DEVELOPMENT CYCLE TIME REDUCTION FOR CUSTOMIZED HELICOPTER WIRING SYSTEMS

by

SCOTT D. HOWARTH

B.S., Civil Engineering
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Signature of Author____
Department of Civil and Environmental Engineering
Sloan School of Management
May 9, 1997

Certified by____
Charles H. Helliwell, Jr., Senior Lecturer
Department of Civil and Environmental Engineering, Thesis Advisor

Certified by____
Lawrence M. Wein, Professor of Management
Sloan School of Management, Thesis Advisor

Accepted by____
Joseph M. Sussman
Chairman, Departmental Committee on Graduate Studies

Accepted by____
Jeffrey A. Barks
Associate Dean, Sloan Master's and Bachelor's Programs

MASSACHUSETTS INSTITUTE
OF TECHNOLOGY

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ABSTRACT

Changes in the competitive environment of the helicopter industry have forced helicopter manufacturers to respond to increasing global competition and increasing rates of innovation to meet customers' needs. In many of these organizations, senior managers have directed their development organizations to reduce development cycle time and cost by more than 30%. Establishing and implementing this change effort requires a problem solving methodology that is tailored to the unique needs of development organizations.

This thesis proposes a methodology to address the problem of development cycle time reduction. The methodology is presented in a general format to ensure its applicability to a wide range of industries, and is based on the following three concepts:

1. A systems view of the "Rework Cycle" provides valuable insight as to where to focus improvement efforts.
2. A queuing network model is an effective tool to analyze the current development process and to explore potential changes.
3. The cycle time reduction effort should concurrently investigate both incremental and radical changes through the use of cross-functional teams.

As an application of the proposed methodology, this thesis chronicles a major American helicopter manufacturer's efforts to confront the challenges of reducing development time for derivative helicopters. Specifically, this thesis focuses on a critical element of the helicopter development process: the design and fabrication of electrical and avionics wiring harnesses.

The company's efforts to reduce development cycle time are described in detail as well as further improvement recommendations. One recommendation calls for the establishment of design-planning teams as a means of achieving improved process performance. Many of the proposed changes will depend on management's ability to lead a large-scale, difficult change effort in both the technological and social systems within the organization.

Thesis supervisors

Charles H. Helliwell, Jr., Department of Civil and Environmental Engineering
Prof. Lawrence M. Wein, Sloan School of Management

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1. Introduction

This thesis proposes a methodology to aid project managers in reducing product development cycle time. In Section 1, a framework for the entire thesis will be provided, beginning with a statement of the problem and justification for research into development cycle time reduction. This section will detail the objectives of the research and provide a road map for the presentation of the arguments and ideas stated within this thesis. This section concludes with an overview of the remaining chapters.

1.1. Statement of the problem

Many companies have realized that competing on time is becoming as important as competing on quality or cost. Companies can no longer dictate the lead time of their products, but must deliver them when their customers want them. Customers are also demanding that products be tailored to meet their specific needs, a requirement which is forcing companies to confront challenges such as customization. Increasing global competition and a growing rate of technological innovation have also increased the demand for new features, which has created even shorter product life cycles. For these reasons, reducing product development cycle time has become a primary focus for improvement efforts in many companies.

The product development process is often on the critical path in the realization of new products. Moreover, with the increasing need for customization of existing products, the development process is also becoming a large part of lead time of what were once standardized products. Unfortunately, however, development processes that focus on customization have unique characteristics which defy the use of traditional continuous improvement tools to reduce cycle time. Most development projects are dynamic and iterative, ranging from months to even years. By their very nature, their end results are unique, therefore the development process is never exactly replicated. As such, many of the tools and techniques presented in continuous improvement methodologies are not applicable to mass customization. Furthermore, customization requires very different organizational structures, values, management roles and systems, learning methods, and ways of relating to customers.[1] Invariably, customized products require the contribution of many people whose skills span different functional disciplines—disciplines which are often strongly tied to ever changing technologies. Typically, these functions do not interact or come together in the same sequence every time. At times, the success of a product development process can also depend on the creativity of its members. While there is often some amount of repeatable tasks, successful product development will always require a significant degree of innovation. For these reasons, product development is an ambiguous process, hard to define and even harder to improve.

Even faced with these challenges, the upper management of many companies are setting aggressive improvement goals for their development organizations, directing them to reduce development cycle time by 30% or more. These ambitious cycle time goals, coupled with the difficulties of improving a large and complex development process, requires a focused and well planned effort that integrates the contributions of many people throughout the company. In addition, creating and guiding such a cycle time reduction effort to an effective solution and a successful implementation requires a problem solving methodology that is tailored to the unique needs of this type of problem.

1.2. Goal of the research project and focusing assumptions

This thesis presents a methodology which addresses the specific problem of product development cycle time. The methodology is based on three key concepts. The first concept is that a systems dynamics model of the rework-cycle provides invaluable intuition as to where to focus development cycle time reduction efforts for complex development projects.

The second concept is that a quantitative model of the current development process provides a critical tool in a cycle time reduction effort. Specifically, a queuing network model is appropriate for this type of problem because it demonstrates the

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[1] Andrew C. Boynton and Joseph Pine II, "Making Mass Customization Work," Harvard Business Review, September-October (1993): 108-119.

significant effects of many tasks vying for the attention of limited engineering and technical resources.

The third concept described in the methodology is that development cycle time reduction efforts should concurrently investigate both incremental and radical changes. This thesis argues that the path leading to incremental change differs considerably from the path leading to radical change. There are benefits to conducting two separate efforts to explore both paths. In addition, the end result, which can combine both types of change, may prove to be the optimal solution.

1.3. Thesis background

This thesis is based on a seven month internship sponsored by United Technologies Corporation's Sikorsky Aircraft in conjunction with the Leaders for Manufacturing program at MIT. Sikorsky Aircraft Corporation is aggressively pursuing cycle time reduction in an effort to increase sales of its S70 helicopter. At one time, the helicopter industry was somewhat immune to the pressures of cycle time reduction, mass customization, and shorter lead times. Today, however, with military spending on new rotorcraft on a seemingly irreversible downward slide, helicopter manufacturers are tailoring their operations to be more responsive to customers' needs.[2] This thesis describes and contributes to the cycle time reduction effort in Sikorsky's Developmental Manufacturing Center II (DMC II), which is responsible for the design and delivery of new and customized S70 helicopters.

The task of designing and building a new or derivative aircraft presents a massive undertaking; therefore, this thesis focuses on a single key element, the development process of the wiring harness assemblies.

The cycle time reduction project at Sikorsky provides a detailed case study of the application of both radical and incremental reduction efforts. Prior to the start of this study, Sikorsky had already made radical process and structural changes. The process changes transformed a sequential development process into a more parallel and

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[2] Robert Ropelewski, "The Helicopter Industry: About to implode?," Aerospace America, April (1996): 38-43.

concurrent process whereby manufacturing engineering could start their planning based on preliminary data released by the design engineers. The structural changes created a new department, the DMC II—a cross-functional team headed by one manager with the authority to allocate resources over a wide range of development projects.

My primary role within the cycle time reduction effort was to study the harness development process, examine the effectiveness of their radical changes to date, and recommend and implement additional changes that would further reduce development cycle time and cost. Consequently, it provided me with an excellent opportunity to formulate and apply a general cycle time reduction methodology that could be used in a variety of different industries.

This thesis has three goals. The first goal is to describe a general methodology to attack the problem of reducing product development cycle time. The second goal is to use the project at Sikorsky as a case study to examine the effectiveness of the proposed methodology. The third goal is to discuss the lessons learned with respect to Sikorsky's use of cross-functional teams to reduce product development cycle time, and how these lessons might apply to large-scale design and construction processes.

1.4. Thesis layout

The thesis is organized into eight chapters to address the three goals listed above. Chapter 2 addresses the first goal by describing a general methodology to reduce product development cycle time. Chapters 3-6 address the second goal by detailing the cycle time reduction effort within Sikorsky. The final two chapters address the third goal with a discussion of the lessons learned from Sikorsky's use of cross-functional teams and how these lessons apply to the construction industry.

- Chapter 2 describes the methodology in general terms. The methodology is based on a "systems view" of the rework cycle and argues the benefits of concurrently pursuing both incremental and radical change. In addition, this methodology can be used as a guide for similar product development cycle time reduction projects.
- Chapter 3 describes the cycle time reduction effort in Sikorsky's Development Manufacturing Center II. It also details the electrical wiring development process and the organization that was in place at the time of the study.

- Chapter 4 applies the cycle time reduction methodology presented in Chapter 2 to the harness development process in the DMC II. It also describes a queuing network model that was used in the pursuit of further incremental improvement. The benefits of this model over existing tools such as Gantt charts, Critical Path Methods, and Pert diagrams are outlined.

- Chapter 5 describes in more detail the approaches that were taken at Sikorsky in pursuit of further incremental and radical process improvement. It also describes a final integrated solution to the harness cycle-time reduction problem—the implementation of design-planning teams.

- Chapter 6 details the implementation plan for design-planning teams to further reduce harness development cycle time. Tradeoffs between design-planning teams and functional teams are discussed, and a final harness development organizational structure is proposed.

- Chapter 7 focuses on the organizational issues surrounding implementing process improvement in the "team" environment existing within the DMC II. It will also discuss the challenges associated with using teams in a downsizing environment.

- Chapter 8 describes the lessons learned from the project at Sikorsky and how these might apply to the construction industry. It will focus on the similarities between large-scale customized helicopter development and the design/development process in the construction industry.

2. Methodology for product development cycle time reduction

Companies have identified that time to market is a key competitive advantage and have set ambitious goals to reduce the cycle time of their product development processes. The first step towards attaining these goals is to define and implement an appropriate methodology for the development cycle time reduction problem. A methodology that will take a company from an urgent need to reduce cycle time, to a definitive strategy that has a realistic chance of achieving improvement targets. This thesis argues that the most efficient way to reach this point depends on the organization's ability to identify the "systemic forces" influencing their working environment, quickly investigate a wide range of options, and then establish consensus on a vision for the future.

In this chapter, general elements of a development cycle time reduction methodology are outlined in detail (Figure 2-1). Chapter 4 will apply this methodology to the harness development cycle time reduction project at Sikorsky. The elements of the methodology are described in general terms to ensure their applicability to a wide range of product development projects beyond the helicopter industry.

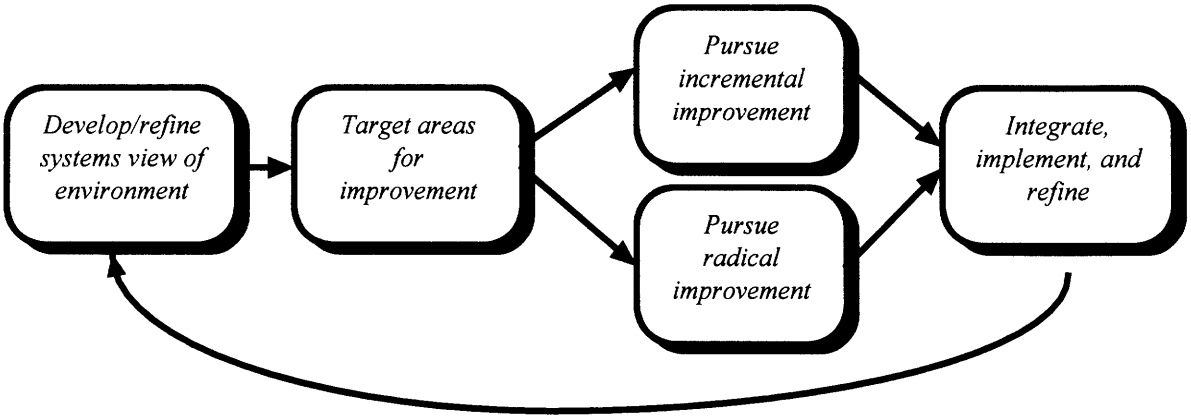

Figure 2-1: General development cycle time reduction methodology.

2.1. Develop a "systems view" of the working environment

Before the start of any cycle time reduction effort, it is imperative that all players have a clear understanding of the system within which they work. This ensures that limited company resources such as time, people, and money are targeted for the right project and also at the right areas or "pressure points" within that project. The field of "systems thinking" provides a valuable framework that aids managers in ensuring well targeted improvement efforts. In The Fifth Discipline, Peter Senge writes that "by developing the capability to see the forest *and* the trees, companies will be in a position to respond powerfully to the challenge of complexity and change."[3] This thesis argues that the first step that should be taken in any cycle time reduction effort should be the formulation of a "systems view" of the development environment. Senge also argues that mastering the language of systems thinking first requires knowledge of other important disciplines such as personal mastery, mental models, shared vision, and team learning. These disciplines combine together to create what he refers to as the "learning organization." As Figure 2-1 suggests, the inherent dynamic nature of a "systems view" will require a flexible, working model, continually updated and validated to reflect inevitable changes.

Since the 1980s, the field of System Dynamics has proven significant to understanding the complex nature of development projects. The concept of the "Rework Cycle" is well described in the work of Kenneth G. Cooper, where he has used its basic structure to model numerous software, construction, electronic systems, and aerospace development projects. The robust nature of the rework cycle makes it particularly applicable to the development environment within Sikorsky's Development Manufacturing Center II. A thorough understanding of the "Rework Cycle" as described by Cooper is essential in the creation of a "systems view" of the development environment--the first element of the development cycle time reduction methodology proposed by this thesis.

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[3] Peter M. Senge, The Fifth Discipline: The Art and Practice of the Learning Organization (New York: Doubleday, 1990): 310.

Even with all of the recent advances in project management systems and tools, managers of large projects continue to get surprised by rework which can result in cost overruns, late deliveries, scarce resources and contract disputes. Unfortunately, conventional project management methods such as the Critical Path Method (CPM) and Gantt charts treat a project as being composed of a set of individual, discrete tasks. Each task is portrayed as having a definable beginning and end, with the work content either "work to be accomplished," "work being accomplished," or "work accomplished." Little account is taken of the quality of the work completed, the release of incomplete or imperfect sub-tasks, or the amount of rework which will be required. These conventional methods are particularly inappropriate for development projects, in which there is a naturally iterative process of design, engineering, and manufacturing. More experienced managers understand the impact of rework and typically build "slack time" into their schedules to account for it. Still, however, the accuracy of these schedules depend on the experience, expertise, and sometimes luck of the individual managers and rarely reflect the actual cycle time of the project.

A model that recognizes rework, plans for it, monitors it, and helps managers reduce its magnitude and duration can be of great value to development organizations. The "Rework Cycle" model "reflects a more strategic view of projects, and accounts for the quality of work done and the causes of productivity variations."[4] Unlike traditional methods, it creates a clearer picture of the effects that management actions can have on staff productivity and the quantity of rework—and how the consequences spread through an entire project. The framework is quite dissimilar to CPM/PERT models; "it treats a project not merely as a sum of a sequence of discrete tasks, but as flows of work in which there are multiple rework cycles."[5] The following paragraphs will describe the underlying structure of Cooper's "Rework Cycle" in detail.

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[4] Kenneth G. Cooper, "The Rework Cycle: Why Projects are Mismanaged," PMNETwork, February 1993.

[5] Ibid.

2.1.1. *The traditional development project view*

Typically, development projects are tracked based on ***work to be accomplished***, ***work being accomplished***, or ***work accomplished***. The first step in creating a more realistic view of development projects is to model the process as a more continuous stream of work as shown below:

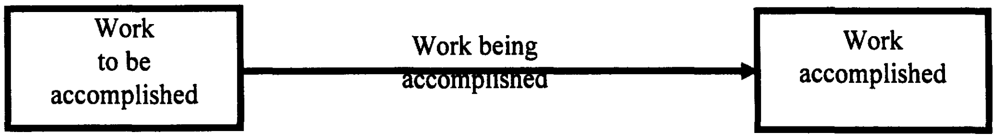

Figure 2-2: Traditional view of development projects.

