project to project, the structure and purpose of each team were the same.

These four projects correlate well with Katzenbach and Smith's (1993) observation that cross-functional teams bring together persons whose complementary skills
These individuals can be described as cross-functional engineers with knowledge in multiple disciplines.

Our research indicates that the cross-functional team configuration contributed to significant savings in time to production for each project we studied. The Sikorsky Blackhawk Growth Blade project and the Boeing F-15 Speed Brake project each incorporated the Integrated Product Development team process for the first time, with significant reduction in time from the project’s inception to completion (approximately half the time required in previous similar projects). In the Blackhawk Tip Case and the Boeing Pre-Coated Fasteners and Rivets case, we noted that even relatively small cross-functional teams were able to realize significant savings of time. The decision to establish cross-functional teams seems to have been a major reason for the overall success of the four projects we researched.

GATEKEEPERS AND/OR BOUNDARY SPANNERS

A study of the four projects we investigated indicates that each team had certain members who served as gatekeepers or boundary spanners throughout the life of the project. These individuals were able to influence the transfer of knowledge throughout the team. They fit the description of boundary spanners or gatekeepers given by Tom Allen in his research on the subject.

Gatekeepers are high-technical performers who connect an organization with outside sources of technology. We saw such a person in the Pre-Coated Fasteners and Rivets project. The project manager established and maintained contact with a number of outside sources, including Hi-Shear, the rivet supplier. The manager’s task was to utilize the expertise of Hi-Shear in producing commercial pre-coated fasteners and to transfer that expertise to a military application.
Another gatekeeper that we observed was the lead designer of the Sikorsky Tip Cap project, who sought out the expertise of personnel from Sikorsky's training school. The head of the training school was able to evaluate the reparable ability of the composite structure and to add to the design knowledge of the tip cap by developing tip cap repairs while the design and development process continued.

There was abundant evidence of team members serving as boundary spanners on virtually every project we studied. Boundary spanners are individuals who may not be high-technical performers, but they have a broad understanding of the culture and function of many functional organizations which have "ownership" of the project, due to their experience in working within a variety of these groups. In the Sikorsky Growth Blade project, both the manufacturing and design supervisors served as boundary spanners by coordinating team meetings within the team and by sharing information concerning the status of the project with the members of senior management.

Another example of a boundary spanner was seen in the Tip Cap Project in the person of the Director of Manufacturing. The Director, a former chief of the Rotors group, had recommended the design alteration that resulted in a one-piece rib configuration for the tip cap. This design eliminated many ribs and fasteners, thus simplifying the design and manufacturing process. His recommendation dramatically improved the ability to produce the tip cap at decreased cost.

In the Boeing F-15 Speed Brake project, the design engineer served as the boundary spanner. In this case, the design engineer, who began the concept development process within the Phantom Works Research Center, stayed with the project by transferring to the St. Louis production facility. Once at the production facility, he spent time on the production floor, examining process problems within the existing brake. After speaking to an installer on the production floor who complained about the brake's installation, the design engineer was able to develop a remedy to the problem, which reduced manufacturing and assembly time.
We noted that the senior manager of the Pre-Coated Fasteners and Rivets project could also be classified as a boundary spanner. Because of his background in manufacturing and operations, he could explain issues to the project management and manufacturing operations and promote the use of pre-coated fasteners and rivets on the C-17.

In general, the more senior members of the projects we studied were boundary spanner-type individuals. They knew how the organization outside the project functioned, as well as the individuals outside the project group who could be called upon to assist during the course of the project.

Within the organization, several of the lead design and manufacturing team participants acted as gatekeepers. Knowledge and information transferred to the other team members through these individuals. The workers recognized them as experts within the company.

**COLLOCATION**

The degree of collocation in the four cases we studied ranged from strong to non-existent. Since Tom Allen’s research (1971) indicates that collocation of team members is necessary to facilitate communication within the group, we were interested in seeing if the physical location of the group members would have an influence on the effectiveness of the group.

The greatest effort to collocate team members was seen in the Speed Brake project. The N/C Programmer was collocated with the Phantom Works group for eight months, and one designer was transferred into production to make certain that the speed brake production went flawlessly. In the opinion of the members of the Speed Brake team, the collocation of the team was the most important factor in the success of the project.
The two Sikorsky projects (Growth Blade and Tip Cap) had moderate collocation by locating the teams’ members within the same building. However, the distances between members sometimes exceeded 300 meters, a distance far in excess of Tom Allen’s recommendation of no more than 25 yards. Most of the daily interchange of information occurred over the telephone, on the shop floor, or at someone’s desk. Team proximity did not play a strong role in communication enhancement at Sikorsky.