At the start of a project, all work resides in the pool of ***work to be accomplished***. As these tasks are drained over time, they flow through ***work being accomplished***, such that at the end of the project all the tasks fill the stock of ***work accomplished***. This model can be taken a step further by recognizing that as a project progresses, changing levels of ***manpower*** working at varying levels of ***productivity*** ultimately determines the pace of ***work being accomplished.***

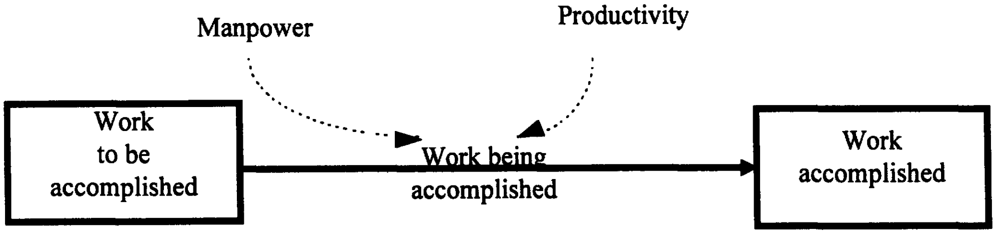

Figure 2-3: Traditional view with factors affecting work being accomplished.

2.1.2. *View of development project which recognizes quality and rework*

A more accurate view of development projects recognizes the existence of rework cycles. Below, what Cooper terms the ***quality*** of work executed should be thought of as a "valve" controlling the portion of the work flow being accomplished that will or will not require rework.

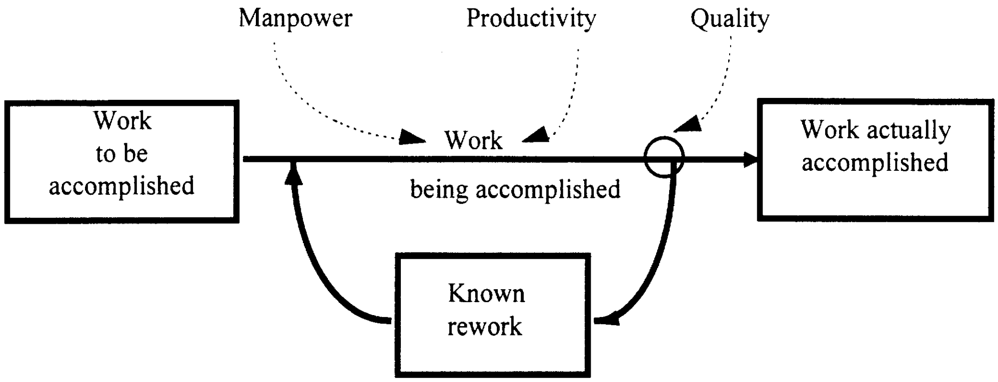

Figure 2-4: Development project view which includes the "Rework Cycle."

Unlike other program analysis tools and systems, the rework cycle recognizes the real-world phenomenon that work is "executed" at varying ***quality*** levels. Potentially ranging from 0 to 1, the valve of quality depends on many variable conditions in the project and company. The fractional value of ***quality*** determines the portion of the ***work being accomplished*** that will enter the pool of ***work actually accomplished***, which will never again need re-doing.

The distinction between ***productivity*** and ***quality*** is important. People may exhibit high ***productivity***, but be putting out work of low ***quality*** that requires later re-working. In this condition, the net throughput to the pool of ***work actually accomplished*** is low.

2.1.3. View of development project which recognizes undiscovered rework

In reality there is a critical "buffer" in which rework lingers until it is identified as needing rework. Cooper has termed this buffer ***undiscovered rework***, which consists of "those tasks or work products that contain as-yet-undetected errors of commission or omissions, and are therefore perceived, and reported by all traditional systems, as being done."[6] The errors are usually detected by downstream efforts or testing. This ***rework discovery*** may occur months or even years later, during which time dependent work has incorporated these errors. The more tightly-coupled and parallel the project tasks are, the greater the effect on subsequent rework cycles will be.

Once discovered, the ***known rework*** demands the application of resources, beyond those needed for executing the original work. Executed rework enters the flow of ***work being accomplished***, subject to similar productivity and quality variations. Even some of the re-worked items may then flow through the rework cycle one or more subsequent times.

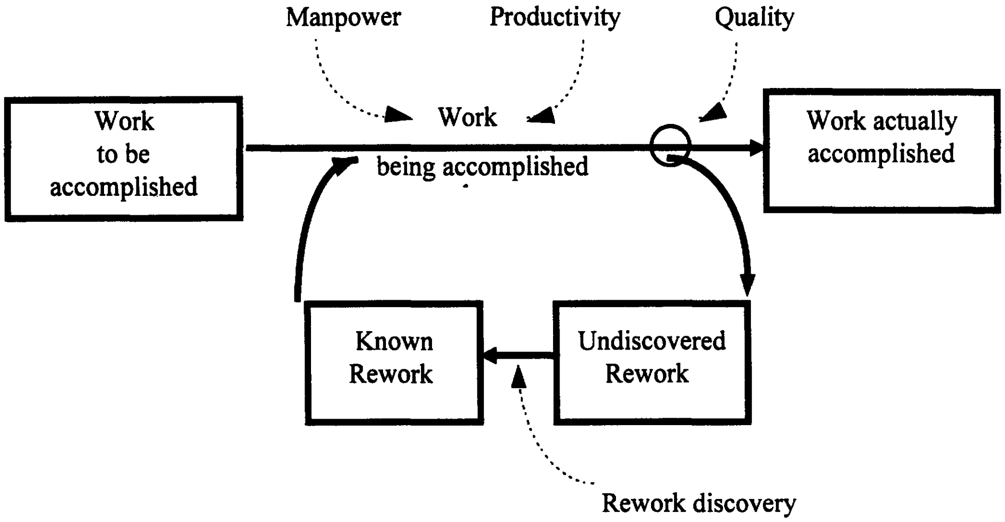

Figure 2-5: Development project view which includes undiscovered rework.[7]

For project management success, it is imperative that ***undiscovered rework*** be acknowledged, aggressively sought out, and prevented as much as possible. Cooper argues that all development plans and schedules should be set accordingly so as to reduce the disruption of the surprise of undiscovered rework. Furthermore, a culture should be cultivated in which early discovery of rework is encouraged.

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[6] Ibid.

[7] Structure adapted from "The Rework Cycle: Benchmarks for the Project Manager," Project Management Journal, March, 1993.

2.2. Target areas for improvement

Having developed a "systems view" of the development environment, managers, process owners, or teams can now specifically target areas for improvement. As identified in Cooper's view of the "Rework Cycle" these areas or "pressure points" include *manpower*, *productivity*, *quality,* and *rework discovery.* The challenge of successful project management and development cycle time improvements focuses on maintaining an optimal balance among these four variables. Often, improvements in one area can lead to increased problems in others. Chapter 4 will discuss the tradeoffs of these variables and how they apply to the harness development process at Sikorsky.

2.3. Pursue both incremental and radical improvement

Now that team members share a common view of the system within which they work, and specific "high payoff" areas have been targeted for improvement, the quest for reduced cycle time can follow two fundamentally different paths, 1) exploring many incremental changes to the current development process, or 2) searching for a radical redefinition of the development process by changing some or all of its basic structural elements. The premise made in this thesis is that although both of these paths will likely lead to quite different solutions, sound reasons exist for investigating both paths concurrently. The primary reason is that at the start of the investigation there is no way to guarantee that the current development process will be able to achieve the desired goals. This assumption stems from the concept that an infrastructure underlies the current process. Hayes, Wheelwright and Clark propose a definition for infrastructure: it is composed of the systems, practices and policies that drive an organization's behavior.[8] Whereas Hayes et al. present a list of infrastructure elements within a manufacturing organization, that list can be modified slightly to fit a product development environment by including the following elements:

1. Human resource policies and practices, including management selection and training.

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[8] Hayes, Robert H., Wheelwright, Steven C. and Clark, Kim B., Dynamic Manufacturing: Creating the Learning Organization (New York: The Free Press, 1988) 362.

2. Quality assurance and control systems.
3. Work scheduling and document control systems.
4. Performance measurement and reward systems.
5. Organization structure and design.

Incremental change will modify the process itself but may not get to the root of the organization--the infrastructure elements. If the infrastructure has an inherent limit or creates a sufficient drag on the performance of the organization, then achieving the cycle time target without impacting these elements may prove too costly or inefficient.

The best possible chance of meeting cycle time goals requires concurrently investigating incremental and radical process improvements. If only a single path is followed, it could result in a proposed solution that is insufficient to meet the cycle time goals, and the exercise must begin again. More likely, there will be no accurate way to judge the true merit of the proposed solution. The exercise may generate enough momentum behind the proposal and the organization will expend a significant amount of effort implementing a poor solution. Thus, the rationale behind this step in the methodology is to reduce the risk of implementing an inefficient or inadequate solution.

2.3.1. Cycle time reduction tools

Although the radical and incremental improvement paths fundamentally differ, they both address the issue of cycle time within the same organization that designs and manufactures the same product. Therefore, both investigations can share a number of common tools and resources. Both paths include the following:

Cross-functional teams: The most important element of cycle time reduction consists of the members of the process improvement team. In the case in which the development process extends beyond a single function, the cycle time reduction team must be staffed with people from the affected functions. A cross-functional team proves crucial for two reasons. First, only by involving experts from each function will the team develop a true understanding of the current process and the potential alternative. Second, this methodology aims not only to find the most appropriate solution, but also to create the momentum and support within the organization to implement change as quickly as possible. The most effective way to build this support within the groups and organizations that will ultimately be impacted, is to use the team members as the core change agents. For both of these reasons, the team members must have not only intimate knowledge of the development process, but also the respect and leverage within the organization to effect change.

Detailed definition of the current process: The team should start the study by developing a shared understanding of the current process and the detailed steps in each functional area. This is a crucial exercise because within a multi-function development process it is very likely that each team member will initially come to the meetings focused solely on the needs of his or her function. Both paths to a solution involve negotiation and compromise between functions, which requires that all team members must first develop an understanding of each other's needs, the functional design processes, and the interfaces and dependencies between functions. Even more important is the development of mutual respect between the team members and the shared belief that all functional groups provide valuable contributions to the process.

Analytical model of the design tasks: A complex development process will often span many months and touch numerous individuals. Amid all of this detail, it is essential to develop a broad and basic model of the product development process. Ideally, this model should be as simple as possible yet still describe all of the essential elements. These elements include the basic development tasks, the resources applied to these tasks, and the dependence, order, and sizes of the different development tasks. Finally, because the goal of the exercise is to address cycle time, the analytical model must capture the effects of these elements on the total cycle time of the development project.

The analytical model has two primary purposes: communication and evaluation. In order for individuals to operate effectively in this type of team, they must develop a common understanding of the entire scope of the development process. The complexity and specialized detail of each individual function acts as a barrier to fostering effective cross-functional discussion. In addition, the combined complexity of all the functions makes it difficult to discuss the development process as a whole. The task of developing a relatively simple model of the process provides an effective mechanism with which to identify the key elements of the process. In addition, any large scale changes will require the approval of people outside the study team, most often upper managers, who have very little knowledge of the entire development process. Defining a simple, yet robust, model which defines the development is an effective way to communicate the current process and the proposed changes. Effective communication to people outside the team is the key to first getting approval for implementing the changes and then spreading the vision of the future to the people who must enact the change.

Finally, there will be many conflicting suggestions and opinions about the effects of potential changes and strategies. An analytical model serves as a tool that can judge the potential gains and costs of the changes. This analysis is often crucial in order to achieve consensus within the process improvement team. In addition, some amount of analysis is required for obtaining upper management buy-in, particularly when the proposed changes are broad and affect a number of organizations.

Before the exercise can proceed to the next stage, the cross-functional teams, the definition of the current process, and the analytical model must be sufficiently refined. Such refinement can be achieved when a cross-functional team 1) has been chartered and is functioning effectively; 2) has documented in detail the current process; and 3) has achieved consensus on an analytical model. The next stage will start by dividing the effort and the people into two sub-teams, each pursuing either an incremental or radical path.

2.3.2. Pursuit of incremental change

The primary purpose of this path is to examine the process at a detailed level, then generate many proposals for separate changes to the process, and, finally, integrate the most effective changes into a single, faster process with fewer rework iterations. This new process must be developed in sufficient detail so that team members can describe it to people outside the team, because those people will be expected to quickly implement the changes in their daily activities.

2.3.3. Pursuit of radical change

The purpose of this path is to discover and evaluate new ideas that will change the fundamental infrastructure of the development process. A single sub-team is formed to travel this path. This team begins with a broad understanding of the development process, which was gained by creating the analytical model of the current process. Through reengineering efforts, the team attempts to define a more efficient, faster development process.

2.4. Integrate findings, implement change, and refine

Having developed two complete proposals for change, the next step requires integrating both sets of ideas into a single implementation plan. It is important in this step not to lose sight of the "systemic view" of the development environment that was discussed earlier. This may prove as simple as accepting both proposals and laying out all of the tasks needed to implement both sets of changes. More likely, though, the integration process will involve negotiation and compromise on both proposals. This integrated solution can then be implemented throughout the organization if the required amount of momentum, acceptance, commitment and responsibility are achieved.

In order to transition this exercise from the investigation of the cycle time reduction problem, to a successful implementation of change, this final integration of ideas must also accomplish the following goals:

1. Gain acceptance at all levels of the organization.
2. Gather momentum for implementing change.
3. Gain commitment of upper management to support the change.
4. Create change agents who accept personal responsibility for making the change happen.

These goals, in fact, underlie every step in the methodology, and many of the earlier activities have laid the ground work for a transition from studying the problem to implementing a solution. Therefore, even while engaging in the generation of new concepts, the team members must think ahead to the time when some of their ideas will be implemented and how these changes will influence the overall development system, specifically, the “Rework Cycle.” This means that throughout the exercise, the sub-teams should be integrating their ideas, presenting them to upper management and the rest of the organization, and imagining what role each team member will play in the implementation. It is crucial that the team members believe that this exercise serves not simply as a study, but rather as the first step towards implementing change.

3. Cycle time reduction of the S70 helicopter

In order to set the stage for the analysis in the following chapters, this chapter will outline the motivation for cycle time reduction at Sikorsky Aircraft and then describe the current wiring harness development process and organization.

Examining cycle time reduction of the S70 helicopter provides a unique opportunity to study a construction project that is carried out on a scale that dwarfs many conventional commercial products. Like most complex, large-scale projects, the S70 development process can be broken into distinct sub-processes, each of which offers a sufficiently large scope to examine the issues of product development. One of these sub-processes, the electrical and avionics wiring development, is the basis of the data for this thesis.

This thesis focuses solely on the sustaining product development process, and does not include the original design work that created the first S70 aircraft. It simply encompasses the development activity expended to customize an S70 for a new customer. It still, however, is a large scale design and manufacturing effort that will be repeated numerous times--hopefully for several decades to come. In addition, each iteration is very similar in types of activities and amount of labor. As a repeatable activity, the S70 harness development process provides a perfect opportunity to analyze a relatively stable development process and then propose changes that can be applied and refined over a number of future projects.

3.1. Cycle time reduction at Sikorsky

At a 1995 UTC Executive Conference in Hartford CT, the President and CEO of United Technologies, George David, emphasized the importance of continuous improvement within UTC, and expressed his fanaticism with the kaizen process. He stated that "kaizen proves to our employees, and to all of us, the leverage of breakthrough thinking. Kaizen blows up barriers, questions the unquestionable, and slaughters sacred cows." At the time of this project, Sikorsky had embraced the kaizen process and had established an Agile Manufacturing Department responsible for training and implementing kaizen principles.

In Sikorsky's pre-kaizen training course, the Agile Manufacturing Department clearly highlights the challenges that Sikorsky is facing in the helicopter market. With reduction in U.S. military purchases and cost plus pricing, Sikorsky is focused on reducing costs to ensure its success in the price-sensitive commercial market. Benchmark information, supplied by the Agile Manufacturing Department, indicated that competitor products typically cost 30% less to produce in 40% less time. Consequently, in order to remain competitive in an increasingly tight market, Sikorsky Aircraft identified cycle time and cost reduction as measurable goals to increase sales of S70 aircraft. To confront this challenge, Sikorsky created a new department, the Development Manufacturing Center II, which was chartered to "provide tailored-to-contract processes based on concurrent design principles that could flexibly develop alternate helicopter configurations to satisfy customer requirements." More specifically, the DMC II's mission was to "perform design, systems integration, test, manufacturing, and installations of low quantity modifications, inclusive of proof-of-principle, prototype, and development programs, drawing upon the technical skills of Sikorsky Aircraft using tailored processes which yield high quality products at a competitive cost."

Faced with fewer U.S. military purchases and tighter program budgets, the DMC II was challenged to take 30% out of the cost of producing derivative and modified helicopters; a remarkable challenge, considering the significant amount of design activity, performed by every engineering discipline, that was needed for each new customer to incorporate unique combinations of standard and non-standard options. For instance the choice of configuration, depicted in Figure 3-1, is carefully tailored to match each customer's specific requirements.

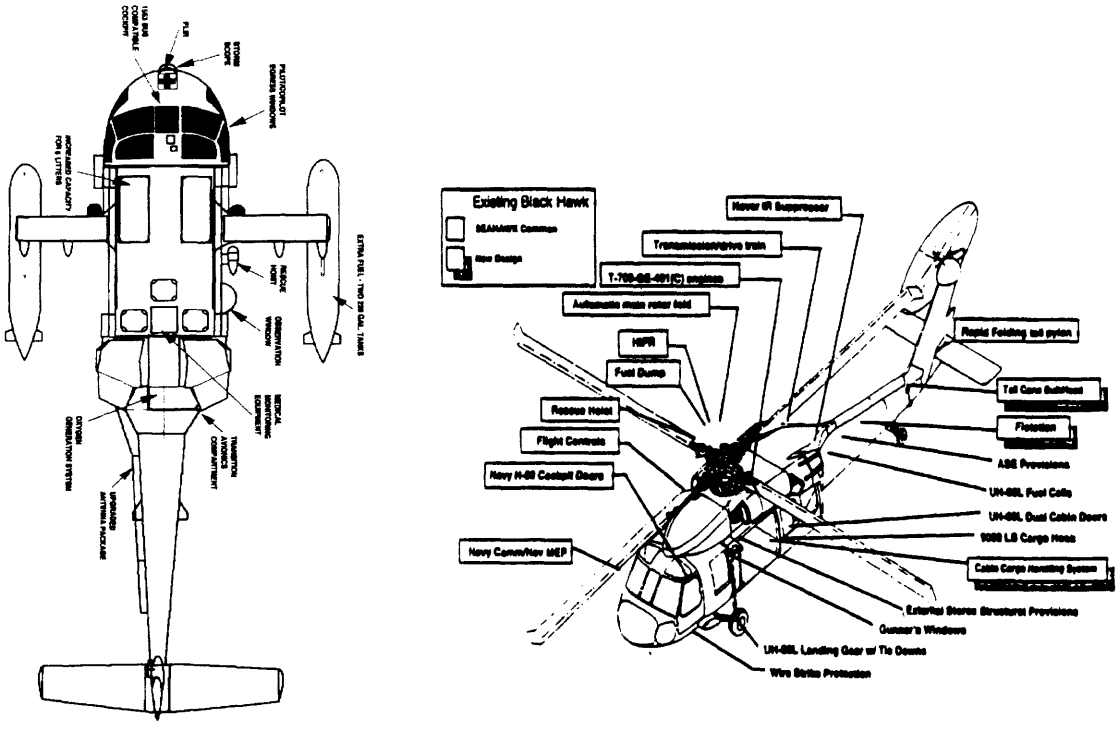

Figure 3-1: Configuration for two development programs.

This design effort, while small relative to the initial development, is a complex task that involves numerous engineers and technicians and can require thousands of person hours of redesign for a single customer.

Typically, S70 derivative customer orders have taken in excess of 18 months from initial implementation until delivery. This long delay means that customers are forced to commit millions of dollars on a helicopter and then wait nearly two years for delivery. The long cycle time also means that Sikorsky makes commitments to its suppliers resulting in larger work-in-process (WIP) inventories. Consequently, to remain competitive in this market, the DMC II was challenged to drastically reduce development cycle time and cost for derivative S70 helicopters.

3.2. S70 Wiring harness development

3.2.1. Wiring Harness Process

The wiring system that connects all the helicopter's electrical and computer systems has the largest amount of variation from one customer to the next. The S70 can have as much as 24,000 to 48,000 feet of loose wiring segments depending on the options included in the platform. With the existing design, approximately one third of all these wire bundles undergoes some modification with each new customer. This involves numerous engineering releases, and often requires expenditures of thousands of person hours, depending on the size and complexity of the customer requirements.

The harness development for each new customer encompasses nine major stages: generation of wiring diagrams, harness EPATS design, production illustration, harness manufacturing planning, wire cutting and coding, 2-D T105 tool construction, harness fabrication, harness installation planning, and installation. For each harness, the sequence of these stages is relatively sequential except for wire cutting/coding and T105 tool construction which are typically performed concurrently.

1. **Generation of wiring schematics**: The primary responsibility of the electrical and avionics designers is to design every aspect of the wiring system associated with each customer order. The design describes every aspect of each wiring system and provides the necessary information needed to requisition all material (except for the length of wire).

2. **Harness EPATS design**: This task begins with the input of the electrical systems schematics,(i.e., the definition of all the electrical components and their pin to pin connections) into Sikorsky's Electrical Planning and Tooling System (EPATS). The primary output of this activity constitutes the complete design of all the wiring harnesses in the aircraft. EPATS interfaces with Sikorsky's MRP II system (IMPACT II) and generates an engineering bill of material that will requisition parts.

3. **Production illustration**: This step has been eliminated by the DMC II in order to save limited engineering resources on producing detailed installation drawings to build only one or two aircraft. Engineers, still, however, through past experience and existing drawings are required to provide a detailed stick diagram of the harness layout depicting routing information and wire lengths. When there is still too much uncertainty in the exact harness routing path, engineers will make long wire estimates which will require connectors to be terminated in the aircraft during harness installation.
4. **Harness manufacturing planning**: Length data for each wire is manually entered into a computer program that will automatically generate a two dimensional stick diagram for each harness assembly. This stick is then manipulated (bent) on a 2-D drawing program so that its full-size print out will fit on 3'x 8' harness board sections. The harness planner also details the fabrication plan that defines the steps, processes, and sequence of all the individual tasks associated with fabricating the harnesses on the boards.
5. **Wire cutting and coding**: For each harness, a wire cutting work order is entered into the MRP II system that will generate a requirement for wires to be cut and coded at the Avionics Systems Center in Shelton, CT. EPATS data is directly transferred to automated CAPRIS wire cutting machines. The wires are then transported back to Stratford for harness fabrication.
6. **2-D T105 tool construction**: The 2-D drawings created by the harness planners are manually attached to 3' x 8' plywood boards to create a harness board. Clips and pins are added to the boards at specified locations to support the routing of wires.
7. **Harness fabrication**: Hourly technicians manually route wires as per the assembly operation sheets created by the harness planners. Connectors, ties, and proper shieldings are added to complete the harness assembly. The harnesses are then inspected after fabrication and typically sent back to Shelton, CT for DITMCO testing.

8. **Harness installation planning**: Installation operation sheets are created to define the steps, processes, and sequence of all the jobs associated with the installation of the wire harness. (2-D illustration drawings to guide the factory workers to install the wire harnesses into the airframe are generally not created in the DMC II. The designer usually goes to the aircraft to answer any questions the technician installing the harness may have.)
9. **Harness installation**: This step constitutes the actual installation of the harnesses into the aircraft. Many of the harnesses are routed based on engineering guidance during construction. Considerable harness rework occurs during this step for "first of a kind" harnesses due to uncertainty in wire routing and wire length data.

3.2.2. Organizational structure

The organizational structure of Sikorsky's Development Operations is divided into two units, the DMC II and the DMC. The entire organization is overseen by one vice president responsible for the cost, delivery, and schedule for all development programs. A second engineering vice president is responsible for both product safety and technical support for DMC II programs.

3.2.2.1. DMC II organizational structure

The organizational structure within the DMC II is based on a "heavyweight project organization" model as shown in Figure 3-2 below.

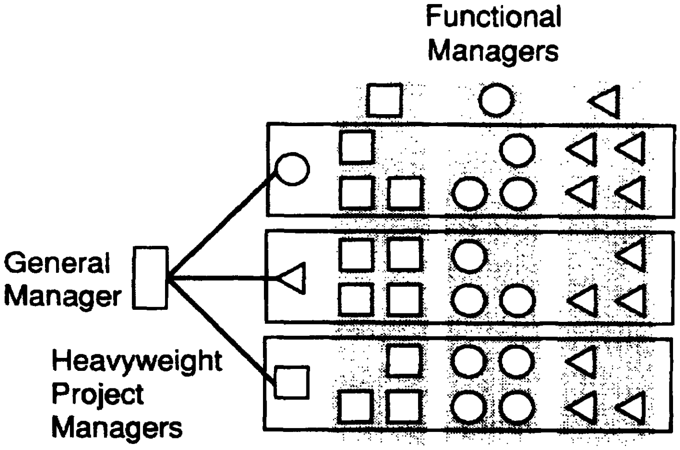

Figure 3-2: Heavyweight product development organization.[9]

As a "heavyweight project organization", the DMC II provides the integration, speed, and coordination benefits associated with true project organizations, but still retains some of the specialization of Sikorsky's functional departments. Consequently, as the DMC II grows, it will require more managers and administrators than that of a truly non-matrix organization. Since the lead functional representatives in the DMC II are evaluated by only the DMC II manager and not their functional departments, much of the conflict between balancing functional responsibilities and project responsibilities (typically associated with true matrix organizations) has been eliminated. With product development speed being one of the overriding tenants crucial to the success of the DMC II, the heavyweight project organization model has thus far proven successful in quickly resolving conflicts between functional representatives and for efficiently coordinating activities between individuals with different functional backgrounds. Overall, relatively little time is spent transferring information, assigning responsibilities, and coordinating tasks between members within the DMC II. Furthermore, over this seven month study, the DMC II continued to develop and refine its processes thereby further speeding coordination time. There are, however, challenges confronting the DMC II that are consistent with organizations modeled along project lines. For example, a project may only require a portion of an electrical engineer's time for a fraction of the duration of a

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[9] Adapted from Karl T. Ulrich and Steven D. Eppinger, Product Design and Development (New York: McGraw-Hill, 1995) 27.

project. In the past, Sikorsky had handled this problem by assigning electrical engineers to a functional department so that several projects could draw on the electrical engineer resource in exactly the amount needed for a particular project. Today, however, in the DMC II environment, engineers are expected to take on broader job responsibilities and flexibly adapt to project needs (sometimes even across multiple projects).

Within the DMC II, platform leaders are identified for each individual program. These platform leaders are held accountable for all aspects of their program and are evaluated based on how well their program adheres to safety, compliance, cost and delivery schedules. In theory, each platform leader has control over all of the critical resources needed for program success. As depicted in Figure 3-3, these resources include: manufacturing, manufacturing engineering, industrial engineering, world wide customer service, product integrity, production control, and engineering.

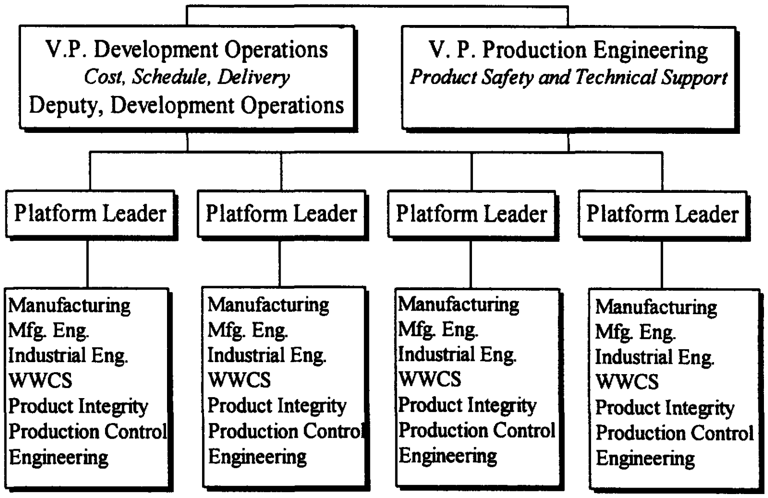
Development Manufacturing Center II

Figure 3-3: Development Manufacturing Center II Organizational Chart

Over my seven month stay within the DMC II, the organization nearly doubled in size and platform leaders began to compete for limited personnel resources. Within the DMC II, there are individuals who are designated as Core Team Members. Each of the major functions was headed by a Core Team Member who was considered the process owner for that particular function. Moreover, they were responsible for interacting with their old functional organizations to request additional manpower and technical support. In effect, they served as "working" functional managers within the DMC II. Core Team Members were not evaluated by their functional departments, but worked directly for the DMC II manager. The majority of the growth within the DMC II during my tenure was attributed to the temporary transfer of design engineers to work on new programs for the DMC II Core Members. These engineers, however, were still evaluated by their functional organizations and were not considered Core DMC II Team Members.

3.2.2.2. Wiring harness organization structure

The nine major stages of the harness development process are performed by three departments: the DMC II, the Avionics Systems Center, and the DMC. The DMC II is responsible for the generation of wiring schematics, EPATS design, production illustrations, and harness installation planning. The DMC generally completes harness manufacturing planning, 2-D T105 tool construction, harness fabrication, and harness installation, while the Avionics Systems Center is responsible for wire cutting and coding and DITMCO testing.

The organizational structure defining the harness development process is somewhat complex and is not accurately depicted in the DMC II organizational chart shown previously. Most programs have one electrical engineer (job classification C5) with overall responsibility for the EPATS design for that program. At the time of this study, only one EPATS designer was considered a Core DMC II Member. Others were brought in temporarily on an "as needed" basis. Some were co-located within the DMC II; others remained in their functional areas. During my stay, some of the EPATS design work was even outsourced to a nearby contractor due to perceived manpower constraints.

Similarly, there was only one systems manufacturing engineer who was a Core DMC II Member. He was identified as the process owner for the portion of the harness development process that remained after the design was complete. His job was noticeably challenging because he still had to work across functional barriers to get work accomplished. For example, harness manufacturing planning, wire cutting, and harness fabrication were performed by individuals outside of the DMC II who were still evaluated by their functional organizations.

3.3. Cycle time reduction of wiring harness development

Reducing the cycle time of the harness development process is critical to achieving the target 30% reduction in aircraft delivery time. Since the electrical and avionics systems ultimately define the wiring functionality and the airframe structure defines the geometric space, harness development is forced to come after the electrical systems, avionics systems, and the aircraft structure have been designed. Historically, harness development has been the longest individual development process for each customer, often requiring more than a year to complete for derivative aircraft. In addition, wiring systems have the highest degree of variation from one customer to the next, where roughly 1/4 to 1/3 of all wiring harnesses undergo some design modification. Finally, the harness development process is considered to be the longest segment of the critical path, spanning over 70% of the total customer order cycle time.

Further reducing cycle time of harness development in the DMC II presents a number of significant obstacles. First and foremost, harness development is a large and complex task. The design of each customer's wiring system travels through a year (or longer) development process and is touched by numerous engineers and technicians. Each activity depends greatly on data from multiple upstream groups, and its data in turn feeds a number of downstream activities. This creates a complex web network of suppliers and customers that differs considerably from project to project. Moreover, almost no single person understands the entire process because individual workers and managers have been traditionally measured on their functional needs and requirements.

Even with all of the radical organizational changes made with the formation of the DMC II, portions of the organization are still split along functional lines. This is attributed to the fact that historically wiring development has been conducted in a very serial fashion. One reason for this serial flow was to allow each functional group to develop a well integrated, aircraft wide solution before passing its data on to the next function. It also facilitated the development of functional experts who spent years learning the processes and the dedicated computer tools which optimize their particular function's development process. This serial flow proved sufficient for production aircraft and production changes, but was wholly inadequate for the flexibility required in the DMC II.