The Pre-Coated Fasteners and Rivets project did not collocate any of its team members. This particular project saw the vendors taking a stronger role in the development and production of these parts than we noted in the other three projects, since the bulk of the activity associated with producing these parts also took place at the vendors’ facilities. This may explain to a certain degree why collocation was not chosen as a means to facilitate communication.

It appears to us that the physical collocation of team members is not as important to the ease of transmitting information as is the ability to create a physical representation of the product, which allows the team members to better identify and investigate problems and come up with solutions.

**BOUNDARY OBJECTS**

We next evaluated each project in terms of the number and kinds of boundary objects used throughout the life of the project. These important communications tools, we felt, should enhance the depth and quality of information exchange among individuals. These boundary objects, as Paul Carlile might say, permit communication in “a common game space”. 48 As a result, each player can share his or her implicit knowledge in an explicit way by using an accurate visual representation that is a completely descriptive object. Accordingly, this object

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allows individuals to better translate their verbally expressed issues and concerns into visual product definition and corrective action.

We observed that all the teams we researched used boundary objects to a significant degree in order to create quality information exchange among many diverse organizations.

The Sikorsky Growth Blade project and the Sikorsky Tip Cap project both used boundary objects extensively. Such objects as the CATIA design software, the Finite Element Method stress analysis software, Stereo-lithography part creation method, existing production tooling, and field service parts enabled the team’s members to more easily communicate service, manufacturing, or design issues during development. The boundary objects proved to be the most effective communications management tools used in each of these projects.

The F-15 Speed Brake project was also able to utilize the existing production line, process tooling, and members who performed the original assembly of the speed brake as major sources of information. Through conversations with the production technicians at their workstations, the lead designer was able to better understand the use of the production tooling and use them as the focus for subsequent discussions concerning problems encountered throughout the production process. Within the IPD team, the 3-dimensional drawing became the primary boundary object. The drawing was created by the N/C group and acted as the physical representation of the brake. The N/C group used the 3-D drawing as the conduit to communicate the need for practical drawing tolerances to the design engineers.

We noted moderate use of boundary objects as a means of transferring knowledge throughout the cross-functional team in the C-17 Pre-Coated Fastener and Rivets project. This project initially used a commercially proven pre-coated fastener as a boundary object in the proposed manufacturing of a military version of a pre-coated fastener and rivet. However, the customer, U.S. Airforce, did not quickly accept this fastener as a simple replacement to the wet application process, because it did
not meet the military contract requirement of complete qualification. It became necessary to prove to the customer that the replacement fastener was equal to or better than the original contract process. Following 12 to 18 months of testing, data was presented to the customer to serve as evidence of the safety of the new product. The data itself served as the boundary object which ultimately convinced the Air Force to switch to the less costly pre-coated fastener and rivet. Because of the time-consuming nature of the data collection, we rate the process as a moderately effective boundary object.

In summary, the most effective boundary objects were those which reflected the actual configuration and knowledge of the product. They were tangible and concrete, such as an existing production tool or field part. They were also easily accessible to anyone on the team who needed to understand an issue. If the boundary object was not tangible, such as a drawing, they were at least easily produced and made accessible in a timely fashion.

**COORDINATION OF MANAGEMENT MECHANISMS**

One basic question for all managers of complex projects is, “Have we reduced time to market as compared to previous attempts?” We sought to compare the rankings of each case in an attempt to discover if there was any unique characteristic that played a role in reducing time to market within each project. Unfortunately, it was impossible to isolate the subtle complexities within each team’s structure from the strong influences of customer desires and funding requirements.

We observed in the Pre-Coated Fastener and Rivet project how resistant the customer was to commercial test results. These improved fasteners underwent an additional 12 to 18-month test cycle in order to convince the customer that they met the requirements. As a result of continued funding problems and customer negotiations, the project took almost five years from inception to application before the first pre-coated fasteners could be implemented into production on the C-17. This example demonstrates that even the best teams with the most advanced
skills, tools, and equipment will not be able to introduce a new product in a timely fashion without customer support. We believe that if either customer support or upper management support is missing, the project will be less efficient in terms of time.

On the other hand, if there is support from management and the customer, a project that uses the four managerial mechanisms is most likely to achieve enormous savings in time and money. For example, the Tip Cap project received strong upper management and customer support. This project developed, produced, and delivered 50 “Lead the Fleet” tip caps in 6 months from initial project approval.