Within the fast-paced, mod-shop environment of the DMC II, the functional mindset creates problems. Although a large amount of design integration is needed within each function, there are also many issues of design integration across functions that must be conducted quickly and efficiently in order to meet customer delivery and cost requirements. For example, the EPATS designer may decide which harness will connect two components. If he specifies that the connection will be integrated into an existing wiring harness, he may greatly influence the routing of the harness, which is within the domain of the engineer designated to provide stick information as well as the technician tasked to install the harness. Gathering and balancing information from these downstream customers is crucial to meeting cycle time improvement targets. In the past, Sikorsky had the luxury of spending considerable amounts of time perfecting designs prior to releasing them downstream. Similarly, they had the time necessary to follow detailed engineering change procedures when problems were found with designs. Slow feedback loops throughout the entire process drove a significant amount of rework into every functional group thereby considerably lengthening development cycle time. Today, however, in the DMC II that luxury is no longer feasible. Teamwork and efficient collaboration between all functions is necessary to meet demanding customer needs. To date, the DMC II organization has taken enormous strides in breaking down functional silos; however, silos still do exist.

Amidst all these challenges, the management of the DMC II accepted the goal of drastically reducing its cycle time. The following chapters integrate the methodology for addressing development cycle time described in Chapter 2 with the DMC II's harness development process.

4. Cycle time reduction methodology applied to S70 wiring harness development

This chapter applies the cycle time reduction methodology presented in Chapter 2 to the harness development process in the DMC II. It also describes a queuing network model and simulation program that was used in pursuit of further incremental and radical improvement. The benefits of simulation based on queuing network theory when addressing development cycle time will be explained by contrasting it to existing project management tools such as Gantt and PERT charts.

4.1. Develop systems view of harness development process

Using the concept of the "Rework Cycle" described in Chapter 2, the harness development process can be modeled as follows:

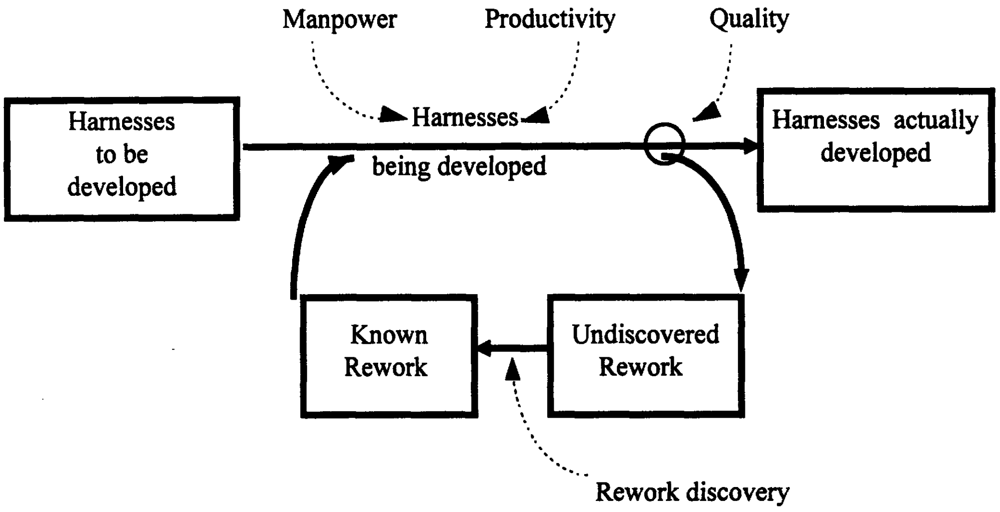

Figure 4-1: "Rework Cycle" applied to harness development process.

The model shown above keeps account of the harnesses that have been developed and the work that remains to be done within a development program. For example, a helicopter development program has two pools of harnesses that need to be developed. They are:

1. **The harnesses initially identified as needing to be developed.** The harnesses in this pool are those which have not been started by engineering. These harnesses include completely new designs as well as similar designs used on other programs that will be modified.
2. **The backlog of rework.** The harnesses in this backlog are those that have been identified as requiring rework due to engineering changes, inadequate length information, or a variety of other quality flaws in the fabrication process.

Similarly, there are two pools of "harnesses developed":

1. **Undiscovered rework.** The harnesses in this pool have started the development process and will require revision, but have not yet been identified as requiring rework. After the need for rework is perceived, these harnesses become part of the recognized backlog of rework in the pool of "known rework."
2. **Harnesses actually developed.** This pool represents harnesses that have been completed, tested, and will not require revision.

The rate of "harnesses being developed" decreases the harness backlogs and adds to the levels of completed harnesses. The rate of accomplishment (in terms of harnesses designed, planned, fabricated, or installed per time period) depends upon the number of people working and their average productivity. As harnesses are developed, they flow to "undiscovered rework" or "harnesses actually developed" depending on "quality." Quality, in this example, represents the fraction of harnesses that will not require rework. The model represents within its structure the behavior of the principal factors affecting quality and productivity in each different phase of the harness development process, such as: manpower skill levels, upstream work availability and correctness, suppliers designs, material availability, and other organizational conditions. These factors represent the target locations to focus improvement efforts. Skillful managers provided with adequate resources will be able to balance these factors to maintain an optimal development effort.

4.2. Target areas to improve harness development cycle time

Having developed a "systems view" of the harness development process, team members can now specifically target areas for improvement. As shown in Figure 4-1, these areas include manpower, productivity, quality, and rework discovery. This section will describe some factors that influence each of these areas and how they pertain to the DMC II harness development process.

4.2.1. The impact that "manpower" has on harness development

The skills, capabilities, and commitment of the members of a development team in large measure determine project performance. When the project team is severely understaffed, performance can sometimes be increased by adding the necessary staff. Similarly, when the project team is overstaffed, performance can sometimes be increased by removing staff.

Some books promote the notion of building up personnel on a project as it progresses.[10] Often, project managers complain that if they only had a few more people, they would be able to deliver on time. Contrary to this belief, Systems Dynamics models have shown that increasing personnel during a project can be counterproductive.[11] The main reason is that adding new people during a project can sometimes increase both the communications and training overhead, which will lower overall *productivity*. Since the time needed to bring someone completely up to speed on a project is usually a significant portion of the project schedule, it is better to bring the person in at the beginning. It is not unusual to see staff added in a panic at the end of a project simply to experience further delays because of the increased coordination requirements. In most projects, implementing with a fixed number of people will result in a lower cost and faster completion time. Research has also shown that any given project has an optimal constant

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[10] Lawrence H. Putnam and Ware Myers, Measures for Excellence (Englewood Cliffs, NJ: Yourdon Press/Prentice Hall, 1992).

staffing level, and that working either above or below that level will increase the schedule and budget, or lower the quality of the project.[12]

Within the DMC II, the more efficiently run programs maintained one EPATS designer and one harness planner who worked on the program from beginning to end. Even greater efficiency was realized when individuals displayed some level of cross-training and could flexibly be used in either the harness design or manufacturing planning functions. Other programs which sought outside assistance for EPATS design would sometimes become overburdened with coordination and monitoring requirements, often negatively impacting the program's budget and performance.

When harness development ran behind schedule on a specific program, the DMC II was organized in such a way that it could easily transfer engineering manpower between programs. This flexibility proved crucial to satisfying customer delivery and cost requirements. For greater flexibility, the DMC II also offloaded specific engineering tasks to nearby suppliers during peak demand periods. The outside firms were typically fast and relatively economical when a set of tasks could be clearly defined and when coordination requirements were not severe.

4.2.2. Improving "productivity" in harness development

Even more noteworthy than the effect that manpower levels can have on development cycle performance, are the potential improvements gained through the efficient use of personnel management, incentive, and reward systems. Traditionally, policies for hiring, firing, overtime, training, and retention are seldom analyzed in development programs. Systems Dynamics models have included such diverse effects as communications overhead, worker overtime, burnout, and schedule pressure.[13] Workers' productivity and error rates ultimately feed back to affect managers' decisions, forcing them continually to evaluate hiring, overtime, and scheduling policies.

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[11] Bradley J. Smith, Nghia Nguyen, Richard F. Vidale, "Death of a Software Manager," American Programmer May 1993: 14.
[12] Ibid. 14.
[13] Ibid. 14.

Once again it is important to recognize the interdependence between "manpower," "productivity," and "quality." While drastic increases in productivity may be attainable, many times they are at the expense of quality. For example, instituting a piece rate compensation system and not tying it directly to quality can quickly result in cost overruns and second rate products. Likewise, as mentioned in the previous section, studies have shown that increasing manpower during the development process may severely hinder overall productivity due to increased communications overhead. This section briefly touches on some of the major factors that, if properly implemented, can have considerable impact on "productivity" in the development process. For that reason, they should be carefully considered in conjunction with normal process improvements when searching for innovative solutions to reduce cycle time and cost.

4.2.2.1. Rewards and incentives

Companies are responding to increased worker skepticism by giving employees a bigger stake in the company's success. For example, Pratt & Whitney's North Berwick, Maine plant recently started a profit-sharing plan for non-union members tied to efficiency efforts, training, and broader job responsibilities. The plan has resulted in "breathtaking improvements," said Pratt President Karl Krapek.[14] The above quote is an example of an innovative way in which one UTC business is rewarding employees and changing traditional compensation systems.

Today, the incentive system within the DMC II continues to foster emphasis on individual performance, often at the expense of team performance. Effective implementation of an incentive system that shifts the focus from individual performance to team performance has the potential to drastically improve S70 development cycle time and cost. The focus in the DMC II remains on individual monetary rewards and promotion while neglecting a vast array of alternative reward opportunities.

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[14] Karl Krapek, "Pratt & Whitney," Hartford Courant, Business Weekly September 1996: A12.

4.2.2.2. Feedback and performance appraisal

Below is an excerpt from the company's *Salary Employee Manual* which describes the importance placed on performance ratings.

> You are paid on the basis of your performance. Each year your supervisor evaluates your performance and in accordance with that year's salary program may determine merit for increase by completing a performance rating. The rating is used for such purposes as selection for promotion or transfer, and provides a structural basis for discussing your accomplishments as well as identifying your training, development and career needs. The rating provides you with the opportunity to review what is expected of you, assess the past year's activities and obtain a clear understanding of your supervisor's expectations.[15]

Core Team Members of the DMC II are formally evaluated yearly by the DMC II manager. As mentioned above, this evaluation determines individual raise increases and provides feedback for further improvement. The actual evaluation form focuses on six areas that include: technical expertise, contribution, business relationships, customer satisfaction, teamwork, organizational skills, compliance, and leadership. Each of the areas have boxes associated with them where the supervisor is obligated to check boxes indicating the employees levels of proficiency in each of the areas.

As mentioned in Chapter 3, employees that are co-located in the DMC II, but are not Core Members still get evaluated by their functional department managers. Ideally, these managers request information from DMC II Core Members on their employee's performance prior to rating.

The other tools used for feedback in the DMC II include drawing release schedules and SALT 24 reports--an Automated Daily Timekeeping System. The drawing release schedule is used by team leaders and senior managers to evaluate whether the program is on schedule. The exercise of actually creating a drawing release schedule remains fairly inconsistent across programs. Generally, however, design release dates are established through compromise—team leaders attempt to balance engineering manpower constraints with actual manufacturing need dates. Once again, this traditional style of scheduling pays little attention to the potential quantity of rework involved after the

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[15] "Compensation," Sikorsky Salary Employee Manual, (Unpublished Work: United Technologies Corporation, 1992) 28.

release of a drawing. More experienced team leaders understand which new designs are riskier than others and typically develop their drawing release schedules to reflect this uncertainty.

The SALT report is a tool used by managers to evaluate whether a program is over or under on budget estimates. Prior to the start of any project, estimates are made indicating the number of hours required to complete the development project. These hours are spread across the expected cycle time of the whole project and are carefully tracked against actual hours spent listed on the SALT report. Team leaders are carefully evaluated on how well they adhere to their budgets. Obviously, due to this metric there is a natural tendency for team leaders to focus less on *quality* and more on keeping their engineering hours below their estimate.

4.2.2.3. Overtime

Below is another excerpt from the company's *Salary Employee Manual*:

> Exempt employees are expected to work occasional overtime without compensation. However, if your job requires regular overtime work for an extended period, you may be put on an approved overtime schedule by your supervisor. All hours worked, whether compensated or not, are to be input into the Automated Daily Timekeeping System (SALT 24).[16]

Most of the programs in the DMC II are typically put on overtime when the DMC II manager or team leader feels they are in threat of not meeting the aircraft delivery schedule. In this situation, engineers typically have a great deal of power in dictating their own overtime schedules. It is common to see some engineers clock considerable amounts of overtime one week only to take vacation time the following week. Generally, there seems to be a much stronger degree of commitment from DMC II Core Team Members than there is from temporarily co-located employees. The sensitivity of the overtime subject and varying levels of commitment is exacerbated by the ongoing downsizing effort throughout the company.

Needless to say, truly high-performance project teams include team members who regularly deliver more than a 40-hour work week to the project. If a few critical tasks

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[16] Ibid. 26.

demand extraordinary effort, most committed teams are willing to devote a few weeks of 14-hour days to get the job done, often outside of their realm of expertise. However, 60 or 70 hour weeks cannot be expected from most team members for more than a few weeks without causing fatigue and "burnout."[17]

4.2.2.4. Overlapping job responsibilities and cross-training

One way to increase productivity on a development program is to have a team of multi-skilled individuals able and willing to take on a variety of tasks to ensure project completion. In effect, the team would focus all its efforts on the tasks that form the project's critical path in an effort to reduce cycle time. If the critical path can be usefully attacked by additional people, the team may choose to temporarily drop some or all other noncritical tasks in order to ensure timely completion of the critical tasks.

Sikorsky has traditionally been a functional organization with little emphasis placed on overlapping job responsibilities and multi-talented employees. The traditional rigidity in its organizational structure is reflected in the following excerpt from the *Salary Employee Manual*:

> In order to determine the relative worth of the work you are assigned, the Company uses a thoroughly tested system of job evaluation. Each job group within the Company has a written job description of your duties and responsibilities. Factors are: education, experience, complexity of duties, supervision received, errors (potential impact on the Company), contact with others, proprietary data, mental and visual demand and working conditions. For those positions with supervisory duties, in addition to the above factors, two other factors are also included: character of supervision and scope of supervision. Each of these factors is assigned a degree which rates to what extent that factor is required to perform the particular job. A numerical value is given to each degree, and the jobs assigned a grade level and a corresponding salary range.[18]

Within the DMC II, there are some examples of overlapping job responsibilities and pockets of excellence where considerable cross-training takes place. However, with

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[17] Bradley J. Smith, Nghia Nguyen, Richard F. Vidale, "Death of a Software Manager," American Programmer May 1993: 15.

[18] "Compensation," Sikorsky Salary Employee Manual, (Unpublished Work: United Technologies Corporation, 1992) 28.

no formal cross-training plan, individuals have been reluctant to take on additional responsibilities. Some employees are even hesitant to relinquish their functional knowledge—an expected consequence in a downsizing environment.

Furthermore, as the DMC II continues to grow with less of an emphasis on team performance, individuals will become increasingly concerned about their own programs or narrow job responsibilities at the expense of others. Only those truly committed to the overall success of the DMC II will share overlapping responsibilities out of career necessity.

4.2.2.5. Co-location and coordination mechanisms

Coordination among the activities of the different members involved in the harness development process is required throughout the lifetime of the project and its effectiveness often determines the success of a program. The need for coordination is a natural outgrowth of dependencies among tasks.[19] Coordination needs also arise from the inevitable changes in the harness plan caused by unanticipated events and new information. Mechanisms that the DMC II used to address communication difficulties and facilitate coordination include meetings, informal communication, and information systems.