In summary, it appears that the most progressive, cross-functional IPD team can be only as efficient as external project influences permit. Customer and upper-management support, along with the utilization of the organizational structures of cross-functional teams, collocation, gatekeepers and boundary spanners, boundary object, and coordination of management mechanisms, will result in the most time-effective projects.
PROJECT MEASURES

The following tables are basic evaluation of the management mechanisms as defined in this research project (Cross-Functional Teams, Gatekeepers and Boundary Spanners, Collocation, Boundary Objects). Each case is rated for the strength of the characteristics that existed during the project. In addition, internal as well as external project influences were assessed for their impact on the successful outcome and influence on schedule of each team's efforts.

The Strong, Medium, Weak, None ranking for each characteristic is derived from the interviews with the team members and represents a comparative assessment by the authors of each project.
Project Measures

Knowledge and Information Transfer Influences

Case 1 – Growth Blade

Internal Project influences

<table>
<thead>
<tr>
<th>Study Characteristics</th>
<th>Transfer Influence Effects</th>
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<tr>
<td>Rating</td>
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</tr>
<tr>
<td>Team</td>
<td></td>
</tr>
<tr>
<td>• Technical Capability</td>
<td>Strong – Whole Team</td>
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<tr>
<td>• Background – Experience</td>
<td>Strong – Both design &amp; ME</td>
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<tr>
<td>Information Management</td>
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<tr>
<td>• ‘Gatekeepers’</td>
<td>Strong – Project Supervisor</td>
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<tr>
<td>• ‘Boundary Spanners’</td>
<td>Strong – Project Designer, Shop ME</td>
</tr>
<tr>
<td>Collocation</td>
<td>Moderate – Within building &gt; 300 meters</td>
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<tr>
<td>Boundary Objects</td>
<td>Strong – CATIA, FEM, Stereo-lithography,</td>
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<tr>
<td></td>
<td>Production Tooling, Field Parts</td>
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<td></td>
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<td>Total</td>
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External Project Influences

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<tr>
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<td>Management Support</td>
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<td></td>
<td>Upper Mgmt not supportive</td>
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NOTES:
• Score: Strong 3, Moderate 2, Weak 1, None 0
Project Measures

Knowledge and Information Transfer Influences

Case 2 – Tip Cap

**Internal Project influences**

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<td>• Technical Capability</td>
<td>Strong – Whole Team</td>
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<tr>
<td>• Background – Experience</td>
<td>Strong – Both design &amp; ME</td>
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<tr>
<td><strong>Information Management</strong></td>
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</tr>
<tr>
<td>• ‘Gatekeepers’</td>
<td>Strong – Project Supervisor</td>
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<tr>
<td>• ‘Boundary Spanners’</td>
<td>Strong – Project Designer, Shop ME</td>
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<tr>
<td><strong>Collocation</strong></td>
<td>Moderate – Within building &gt; 300 meters</td>
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<td><strong>Boundary Objects</strong></td>
<td>Strong – CATIA, FEM, Stereo-lithography, Production Tooling, Field Parts</td>
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| Total 17 |

**External Project Influences**

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| Total 6 |

SCORE 23

**NOTES:**
- Score: Strong 3, Moderate 2, Weak 1, None 0
## Project Measures

Knowledge and Information Transfer Influences

### Case 3 – Speed Brake

#### Internal Project Influences

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<tr>
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<td>• Technical Capability</td>
<td>Strong – Design &amp; Mechanics</td>
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<td>• Background – Experience</td>
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<td>• ‘Gatekeepers’</td>
<td>Strong –</td>
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<tr>
<td>• ‘Boundary Spanners’</td>
<td>Strong – Design Engineer</td>
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<td></td>
<td>Strong – Designer transfer into production</td>
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<tr>
<td><strong>Boundary Objects</strong></td>
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</tr>
<tr>
<td></td>
<td>Moderate – CATIA, FEM, Field Parts</td>
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**Total** 17

#### External Project Influences

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<th>Transfer Influence Effects</th>
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<tr>
<td><strong>Management Support</strong></td>
<td>Moderate – Cost reduction program</td>
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**Total** 4