4.2.2.6. Meetings

The primary formal communication mechanism for platform leaders was meetings. Most projects in the DMC II met formally at least once each week, and some as many as five times a week depending on the stage of development. Teams located in the same work area needed fewer formal meetings than those whose members were geographically separated. In order to minimize the amount of time wasted in meetings, some teams that held meetings every day met standing up to emphasize that the meeting was intended to be quick. Other techniques for controlling the length of meetings included preparing a written agenda, appointing someone to run the meeting, and holding the meeting at breakfast time. The most successful meetings seemed to be those that were held at a regular time and place so that no extra effort was expended in scheduling the meeting and in informing the team of its time and location. Sometimes a simple change from weekly to daily meetings increased the "driving frequency" of the information flow among team members and enabled more rapid completion of tasks.

4.2.2.7. Informal communications

Team members engaged in a harness development project often communicated with other team members dozens of times per day. Many of these communications were informal; they often involved a spontaneous stop by someone's desk or a telephone call to gather information. Informal communication was dramatically enhanced with the co-location of team members and served as an effective mechanism in breaking down individual and organizational barriers to cross-functional cooperation. This is consistent with the work of Allen who has shown that communication frequency is inversely related to physical separation and falls off rapidly when people are located more than a few meters from one another.[20] Figure 4-2 shows this relationship for individuals with an organizational bond, such as individuals belonging to the same product development organization. Within the DMC II, electronic mail, and voice mail also provided effective means of fostering informal communication among people who were already well acquainted with one another.

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[19] Karl T. Ulrich and Steven D Eppinger, Product Design and Development (New York: McGraw-Hill, 1995) 274.

[20] Thomas J. Allen, Managing the Flow of Technology: Technology Transfer and the Dissemination of Technological Information within the R&D Organization, (Cambridge, MA: MIT Press, 1977).

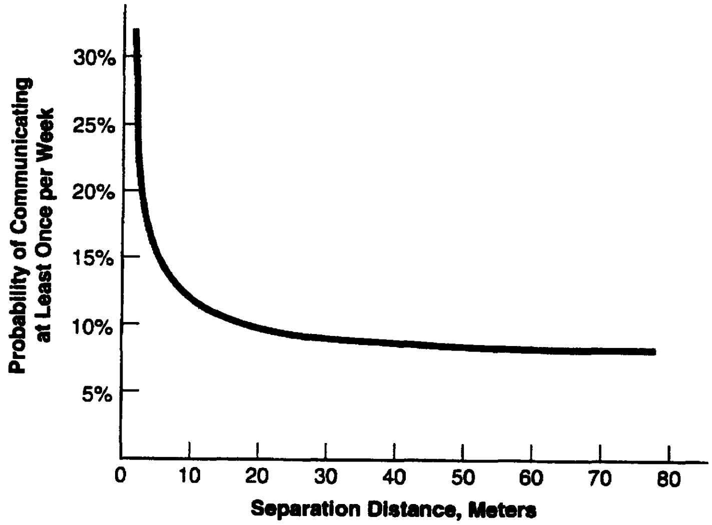

Figure 4-2: Communication frequency versus separation distance.[21]

4.2.2.8. Information systems

Information systems generally refer to the structured means that teams exchange information. The most important information system that the DMC II used in project execution was the development schedule. The more successful projects had a single person who was responsible for monitoring the project schedule. Team members generally understand the importance of accurate schedule projections and were cooperative in supplying this information. Schedule updates were usually displayed in Gantt chart form.

4.2.3. Improving "quality" in harness development

Overall, its relatively easy to measure a development projects' "quality." Within the harness development process, the number of engineering changes occurring after the start of fabrication is one good measure. A second measure might be the number of wiring changes required during installation—to include terminations made on the helicopter because of a lack of length information in design. Lack of information and unforeseen changes all result in lower quality levels that direct work away from being complete to "undiscovered rework" and "known rework." As a result, harnesses may cycle four or five times through the "Rework Cycle" before they can be classified as

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[21] Karl T. Ulrich and Steven D Eppinger, Product Design and Development (New York: McGraw-Hill, 1995) 275.

actually complete. Improvements in quality can be classified as anything that prevents a harness from traveling through the "Rework Cycle" and having to be touched more than once by either an engineer or technician.

4.2.3.1. Rule based technologies and 3-D modeling

Recent advances in technology have revolutionized engineering quality levels and have made many traditional development tools obsolete. Noteworthy success stories highlighting the benefits associated with 3-D modeling and rule based technologies have become commonplace. Unfortunately, since the original S70 helicopter design was developed in 2-D, many of the advantages gained through the use of rule based technologies go unrealized without considerable 3-D modeling investment.

Studies have shown that 80% of all engineering activity is actually nothing more than a minor variation of pre-existing practice or procedure—routine work.[22] Object oriented technology has enabled the rapid development and deployment of engineering applications by automating these routine operations. Combining this technology with a methodology for acquiring and structuring knowledge enables engineers to rapidly generate new designs directly from functional specifications. With this technology, market-leading companies worldwide in the aerospace, automotive, industrial equipment, construction, computers and telecommunications industries are creating customer-driven product designs, product configuration, and sales proposal in minutes, not months. Applications for rule-based technologies are continually evaluated at Sikorsky. In fact, the manufacturing engineering department deemed RBT to be so important that they have assigned it as a special project within their department.

4.2.3.2. Prototype/ mock-up design

Given the challenges and investment required for developing an effective rule based technology for the harness development process, alternate solutions that eliminate rework must be examined. One such solution is the use of mock-up designs to acquire accurate length and interference data. Taking the time up-front, during the generation of

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[22] "The ICAD System," Concentra Corporation, 1995.

stick and length data stage of harness development, to conduct a mock-up will result in less work being done on the aircraft during installation. The tradeoff, however, is to determine whether this increased engineering effort is less expensive than the current manufacturing effort—a constant struggle between the DMC and DMC II. This struggle is exacerbated by the current performance metrics used by each organization.

4.2.4. Factors that will facilitate "rework discovery" in harness development

No matter what the quality improvement effort and impact, undetected errors and rework cycles are unavoidable in harness development as they are in other complex development projects. When rework is generated, however, it has its most destructive effect on the whole project when it is in the state of "undiscovered rework."[23] Discovering the rework earlier and faster removes much of the program-wide disruption, especially the delivery schedule impacts. Studies have shown that the value achieved by accelerating the detection of undiscovered rework is indeed non-linear.[24] Cooper suggests that lowering the rework discovery time in an organization is most leveraged in improving schedule performance when quality is not at extremely low or extremely high levels. At extremely high quality levels, there is not as much room for improvement of schedule performance. And in the stages of a development when extremely low quality prevails, rapid rework discovery ends up subjecting the execution of the discovered rework to the same low-quality conditions that caused it to cycle in the first place. In such conditions it is best to work first on quality enhancement practices and systems, then to accelerate the benefit with rework discovery enhancements.

With improved rework discovery mechanisms in place, team leaders can also attain a much more accurate assessment of real project progress and not be misled by perceived project performance--a phenomenon described by Cooper as the "90% Syndrome," where for a prolonged time project managers report to executives that their effort is 90% complete when only 75% or less is really done. This reporting continues until, after much disappointment and cost, 90% is finally achieved and the project moves

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[23] Kenneth G. Cooper, "The Rework Cycle: How it Really Works," PMNETwork, February 1993.
[24] Ibid.

on to completion. The "Rework Cycle" explains the systemic causes of the "90% Syndrome" through varying degrees of quality and rework discovery. According to Cooper, projects that have *low* quality levels and *long* rework discovery times exhibit the following characteristics:

1. A large, long-lasting gap between real progress and that which is perceived.
2. A significant gap that still persists in the final stages of the project.
3. Great uncertainty in the size of the gap.
4. A point of maximum uncertainty about real progress late in the project.

Figure 4-3 depicts a progress ramp of real progress vs. perceived progress when quality is assigned a value of 0.2 and rework discovery is 0.75.

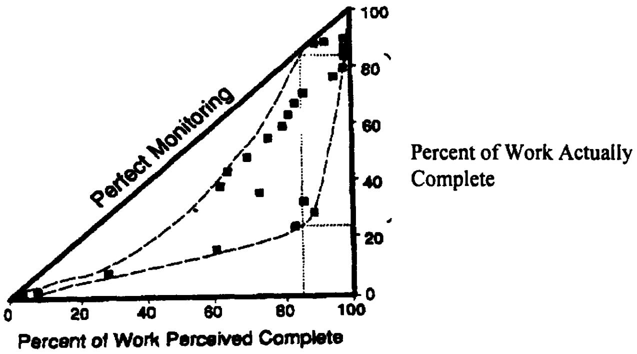

Figure 4-3: Percent of work actually complete vs. Percent of work perceived complete with low quality and long rework discovery.[25]

Successful initiatives to improve rework discovery will change the "culture" of the organization. Rather than mandate levels of quality, management will have to influence quality indirectly through that which they can control, or more directly influence—interim schedule targets, staffing, monitoring systems, and testing practices. Within the DMC II, some of the factors which can improve "rework discovery time" include: 1) Cultivation of a more collaborative work environment which encourages early detection of rework, 2) Early and improved review of EPATS design by knowledgeable team leaders, 3) Installation and test of harnesses as soon as possible in the build plan, and 4) Assignment of proactive management with a thorough understanding of the entire development process.

4.3. Pursuit of incremental and radical improvement in the harness development process

Ideally, the best working environment would be one in which there is sufficient time and resources available to devote to large scale process improvement—considerably challenging in a downsizing environment. This activity, the fourth step in the methodology, represents a collaborative effort to improve "productivity" and increase "quality" as applied to the "Rework Cycle." This thesis argues that two teams should be devised to study both incremental and radical improvements concurrently. The radical process team should confront such issues as supplier lead time and costs, major technological improvements, managerial selection and training, and quality assurance. The formation of the DMC II in and of itself was a severe radical change that had taken place prior to the start of this study. Due to manpower constraints within the DMC II, however, formation of radical process improvement teams for further radical change was limited. Consequently, this step in the methodology focuses on incremental improvements to the current harness development process. The incremental process improvement path started with the construction of a process flow diagram and the development of a simulation model to aid in decision making. The following sections will briefly discuss the advantages of simulation over traditional cycle time measurement tools.

4.3.1. Traditional cycle time measurement tools

To address the issue of product development cycle time, there is a fundamental need for analytical tools and methods to describe and plan development projects. One traditional tool used to manage and schedule projects is a Gantt chart, a bar graph which maps activities on the vertical axis against time on the horizontal axis. A second tool is a PERT (project evaluation and review technique) diagram, which describes all the activities related to a project with a network of nodes representing the activities and

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[25] Kenneth G. Cooper, "The Rework Cycle: Benchmarks for the Project Manager," Project Management Journal XXIV, March 1993.

connecting arcs representing the precedence of all the activities. This section describes how Sikorsky utilized these traditional tools.

Gantt Chart: The primary engineering project management tools currently being used at Sikorsky are Gantt charts and computerized scheduling systems to track start and completion dates. The steps in the engineering process are defined down to the task level and labor estimates are collected from each engineering group. The labor estimates are aggregated to define the length of time required for major functional activities, and these activities are drawn on Gantt charts. For each function, milestones are set for each engineering team, primarily indicating when all drawings, models or specific data must be released to a downstream group. All inter-group activities, where one group needs a special piece of information from another group, are negotiated and agreed upon and that date is added as a target completion date.

From this system, many levels of Gantt charts are created to track the project. The project as a whole is charted across the entire engineering department. Individual engineering leaders, such as manufacturing engineering, create their own Gantt charts. Finally, groups such as the harness planners will chart their own activities and milestones.

These Gantt charts, drawing release schedules, and the MRP II system constitute the primary tools used to drive the system. Each manufacturing back shop is provided with a MRP II generated report, either for a single customer or for all customers, of what is due to be released. While the project is in progress, the scheduling system is used to track the performance of each department. When each model or task has been completed, that information is entered in the system. Thus, on a daily basis reports are generated for each department detailing whether it is ahead or behind on a single customer or on all of its customer tasks. This drives the day to day scheduling down to the engineer or technician level and serves as the primary tool by which each team or department is measured and rewarded.

The Gantt Chart provides an effective driver and monitor of a very large scale engineering project, but it also has a number of disadvantages in the following areas:

- ***Size:*** Using Gantt charts requires a large overhead in time and people. Within the DMC II, there is an individual permanently assigned to record and track data. While this person works closely with the engineers, he is not directly involved in the engineering process. Therefore, a significant amount of time is spent by the engineer and the scheduler satisfying the requirements of the scheduling system.

- ***Complexity:*** As the scheduling tool tries to aggregate thousands of individual tasks it begins to drive the engineering activity on a very macro level. Therefore, it is not a very sensitive tool for anticipating problems which are more than a few weeks into the future. It often reports backlogs of work much too late, once groups have already fallen behind and have begun missing release dates.
- ***Incentives:*** Often the scheduling system enforces the wrong incentives. Individuals are judged by how well they meet a schedule that is based on their labor estimates. This encourages them to be quite conservative when committing to a schedule. Once the dates are established, individual engineers work to those dates, often holding onto finished work until it is required by the schedule. Finally, by forcing groups to meet dates that were often estimated a year in advance, the schedule encourages the release of incomplete data that causes disruption and rework later in the process.
- ***Design:*** The adherence to a detailed scheduling system breaks customer design into two stages. Within the first month, all the engineering groups spend just enough time on the design to estimate their future costs. This estimation activity follows the same sequential design process, in which each group's estimate is based on, and waits for, the upstream groups' estimates. That customer's design is then set aside until it reappears in the sequential design process, which may be up to one year later. Some engineers feel that the time it takes to estimate what they are going to do sometimes takes as long as the final engineering effort, thus doubling the amount of work they have to do.

This list of the faults of the scheduling system is not meant to diminish the value it provides to Sikorsky. In fact, this system effectively serves as the integrator and driver of an extremely complex engineering project. Rather, the point to be made is that dependence on this scheduling system makes the task of reducing development cycle time more difficult.

The development process for an individual customer is described by the Gantt charts that are taken directly from the scheduling system. The cycle time for that customer is typically calculated directly from these Gantt charts based on a Critical Path Method (CPM), i.e. adding up the longest path of functional activities to provide an estimate of the total amount of time required to complete the customer design. The size and complexity of the scheduling system creates an inaccurate picture of tasks that need to be performed, and then the system forces the groups to adhere to that picture, while adding non-value activities to the process. Accepting this assumption leads to the conclusion that the scheduling system is not an effective tool to define, much less understand and improve, the true cycle time of the development process. Therefore, the first step to reducing the development cycle time is to develop a better description of the process itself, a description which will more accurately define the amount of time for the sub-tasks and, in aggregate, the cycle time of each customer.

PERT diagrams: Another common tool used to describe design processes is the traditional PERT style diagrams. PERT diagrams define a network of activities or tasks tied to specific groups of people. The difference between this representation and the GANTT chart is that the PERT chart clearly shows the precedents of tasks. A PERT diagram is one of the primary tools used by the Sikorsky process improvement or "kaizen" teams to understand their processes. The following is a relatively detailed process flow diagram of the harness development process:

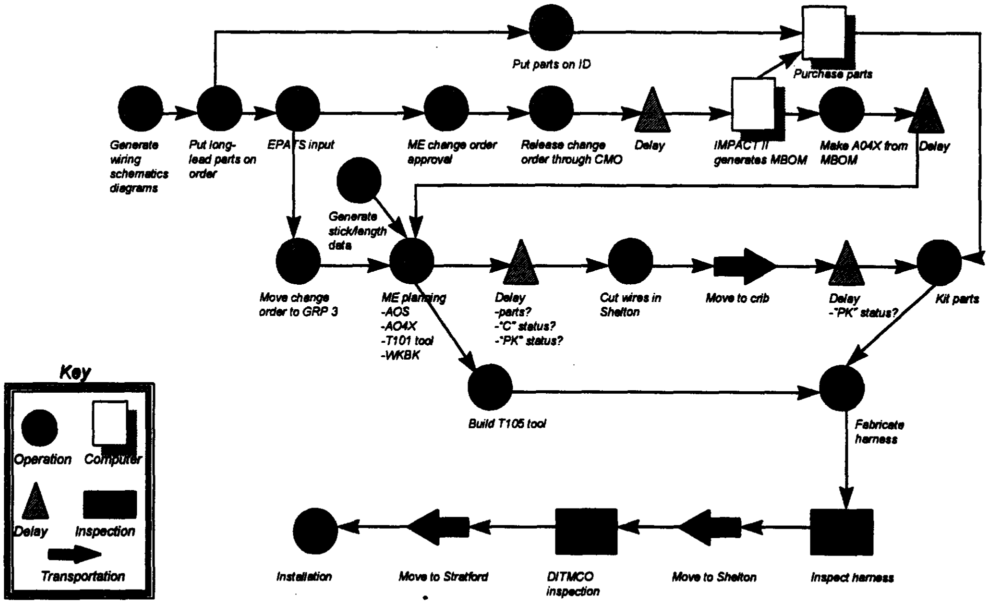

Figure 4-4: Process flow diagram of harness development process.

Without computer simulation, however, it is difficult to use PERT diagrams to define the cycle time of a complex process like the one shown above. It is imperative that the concepts of feedback and iteration loops be included since they significantly affect cycle time.

4.3.2. Queuing network model of wiring harness development

A slightly different interpretation of the standard PERT diagram is to define each node as a specific resource available for each task activity or set of jobs. A customer project enters the network and starts with the first task to be performed by the first work station. As each set of jobs is completed, the next steps can be performed by the same work station or the next station in the system. Finally, once all the jobs have been completed, the project exits the system. The total cycle time is defined as the length of time the project is in process in the system.

A simpler version of the process flow diagram shown in Figure 4-4 is shown as a queuing network diagram in Figure 4-5.

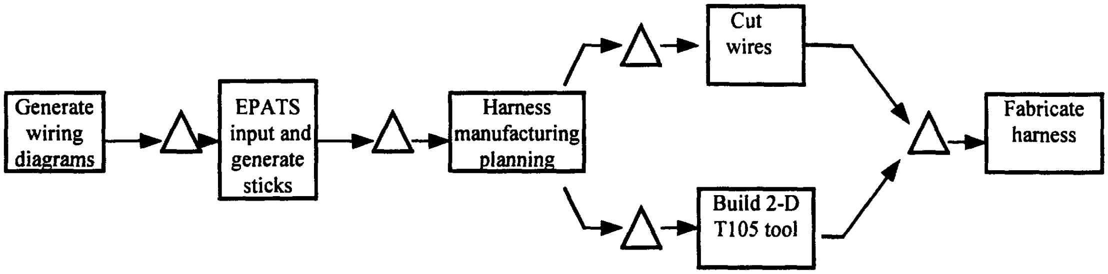

Figure 4-5: Queuing harness development network

By adding queues before each node, an additional time element is defined, separating the time required for each individual job into queue time and processing time. This enables the diagram to reflect the reality of limited engineering resources, not only regarding the length of time a task requires once it is in service, but also the period of time each task must be delayed while resources are focused on other tasks and projects.

Queuing models have long been the subject of operations research, used to address such problems as inventory and production control. The introduction of automated manufacturing systems focused the development of queuing models on the problems of resource contention between production equipment. In addition, the modeling of computer systems and data transmission systems has greatly increased the understanding of complex queuing networks. All these traditional applications have relied on queuing models to help design and improve the performance of systems of machines and equipment.

The concept of using queuing networks to model design activities is well described in the work of Adler et al., where the authors use a stochastic processing network to model product development projects. They define each project as a series of jobs that are represented by a pool of engineers or technicians who are able to perform a subset of the jobs. Each work station is preceded by a queue, thus an existing job in the system is either being processed by that work station or is waiting in the queue while the resources of that work station are occupied with other jobs.

This model fits very well with the type of product development activity that is currently performed by the DMC II with respect to harness development. Each helicopter order breaks down into a relatively uniform set of jobs and follows the same sequence through the DMC II. For example, if a helicopter requires some modification of 40 wiring harnesses across 6 defined areas of the aircraft, the modification can be broken down into 40 jobs flowing through the queuing network.

When the customer order enters the network, the first 40 jobs appear in the Generate Wiring Schematics queue. As those jobs are finished, the EPATS design jobs enter their queue. Thus the process defines the order of the jobs entering the system and each set of jobs appears in the appropriate queue when the corresponding upstream jobs have been completed. When all the jobs have been serviced, the work for that customer is complete and the customer order exits the network. The total amount of time that the customer order is in the network constitutes the wiring harness development cycle time for that customer.

When working specifically to reduce product development time, a true understanding of the nature of time is crucial. Clearly, queue time exerts an effect and must be accounted for. Elements such as feedback and iterating loops are also significant. Prioritization of tasks must be considered. Both sequential and parallel processing of jobs across functional groups must be explored. Finally, when searching for a solution, availability of resources must be examined and tied to the arrival of work in the different stages of the process. The queuing network provides a model which can characterize all of these important elements.

4.3.3. Queuing network simulation tool

4.3.3.1. Purpose of simulation

An analytical model can be used in a number of ways to help in a process improvement project. The definition of the model can be used to develop a basic understanding of the significant elements of the current process. A more significant application of the model is to use it to estimate the potential effects of specific changes.

The model can be used to define the relationship between the inputs to the system and the performance of the system.

Queuing network theory offers two alternative techniques. The first approach is to use analytical formulas such as Little's and Jackson's Theory to define specific relationships between arrival rates, service time and queue time of the subcomponents of the system or the system as a whole. A second approach is to use a computer simulation to experiment with changes in both the input conditions and the specifics of the system.

In the Adler study, stochastic networks were used to model product development processes because they were able to characterize the processing time and inter-arrival time using a defined set of probability distributions. In this study, the harness jobs' service times could be characterized using a probability distribution but the inter-arrival times of the customer orders were somewhat deterministic. The start of a project, as in many product development departments, is timed to coincide with the freeing up of resources. Thus the harness development process cannot be modeled as a memory-less system. Each project is selected based on the current projects in progress, the size of current and proposed projects, and the resources available. For example, if the DMC II were overworked with projects, the functional design groups would get some of the work. The deterministic nature of this process leads away from using analytical techniques, since many of those techniques can only be applied to memory-less systems.

For the purposes of this process improvement project, there are additional reasons why simulation is the more applicable approach. The purpose of the simulation exercise goes beyond just understanding the specific relationship between the process and cycle times. As a more flexible tool, it can be used to investigate more abstract questions such as what is the degree of queue time versus processing time or what is the effect of rework due to late changes? In addition, it provides a much more intuitive tool because it is based on basic elements that people involved in the process come in contact with every day, i.e. specific jobs, resources, and relationships. As such, it can be used to effectively demonstrate new concepts and alternative processes. Furthermore, a simple and intuitive analytical tool is essential to get the buy-in for change from both the team members and upper management.

A simulation program was used as a tool to help explain the current process and explore alternatives to the process and the underlying model. Early on in this project, it was recognized that it was only a single tool that had to be integrated with other forms of analysis, thus it did not become an end in itself. Once the current model and process had been simulated, the simulation tool was used to explore very specific question such as: what are the effects of a different level of parallel flow; what is the effect of transferring individual jobs from one group to another; and what is the effect of a broader skill set?

Within the body of this thesis, the simulation results will be used to clarify the specific issues under discussion. In order to effectively use the simulation results, the following section will define the primary elements used in the simulation and then present the results of modeling the current process.

4.3.3.2. Simulation details

The simulation was developed on a PC program called Arena, produced by Systems Modeling Corporation. This program, originally designed for production simulation, provides a generic set of modules to define a queuing network of manufacturing work cells. These modules include machines, buffers, and parts. Renaming these elements allows the use of this simulation package to define the general elements of the wiring harness development process within the DMC II. Instead of machines, there are engineers and technicians. Instead of parts, there are specific jobs such as creating a 2-D tool for wire lay-up. Instead of part buffers, each job sits in a queue (or computerized in-basket) until an engineer or technician is free to work on it.

Work stations: In this simulation, work station modules represent the first seven of the nine major steps in the harness development process: Generation of wiring diagrams, EPATS input, production illustration, harness manufacturing planning, wire cutting, 2-D T105 tool construction, and harness fabrication. For purposes of the simulation, EPATS input and production illustration are combined into one work station and the simulation ends at the fabrication stage of harness development. The number of people in each work station remains fairly consistent from program to program. Typically, in the DMC II, there are one or two people who generate the wiring diagrams for each program. In some instances these diagrams are actually provided by a customer or supplier and hence no work is required at all. There is usually one engineer who completes all of the EPATS input for all the harnesses in a program. Similarly, there is usually one manufacturing engineer who does all of the harness planning for an entire program and one tool fabricator who constructs all of the 2-D T105 tools for all of the programs. All wires are cut and coded by one of two Capri wire cutting machines at Sikorsky's Avionics Systems Center (ASC) in Shelton, CT. These machines have the capability to automatically download wiring details such as wire length, type, and routing information directly from the EPATS system. Harness fabrication, staffed by hourly technicians, varies considerably from month to month depending on workload. During my stay manpower ranged from 5 to 10 people over primarily one shift. For the purposes of the simulation, it is assumed that no person is on task all of the time, since they devote a portion of their time to breaks, training, and other side projects. Therefore, using a standard resource estimate, each person in the simulation works 33 hours out of a 40 hour week. For the remaining 7 hours, randomly dispersed throughout the week, the simulated worker sits idle, interrupting the current job or waiting to pull a new job from a queue.

***Jobs**:* Jobs represent the work done at each work station to satisfy a customer's design. A single customer order enters the system when a customer contracts to buy a new helicopter. From that one customer order, a specified quantity of different type jobs enters the system to be worked by the appropriate work stations. These jobs represent a single task or aggregation of a few tasks that an engineer or technician must process. Besides type and customer number, each job has an attribute called process time that defines the length of time it must be worked on at a specific work station until it is considered to be complete. Once a job passes through the last work station, it departs the system. When all the jobs associated with a customer are complete, the customer leaves the system signifying the overall project cycle time.

The job types were selected by examining each work station's activity related to a specific customer, and narrowing down the work to the single worker level. For example, the EPATS design work station defined wiring harnesses from system diagrams and input this data into the Electrical Planning and Tooling System (EPATS). Once the definition of jobs were defined, the average number of jobs for each customer could be calculated from the history of the first few customers. For the EPATS work station, the average number of harnesses that changed (either modified or created) translated into the number of harness engineering change orders for each customer.

Once these job types were defined, the mean and distribution of their processing times were calculated for each work station. It was found that a single mean and distribution was not sufficient to define all harnesses that passed through a work station. In the case of an EPATS input job, approximately 20% of the harnesses touched per customer had to be created from scratch as opposed to being modified from an old design. The new harness jobs had a much larger mean service time and a different distribution. Also, the size of the harness greatly affected its processing time. Consequently, each work station had specific job types associated with it, and the processing time for each job type varied depending on the size and complexity of the harness.

The specific job types at each station are outlined in Table 4-1. The only work station that has more than one job type is Harness Manufacturing Planning. In that case, the internal process was broken into three sub-jobs because these different jobs caused a release of work to the Wire Cutting and 2-D T105 Tool Construction work stations at different times.

Work station	Job type	Harness size & complexity	Description
Generation of wiring schematics	Create wiring diagram	Main, Main revision, Medium, Medium revision, Small, Small revision	Definition of the contents of a single wiring harness
EPATS input	Create harness engineering change order	Main, Main revision, Medium, Medium revision, Small, Small revision	Computer input of wire code, type, and routing information
Generate sticks	Create stick diagram	Main, Main revision, Medium, Medium revision, Small, Small revision	Engineers draw stick diagram of harness lengths and connector locations
Manufacturing engineering planning	- Create assembly operations sheets - Create 2-D harness diagram (T101) - Create harness assembly workbook	Main, Main revision, Medium, Medium revision, Small, Small revision	Manufacturing engineers create detailed instructions for harness fabrication
Wire cutting	Cut and code wire bundles	Main, Medium, Small	Wires are automatically cut by downloading EPATS data
2-D T105 tool construction	Construct T105 tool	Main, Medium, Small	2-D T101 drawing is attached to plywood to fabricate harness
Harness fabrication	Fabricate wiring harness	Main, Medium, Small	Harness is fabricated on T105 by using the assembly workbook

Table 4-1: Simulation Job Types

Rework jobs: The customer jobs defined above in no way represent all the work in the harness development process. They represent the work that normally flows from a customer order if there are no iterations in design, changes to the customer order, or errors in the initial design discovered later in the development process, i.e. elements that are depicted by the "Rework Cycle." All this additional activity clearly has a significant effect on the availability of resources and therefore on cycle time. In order to characterize this effect, a new type of job was added to the simulation that was called "rework." Rework jobs represent work that would appear with little notice and have a higher priority than the current customer being worked since they are associated with an earlier customer that has a more immediate delivery date.

To model the detailed cause and effect of rework jobs, a relatively simple addition was made to the model. By questioning each of the work stations, it was found that roughly 3/4 of the jobs being worked in the planning, wire cutting, or tool construction stages were the initial customer jobs; the other 1/4 were some form of rework job. In addition, rework jobs had approximately half the processing times of the initial customer jobs.

Queues: When a job for a specific work station enters the simulated harness development system, it enters a queue for that work station. Each work station has one queue, that handles both rework jobs and normal jobs. In the simulation, as soon as a worker is free, the job with the highest priority in the queue goes to that worker. Priority is based on rework jobs and customer order number. If there is no rework job, the first normal customer job is pulled and processed. For example, all of customer #2's jobs are serviced first-in-first-out (FIFO), but if a customer #1 job appears, it goes in front of all customer #2 jobs already in the queue.

Stopped jobs: For most jobs in the simulation, once they are pulled from the queue, the worker will process the job for the entire service time. In the real work stations, the engineers and technicians do not always have the luxury of working a single job until it is complete. Often, the job is interrupted by external changes or by rush jobs that require immediate attention, or the job has to be put aside due to incomplete information or parts shortages. The percentage of stopped jobs varies from work station to work station, ranging from 5% to 50%. This phenomenon is simulated by tagging the appropriate percentage of customer jobs for each work station as stoppers. If a job is designated as a stopper, it is pulled from the work station's queue, as usual, but it will only be in service half the required time. It is then placed back into the queue, behind the other jobs of the current customer. When it again advances to the front of the queue, the stopped job is pulled once again, completed and finally released from the system.

4.3.3.3. Simulation input and output

While there were many variables that made up the simulation, a number of key inputs were used to tune the current model and examine alternatives. These included:

1. **Customer size**: Number of jobs associated with each new customer, with the service time per job defined by a set of means and distributions.

2. **Customer arrival rate**: How often a customer enters the system. In the current model, it was set at one customer arrival every three months.
3. **Resources**: Number of people in each work station.
4. **Rework jobs**: Number of rework jobs and their service times.

The primary output of the simulation was the cycle time of the customer order and of each individual job type. Each customer's jobs were carefully tracked, recording across the life of the customer how many jobs of each type had been completed, were currently in process, or were waiting in a queue for service. Monitoring the queues for each work station showed where backlogs were building and the length of time required to reduce those backlogs.

4.3.4. Current model simulation results

The results for the current process and model were examined on a customer level and a work station level. At the customer level, the cycle time was defined as the time between the original order date and the date that all the harnesses were completely fabricated. The time required to install the harnesses into the helicopter was not considered. With the existing customer arrival rate and size, the simulated cycle time averaged 6.8 months. This included the time from initial customer arrival until the first wiring diagram job was available, which represented the time required to get the information from the external groups to the design engineers generating the wiring diagrams.

The work flow of a single customer across five of the work stations is graphed in Figure 4-6. It clearly demonstrates the sequential nature of the work flow. Each line in the graph represents the completion of jobs for one work station associated with a single customer as a percentage of the total required.