**SCORE** 21

**NOTES:**
- Score: Strong 3, Moderate 2, Weak 1, None 0
Project Measures
Knowledge and Information Transfer Influences

Case 4 – Coated Rivets

Internal Project Influences

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<tr>
<td>• Technical Capability</td>
<td>Strong - PM &amp; ME/OPS</td>
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<td>• Background – Experience</td>
<td>Strong - Senior Manager &amp; ME/OPS</td>
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<td>Information Management</td>
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<td>• ‘Gatekeepers’</td>
<td>Strong – PM brought in new technology</td>
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<td>• ‘Boundary Spanners’</td>
<td>Strong – Senior Mgr. networked with ME and OPS personnel</td>
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<td>Collocation</td>
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<td>Boundary Objects</td>
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Total 14

External Project Influences

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<tr>
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Total 2

SCORE 16

NOTES:
• Score: Strong 3, Moderate 2, Weak 1, None 0
CONCLUSIONS

The use of Integrated Product Development Teams was universally accepted and applied to every project we investigated. Within these teams several management mechanisms were implemented to improve the method of communication. The mixture of these mechanisms within each team may not have been planned, but this mixture affected the outcome of each project. We have derived the following conclusions from the four case studies.

- Management accepted multi-discipline teams as the best approach to effectively develop successful new products.
- Bringing cross functionally trained individuals into the leadership role enhanced the level of communication.
- Team leaders with a cross-functional background often acted as boundary spanners when information required transfer to other functional organizations.
- Team awareness of technical information was enhanced within the group through the use of individuals who acted as gatekeepers during the project.
- Non-design team members within each project enhanced communication with the designer via the use of boundary objects during discussions.
- Time management within a project was strongly influenced by external sources of support, such as funding, management and customer interest.
• Projects with pre-existing production processes and known field operation problems began with a richer database, giving the cross-functional team members greater means to communicate concrete issues.

The above findings facilitated the pull of technical knowledge from research concept, design development into a complex production environment.

RECOMMENDATIONS

1) Boundary Objects

   a) Management must plan the use boundary object types, such as tools and equipment like 3-D CAD/CAM Systems, Prototypes, Shared Databases, etc. An effective boundary object, such as a 3-D CAD/CAM system, is necessary to enhance communication within a multi-functional team.

   b) Create a master database which guarantees that the group's members are able to see the relevant data whenever it is needed. A central repository gives members a common language tool to express their knowledge and to coordinate that knowledge with other members.

2) Cross-functional Team Structure - Gatekeepers, Boundary-Spanners

   a) Management should carefully select the members of the core team. Their levels of expertise must be outstanding, and they must be willing “team players”. They must also have complementary skills in other functions, so as to promote a learning environment and nurture high motivation.

   b) Train team members regarding effective implementation of the managerial mechanisms prior to getting a project underway. For example, stress communication methods such as the importance of using boundary objects (3-D CAD/CAM systems, prototypes, etc.) in a project.
c) Give the core team the power to make and implement major decisions, without the intervention of management. The original teams that were studied had the ability to make many important decisions because management was supportive.

d) Management should assure that there are data protocol rules and a disciplined communication process, such as scheduled meetings, reporting methods, and problem resolution, etc. In order for the knowledge transfer to occur, it is imperative that all parties receive regular and accurate communication. There must also be agreement about how data is passed through the electronic transmittal process. This recommendation relates directly back to Ancona and Caldwell's work on task coordination as an important boundary pattern for transference of knowledge across teams.

e) Cross-Functional teams must coordinate with outside sources, such as: (1.) Management; (2.) Customers; and (3.) Suppliers right from the onset of a project. This establishes and maintains credibility within the product value chain.

f) Direct involvement of all players is crucial so that organizational boundaries can be understood and then communication tools can be defined and applied to those defined boundaries.

3) Collocation

a) Collocation should be viewed in terms of an individual's proximity to the problem where effective communication can develop, rather than a physical proximity to an individual.
4) Management and Customer Support

a) A comprehensive assembly of all structures and tools will likely increase the probability of being successful in pulling technological knowledge through a project.

FUTURE INVESTIGATIONS

- Because of their complexity, project teams that have successfully implemented all of these observed managerial mechanisms require continued investigation. It is important to understand the required mix of talent during the development of the project. In addition, it is necessary to understand whether there is a time during a project when personnel changes are needed within the team. We would like to track type of individuals used during the project, when they joined the team, and how long are they were needed.

- A far more in-depth investigation of team interactions is needed in order to better understand the relational importance of each team mechanism and its overall influence on the outcome of the project.

- Continue to study at least 5 different projects in 5 different companies that have proactively embraced these management mechanisms. Evaluate how well technological knowledge has been pulled through the organization.

- Evaluate the time spent up front in setting up these managerial mechanisms for a project versus the linear time spent in a project’s product development cycle.


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