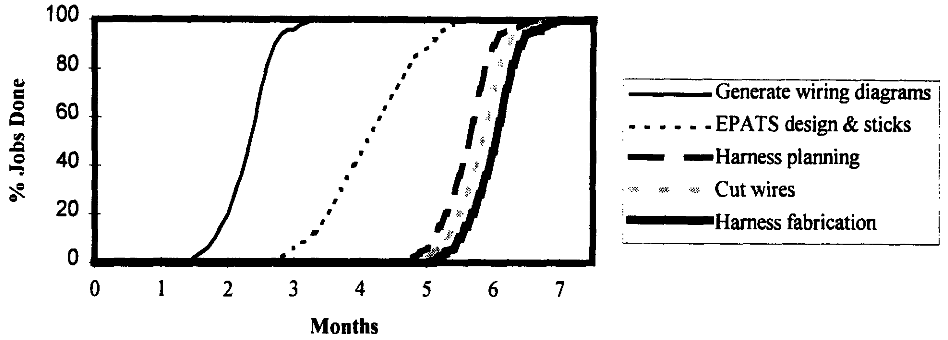

Figure 4-6: Completion of jobs for a single customer.

It can be seen that the Generate wiring diagrams work center works almost completely in isolation, with delays between when they finish a job and when the EPATS designers start to design harnesses. This is due to the need for several different system diagrams before the start of harness design. While not accurately reflected in the simulation, there is a clear lag between the start of harness planning and the completion of EPATS design. This lag is due to the need for accurate routing and length information for all newly designed harnesses. This often requires significant engineering judgment and experience in estimating wire lengths and pinpointing the exact locations of new equipment. Lack of information and experienced personnel can create large delays and uncertainty between EPATS design and harness planning.

Examining the arrival of work for each work station provides insight to the delays between stations. Figure 4-7 represents the arrival of work for a single customer into the queues of each work station. Each line represents all the hours for a single customer as it arrives into its customer queue. The backlog is worked off as individual jobs are serviced and released.

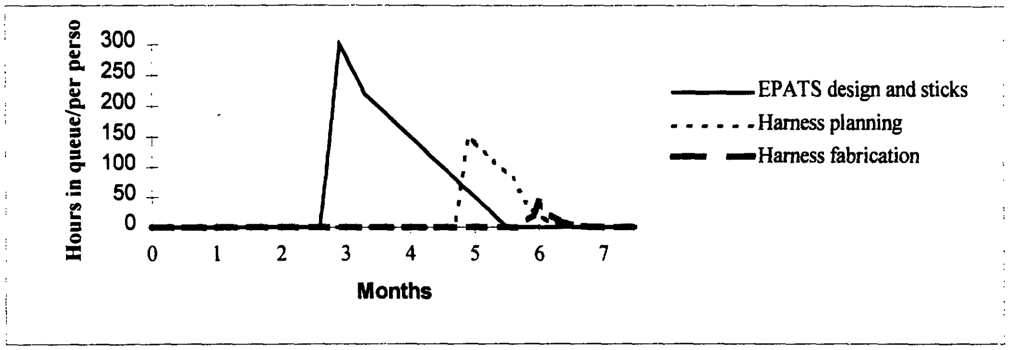

Figure 4-7: Backlog of hours per person per work station.

The hours have been standardized across the work stations by dividing them by the number of people in each work station. The worst backlogs occur at the EPATS design and generate stick work station. In the space of one month, a huge backlog of close to 300 hours per person builds at this station, which is more than twice the amount of the next largest backlog .

Backlogs relate directly to the queue time of the jobs at each work station. If all work arrives in large batches, the jobs at the end of the queue must wait for the backlog to clear and are even more delayed by the arrival of higher priority rework jobs. As Figure 4-8 illustrates, the amount of time the customer's jobs wait in a queue ranges from 64% to 81% of the total time in the system.

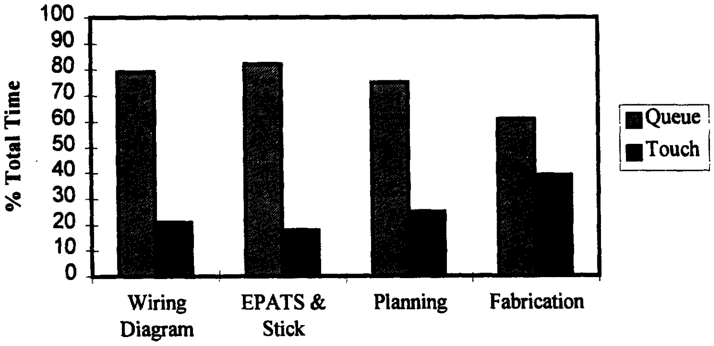

Figure 4-8: Average queue times and touch times of each job type as a percentage of the total time in the system.

When deciding on the validity of the simulation model, it is important to remember its original purpose. This model was not meant to be a tool to accurately predict the usage of resources or the completion of specific projects. Rather, it was meant as a tool to understand and communicate the current harness development process and to estimate the relative effects on cycle time resulting from changes in the process. Once the relationships between the different work stations had been established, the current simulation was then used as a baseline to compare the effects of proposed changes. In addition, the dominance of queue time over touch time in the current system supports the original hypothesis that this study required a tool that could separate the two different time elements.

4.4. Integrate findings, implement change and refine harness development

Ideally, at this stage of the cycle time reduction methodology there should be two complete proposals for process improvement—one requiring radical change, the other incremental process improvement. Both proposals were attained through the aid of cycle time reduction tools such as cross-functional teams and queuing network simulation. Underlying these two separate proposals are the systemic forces affecting harness development discussed in Section 4.2 and explained by the "Rework Cycle." These include variables, often separate from process improvement recommendations, which accelerate or eliminate work through the "Rework Cycle" by impacting *manpower*, *productivity*, *quality*, or *rework discovery*.

This stage of the methodology requires the integration of both proposals with the systemic forces affecting the "Rework Cycle." Chapter 5 will detail the two specific proposals attained through incremental and radical process improvement and will discuss their feasibility. Chapter 6 will then integrate these proposals into a practical implementation plan which incorporates elements of the "Rework Cycle." As discussed in Chapter 2, the final transition to a successful implementation plan must also accomplish the following goals:

1. Gain acceptance at all levels of the organization.
2. Gather momentum for implementing change.
3. Gain commitment of upper management to support the change.

4. Create change agents who accept personal responsibility for making the change happen.

These goals, in fact, underlie every step in this exercise, and many of the earlier activities should have laid the ground work for a transition from studying the problem to implementing a solution.

5. Incremental and radical process improvements

The cycle time reduction effort for the harness development process was closely examined by a newly appointed process owner (a DMC II Core Team Member), and myself over a seven month period while four development programs were going on concurrently. We examined the process in great detail and implemented numerous incremental changes to improve cycle time. Furthermore, we explored several more radical process improvements that will require organizational changes within the DMC II. This chapter will outline the approach we took to identify both radical and incremental process improvements and will discuss their feasibility.

5.1. Efforts to achieve cycle time reduction through process improvements

As stated in Chapter 2, this thesis makes the assumption that the steps and methodologies used to create incremental change are different than those needed to create radical change. Many of the steps needed for incremental improvement are described in a large body of TQM and continuous improvement literature. The more recent trend of reengineering has differentiated itself by proposing methods aimed strictly at creating radical change. Many of the concepts and methods from both these movements were used to guide cycle time reduction for the DMC II harness development process.

Prior to the start of the process improvement effort it was critical to gain a clear understanding of the development environment described by the "Rework Cycle." This provided valuable insight as to where to focus improvement efforts and gave all team members a shared mental picture of the system within which they worked. Since harness development was by far the most iterative design mode in S70 derivative development, there were several ways that development cycle time could be accelerated. Smith and Eppinger recommend that teams consider two general strategies: faster iterations and/or fewer iterations through the rework cycle.[26] They suggest that faster iterations can be achieved by introducing the following process improvements:

1. Computer-aided design systems which accelerate some of the individual design tasks.
2. Engineering analysis tools such as simulation techniques which reduce the need for time-consuming prototype/test cycles.
3. Information systems involving database management and networking software which facilitate rapid exchange of technical information among individuals on the design team.
4. Removing extraneous activities from the iterative process.

Similarly, Smith and Eppinger suggest that fewer iterations can be achieved through:

1. The improved coordination of individuals whose work depends on one another.
2. The co-location of team members responsible for tightly coupled activities, allowing faster and more frequent information exchanges and quicker resolution of conflicting issues.
3. The minimization of team size, which allows a core set of individuals to work more efficiently.
4. The proper specification of interfaces, allowing for reduced need for interactions between individuals and teams within the development process.
5. The use of engineering models capable of predicting performance along multiple dimensions, eliminating the need for separate analyses.

The improvements which create faster iterations primarily involve shortening the times for each task by improving *productivity*, or by reducing the *rework discovery* rate. The improvements for achieving fewer iterations primarily involve changing the rework quantities by improving *quality*.

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[26] Robert P. Smith and Steven D. Eppinger, "Identifying Controlling Features of Engineering Design Iteration," Working Paper #3348, MIT Sloan School of Management, 1995.

5.1.1. Incremental process improvements

The drive for incremental process improvement was continuously ongoing over the seven month study, and focused on detailed changes to the current process. This effort was carried out through an existing team of functional representatives. Each member was primarily responsible for developing improvements to his or her internal processes and negotiating improvements with immediate customers or suppliers. At the end of the study, this activity was still ongoing and is expected to continue indefinitely. Over the seven month study several process improvements did emerge, but the existing functional structures and roles remained the same. The following sections outline the approach that the DMC II took in obtaining incremental process improvements.

5.1.1.1. Documenting the existing process

The first step in identifying incremental process improvements was to develop a clear understanding of the current process. This task took several months and, among other purposes, served to bring different functional members together as a team. Each functional representative was encouraged to document a process that would have the shortest possible cycle time.

Out of this initial phase of study, we created the following process improvement tools:

1. Process flow diagrams of the current process.
2. Receivable and deliverables for each major task in the process.
3. Identification of all mechanisms for transferring information between groups.
4. List of critical assumptions.

5.1.1.2. Breakdown problem

Brainstorming and integrating ideas within a large team is difficult, especially when starting from the detailed process definition. Therefore, sub-teams were created, each focusing on some division of the harness development process. An appropriate method to divide the problem is to create a single sub-team for each major deliverable of the development process. For example, use one team to focus primarily on EPATS improvements, and another to focus solely on T105 construction improvements. The participants in each sub-team should only represent the functions that are the primary inputs to the deliverable in question.

5.1.1.3. Brainstorm changes

Each sub-team underwent a brainstorming exercise, focusing on changes that would speed the development of its narrow deliverable. The purpose of the exercise is to capture and document as many potential changes as possible in a relatively short time. The following guidelines were established to govern the incremental process improvement brainstorming sessions:

1. Start with the customer needs by visiting the end user of each process step.
2. Examine where parallel flow is possible, but if using preliminary information, identify the risk of rework.
3. Combine, eliminate, and reduce tasks.
4. Clarify mechanisms of passing information.
5. Reduce the total flow time.
6. Reduce feedback loops or try to do it more quickly through fewer layers.
7. Minimize queuing time.
8. Think about dealing with multiple customers at the same time.

5.1.1.4. Integrate and develop incremental preferred process

The preferred process that developed through this exercise encompassed many incremental changes to the existing development process. This section will attempt to describe the main improvements in cycle time, without delving too deeply into the details of the process.

Many of the specific process changes can be characterized by a shift from serial to parallel work flow and by improved communications. The focus on the receivable of each function identified the information needed to begin specific tasks within each function. The upstream functions could often pass a preliminary version of that specific information, thus allowing each function to start its planning and coordination activities much earlier.

The changes in the process that resulted in a more parallel work flow include:

1. The wiring development process starts with a series of cross-functional "kick-off" meetings to define the work statement and identify all the work that could be done immediately.
2. The wire design process begins immediately with red-lined schematics of the electrical system. Attempt to use customer furnished drawings as much as possible to eliminate the time required to transform them to Sikorsky drawings.
3. The EPATS designers immediately notify planners when there is enough preliminary data to start manufacturing planning.
4. Wire installation drawings or sticks are completed in parallel with the harness design.
5. Harness work orders are put into the MRP system as soon as they are identified as a requirement by engineering.
6. Manufacturing wire-cutting part numbers are defined immediately after the harness change order has passed through the Configuration Management Office (CMO).
7. Wire cutting work orders are put into the MRP system immediately after the manufacturing wire-cutting part number is defined.
8. T105 tools are constructed in parallel with wire-cutting.

The new preferred process greatly increased the use of preliminary data release. In cases where an integrated design of the entire helicopter must be developed, the upstream function releases a preliminary version from which the downstream function could begin its tasks. The challenge with preliminary releases is that the final version must be released later without causing much downstream rework.

5.1.2. Radical process improvements

The second effort undertaken by the DMC II, consistent with its "thinking out of the box" culture, was to introduce radical change by redefining the underlying model upon which the development process and its organization structure were based. Several brainstorming sessions were conducted within the DMC II which focused on more radical harness development process improvements. Most of the suggestions can be grouped into four main categories:

1. **Design-planning teams**: Reorganizing to focus more on end products rather than individual functions.

2. **Cross-training**: Spreading the work more evenly across each functional group and cross-training to allow specific tasks to be shared by more people.
3. **Design philosophy**: Developing a more modular design to reduce the amount of redesigns for each customer.
4. **3-D modeling**: Developing a 3-D model of the S70 to allow for more accurate and timely harness routing information.

5.1.2.1. Design-planning teams

The notion of design-planning teams was slowly gaining popularity within Sikorsky at the time of this study. Underlying this assumption, was the premise that the basic element of the development organization should more closely match the final product, i.e., the helicopter, rather than the different functions involved in the development process. The design-planning model was defined as consisting of a small cross-functional team that performed the entire harness development process for each derivative helicopter program.

This concept had its roots in much of the success that Sikorsky had with its Comanche Integrated Product Teams, which handled the cross-functional integration that was needed for its initial development. The underlying purpose of the design-planning team would be to provide an organizational tool to successfully implement a more parallel process flow. In order to change the working relationship between the functions, there had to be a fundamental shift in the focus and responsibility of the teams. What was still missing in the current organization was a focus on the end product. Between the two departments, Engineering and Manufacturing Engineering, there was no one person who had responsibility for the entire harness development process across all nine functions. Breaking the harness development process into smaller, cross-functional teams that perform the entire process and share ownership of every aspect of the final harness development was a means to address the needs of a short flow parallel process.

5.1.2.2. Cross-training

With dedicated teams of functional experts, there will always be periods where one group is busy while the next is not. In addition, when incremental release is not possible, there will always be spikes of work moving through each group in a sequential manner. The ability to work down the queue quickly is a function of how many people are available to work each kind of job. The work of Adler, et. al. suggests the importance of balancing workloads in a product development environment as a means to reduce cycle time.[27]

The concept of merging skills across functions raised resistance throughout the functional departments within Sikorsky. There were many reasons for this resistance. First, individuals within functions had required a significant amount of training to become competent in all aspects of their function. Senior employees had spent ten or more years developing their expertise. The idea that a single person could become an expert in more than one function seemed impossible. Also, the idea of merging functions and skills was extremely threatening because it implied that one or more functions could be combined, thus eliminating jobs.

5.1.2.3. Design philosophy

Another set of ideas generated in radical improvement brainstorming sessions suggested that a more modular wiring design, in which off the shelf solutions could be used for each customer, would have a clear effect on cycle time. This is equivalent of shrinking the size of each customer introduction by taking away a percentage of the jobs. This was an especially attractive idea since the existing development process frequently resulted in the revision of as many as 50% of the harnesses for each new customer.

The concept of modular design, however, contradicted the focus within the DMC II of satisfying customer requirements. Some of Sikorsky's customers were willing to pay the extra money for special features, and, consequently, would not have purchased the helicopter if they had been constrained by a set of standard options. Furthermore, the existing Electrical Planning and Tooling System (EPATS) used by Sikorsky did not lend itself to separating and merging individual harnesses to aid in their manufacture.

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[27] P. Adler, A. Mandelbaum, E. Schwerer, and Vien Nguyen, "From Project to Process Management in Engineering: An Empirically-based Framework for the Analysis of Product Development," Working Paper #3503-92-MSA, Sloan School of Management, 1992.

5.1.2.4. 3-D modeling

As noted in Chapter 4, one of the most effective ways to improve the quality of design and to reduce harness routing rework is to use 3-D modeling in the early stages of development. For Sikorsky the tradeoff, however, is the significant capital investment that must be undertaken to incorporate the S70 into a 3-D model. Without a clear definition of the future sales projection for the S70, it is risky to allocate the resources for such a capital investment. The use of 3-D modeling would further challenge the DMC II by requiring additional training to make engineers proficient in its use.

5.2. Integration of incremental and radical process improvements

An analysis of both the incremental and radical process improvement recommendations led to the same conclusion: in order to reduce development cycle time, the harness development organization must successfully implement a more parallel development process. To that end, the harness development organization must achieve the following goals:

1. Reduce the size and complexity of customer orders, by reducing the scope of the design and isolating cross-functional interaction within a single team.
2. Focus on the needs of the end product by fostering cross-functional cooperation driven by common metrics, goals, and schedules.
3. Provide better mechanisms for addressing rework, design iteration, and modular design.
4. Encourage cross-training and the evolution of the development process.

By the end of this research effort and the subsequent analysis of the benefits of the proposed changes, some members within the DMC II felt strongly that the design-planning team model could provide the basic organizational mechanisms needed to achieve aggressive cycle time improvement goals. And, if properly implemented, the use of design-planning teams would be a catalyst for additional benefits such as cross-training and modular design ideas. The next chapter will detail the proposal for the design-planning team structure that will create a more flexible and responsive parallel design process.

6. Implementation plan for Design-Planning Teams

This chapter, consistent with step 4 of the methodology, proposes an implementation plan for design-planning teams to meet cycle time reduction goals in the DMC II. The final plan reflects a combination of the incremental and radical process improvement proposals, and is founded on the underlying structure of the development process described by the "Rework Cycle." If implemented properly, the final, integrated plan has the best possible chance of success given the current systemic framework. The main elements of the plan include: the charter for the teams, the team breakdown, the new roles of the design-planning team members, and the management of the development process across the teams. A final proposal for the harness development organization structure will then be described. The material presented in this chapter is based on the many discussions that were required to define a feasible organization structure that achieves the goals of the design-planning team model.

6.1. Elements of the Design-Planning team structure

6.1.1. Charter

The charter of the design-planning teams defines the primary responsibilities and scope of the individual team, as well as the responsibilities that are shared across the teams. Each team owns the harness development within a given helicopter program. This ownership includes the following four responsibilities:

1. **Definition of Change:** Each design-planning team is responsible for determining all the required wiring changes for their customer order and scheduling its team members to perform all tasks required to deliver the required documents and releases to meet the manufacturing schedule. Each team must coordinate its design and work schedule with other design-planning teams to ensure downstream departments are not overburdened with peaks of work.

2. **Harness Design:** Each team is responsible for every aspect of the wiring design within the helicopter. This responsibility includes implementing all design changes, maintaining all documentation, delivering the final products that meet the manufacturing schedule, responding to and correcting any design defects, and meeting cost and quality targets. Each team is responsible for developing entire cost estimates from initial design to final installation and will be challenged to meet these estimates. This effort will require close interaction with both fabrication and installation technicians.
3. **Manufacturing Plan:** Each team must incorporate all design changes into the manufacturing plan, and provide liaison effort during fabrication and installation.
4. **Cross-training Plan:** Each team must switch roles on certain harnesses to ensure some level of cross-training is taking place. Furthermore, the DMC II harness development process owner will facilitate lessons learned among the different teams in the spirit of continuous improvement and best practices.

There are also some responsibilities that must be shared by all the design-planning teams. The requirement to spread tasks across the product teams is driven by the necessity to provide manufacturing with a single consistent product. Therefore, there must be standard parts, tools, and processes that are used across all the teams. Part of the charter of each team is to provide the resources and cooperation needed to properly integrate its activities with those of the other product teams.

6.1.2. Team composition

Each harness design-planning team should consist of the platform leader (preferably one with electrical or avionics background), at least one electrical EPATS designer, one manufacturing engineer, and one engineer familiar with production illustration (harness routing). Since most programs keep the same fabrication and installation technicians on the program from start to finish, it would be valuable to provide these individuals with frequent program updates and include them in all improvement brainstorming sessions. If a platform leader is selected who does not have an avionics or electrical background, it is important to put one of the more competent EPATS designers on the program.

6.1.3. Team roles

The goals and challenges of a product team are significantly different from those of the existing functional teams. All the original functional tasks must be performed, but the need to create a strong cross-functional team redefines the roles of all the team members. The existing hierarchy of supervisor, engineer, or technician will still exist but their roles become fundamentally different.

The best analogy of the new role of the platform leader is that of a coach. In this new team environment, the coach has to focus on the goals of the end products by fostering and maintaining close cross-functional cooperation within his or her team. This is especially crucial in a parallel process where functional targets and metrics are much less defined. The internal metrics that must be stressed in a product team are those that can be tied to the final product, such as the amount of rework across all functions and the design errors seen by manufacturing. To achieve vast improvements in those metrics, problem solving within the product team must focus on the systemic causes of errors, not by placing blame on individuals. The success of this cross-functional problem solving and continuous improvement will be dependent on the leadership of the coach.

6.1.4. Harness development management: Standardization and improvement

Moving to autonomous product teams has the potential to raise a number of questions about maintaining a consistent and common process throughout the entire harness development organization. It is imperative that the product from the platform teams remains consistent in detail and quality because each team is supplying a common customer, the harness shop and the installation technicians.

In addition to incorporating this need for standardization into the team charters, a Core Member of the DMC II is tasked with the responsibility to oversee quality and commonality throughout the entire harness development process. The basic concept of this position is to close the feedback loop between the needs of the manufacturing customers and the improvement efforts and goals of the product teams. Furthermore, this individual will be responsible for sharing best practices across teams and implementing a training development program for all team members.

6.2. Final proposal for harness development organizational structure

The cycle time reduction effort for S70 harness development within the DMC II resulted in a proposal for the matrixed structure depicted in Figure 6-1. It is considered a matrixed organization because each harness design-planning team is coached by both the platform leader and the DMC II harness process owner.

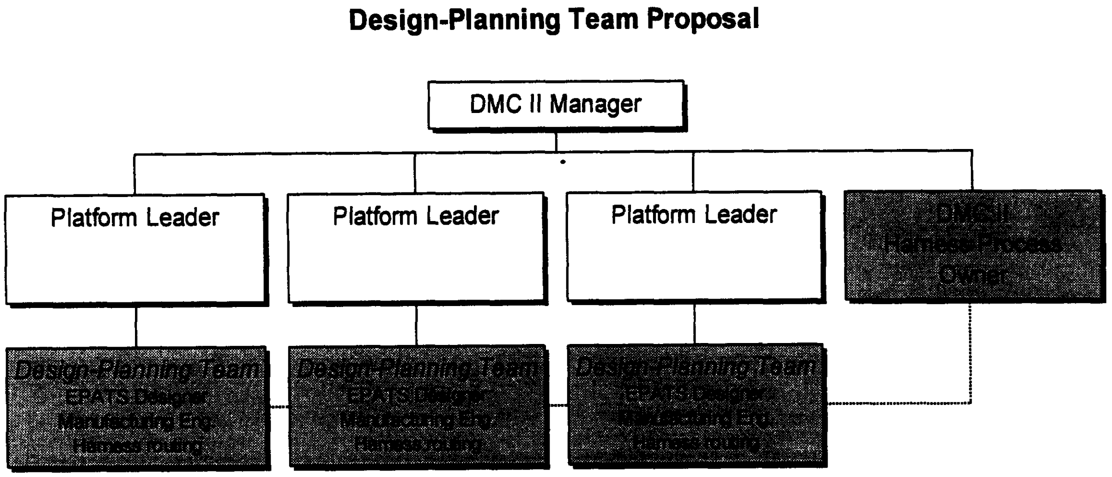

Figure 6-1: Harness Design-Planning organizational structure.

Both the platform leader and the process owner would be responsible for providing feedback to the teams on their performance and providing them with recommendation for improvement. It differs from the existing structure in that the harness design-planning teams carry more responsibility. As indicated in 6.1.1, each team now has a "cradle to grave" responsibility for their program as well as the responsibility to improve the entire harness development system, facilitated by the DMC II harness process owner. Overall, functional barriers in this structure have been minimized and emphasis has shifted away from non-valued actions such as protecting turf, to actions valued by the customer.

7. Organizational barriers to implementing Design-Planning Teams

In this chapter, I argue that the successful transition to design-planning teams within the DMC II will depend on the ability of management to lead a large-scale, difficult change effort in both the technological and social systems within the organization. Further challenged by the fact that this change will focus on the use of cross-functional teams in a downsizing environment.

In their work on the organizational complexities that create barriers to enacting design for manufacturing (DFM) principles, Liker and Fleischer identify an organization's goals, values, language, and symbols (what they term the organizational context) as an often overlooked, but critical source of opposition to the adoption of cross-functional processes like harness design-planning teams.[28] Their framework portrays the organizational context as a set of contingencies that influence the success of management's cross-functional programs. That is, the success of any cross-functional program like harness design-planning teams depends heavily on the support of the broader organizational context, and not just on the specific policies and practices which accompany the initiative.

This section will analyze organizational context barriers using the three-category framework (formal organization, political, and cultural) proposed by Liker and Fleischer. These organizational context barriers will then be supplemented in Section 7.4 by a list of some specific challenges that teams typically encounter. Together, they describe a vast array of organizational challenges facing management in its drive to implement cycle-time and cost reduction in the harness development process through the use of cross-functional teams.

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[28] Jeffrey Liker and Mitchell Fleischer, "Organizational Context Barriers to DFM," Integrating Design and Manufacturing for Competitive Advantage (New York: Oxford University Press, 1992): 135.

7.1. Formal organizational barriers

Functional boundaries still exist between the Engineering and Manufacturing Engineering organizations, and between the DMC and the DMC II. These rigid barriers exist primarily in order to facilitate the retention of functional expertise within strong, independent functional departments. Although the use of cross-functional teams has increased in everything from helicopter design to manufacturing process troubleshooting, these teams are essentially parallel, redundant structures in the organization.

The effectiveness of cross-functional teams is limited if they are not used within an organization with permanent cross-functional structures.[29] The absence of any permanent cross-functional mechanisms impedes the vital horizontal flow of communication required by the interdependence of tasks in the harness development process. The tendency to analyze and optimize only a specific, functionally-defined part of the process is encouraged by the rigid barriers between functions, as is the tendency to look vertically for solutions to difficult problems. Both present significant challenges for the DMC II harness process owner—a manager responsible for implementing a fundamentally cross-functional process.

7.2. Political barriers

7.2.1. Organizational politics

The implementation of harness design-planning teams in the DMC II could cause political tension between the Manufacturing Engineering organization and the DMC II. The use of politics in organizational decision-making is most likely to occur whenever five conditions are present: important decision issues, interdependence of responsibilities, conflicting goals, scarcity of resources, and diffuse distributions of power.[30] The implementation of harness design-planning teams within the DMC II satisfies all five of these conditions, and political resistance is expected to be strongest in those organizations positioned to lose significant amounts of power. The political

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[29] Ibid.

[30] Jeffrey Pfeffer, Power in Organizations (Marshfield, MA: Pitman, 1981): 32.

decision-making process is not inherently bad, and indeed can never be completely avoided within industrial organizations, but the end result of such a power struggle may very well be the subordination of the goals of the DMC II to those of the functional departments.

Harness design-planning teams will also cause political tensions between the Engineering and Manufacturing Engineering organizations. The historic separation between the two organizations has already been blurred substantially by the successful use of Integrated Product Teams (IPTs), and the implementation of harness design-planning teams will serve to further reduce the distinction between the two departments. Because that distinction was what allowed the two organizations to claim large amounts of organizational power, they will object to further encroachment on what they see as their organizational turf.

In transforming the structure of an organization, we do not have the luxury of recruiting a new staff to perfectly fill each slot. The most difficult task that the harness development organization faces is fitting the existing people into very new roles. This task is further exacerbated because it is being done in a downsizing environment. The difficulty in this fit lies in the numbers and the skills of the current workforce. The number of managers and team leaders may not match that of the new organization. In addition, the existing workforce may not yet have the skills to step into their new roles.

7.2.2. Career progression

It was argued above that to be effective, the cross-functional relationships required by harness design-planning teams must be more than just parallel, ad-hoc structures within the DMC II. But individuals facing permanent assignment to a cross-functional team are being asked to abandon well-defined functional career paths for something without nearly as much definition.[31] This uncertainty within individuals will manifest itself as an organizational reluctance to support the concept of cross-functional harness design-planning teams.

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[31] James P. Womack and Daniel T. Jones, "From Lean Production to the Lean Enterprise," Harvard Business Review March-April 1994: 95.

7.2.3. Layoffs

Like all defense manufacturers, the company which sponsored this research has been affected by the recent downturn in the defense industry. In 1996, during the time of this study, the organization was forced to layoff a portion of its workforce. It now maintains a workforce of roughly half of what it once had in the mid 1980s. Trying to obtain employee support for new initiatives during such difficult times is never easy. When combined with the observation that harness design-planning teams may result in further reductions in head count, obtaining the necessary employee buy-in will be challenging to say the least.

7.3. Cultural barriers

Cultural barriers represent a significant challenge for management because they may be difficult to identify, let alone address. Edward Schein defines culture as "a pattern of shared basic assumptions that the group learned as it solved its problems of external adaptation and internal integration, that has worked well enough to be considered valid and, therefore, to be taught to new members as the correct way to perceive, think, and feel in relation to those problems."[32] Using the framework and terminology provided by Schein, organizational members will tend to resist the adoption of harness design-planning teams because it directly attacks the validity of what has been done for several decades.

Schein also distinguishes between three levels of culture: artifacts, espoused values, and basic underlying assumptions. Artifacts are the visible products of the group, including such attributes as the architecture of its physical environment, language, technology, products, artistic creations, and published lists of values.[33] Espoused values are those perceptions held within the organization of what ought to be as distinct from what is. Espoused values will predict much of what happens at the level of artifacts, but care must be taken to distinguish between what organizational members say and what they actually do. The third level of an organization's culture, and the one which is most

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[32] Edgar H. Schein, Organizational Culture and Leadership, (San Francisco, CA: Jossey-Bass Publishers, 1992) 12.

difficult to change, are the shared basic assumptions. Basic assumptions are solutions which have worked repeatedly in the past and have been taken for granted by virtually all organizational members. Behavior inconsistent with these assumptions is simply considered inconceivable.

During the research period, I identified three significant cultural barriers to the implementation of harness design-planning teams. At the level of artifacts, using the framework provided by Schein, there exists a tangible sense in most members of the organization that their company is the dominant defense helicopter manufacturer in the U.S. and will be kept alive by the defense department. At the level of espoused values, an emphasis on meeting schedules has proven so successful in the past that many operations decisions are made with the sole intent of keeping the production line moving. Finally, and potentially the most problematic for the implementation of harness design-planning teams, the deeply-rooted emphasis on defense driven compliance issues.

7.3.1. Complacency bred by military helicopter industry

The company which sponsored this research has historically been a defense contractor. Their competitive advantage has always been their ability to produce quality rotory wing aircraft for the military. Barriers to entry in the military helicopter industry are significantly different than those on the civil side. Capital investment, design expertise, manufacturing capability requirements and market size all posed significant barriers for new firms seeking to enter the military helicopter business. Now, Sikorsky is placed in a difficult predicament as it attempts to shift its focus from the security of defense contracts to the commercial side of the helicopter industry. The question remains whether they can make a change like harness design-planning teams quickly and smoothly enough while there is still a prevailing sense of dissatisfaction with the status quo.

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[33] Ibid.

7.3.2. Emphasis on schedule

Meeting the scheduled delivery date has historically taken precedence over those activities designed to reduce the amount of rejection and rework in the manufacturing process. This focus on meeting schedule is found in every part of the organization, and results in shortage meetings, hot lists, quick-response action teams, and parts chasers. All were designed with the intent to keep the production line moving and to meeting schedule. The focus will need to shift from an emphasis on meeting schedule to eliminating non-value added tasks and rework. The DMC II has taken the first step in challenging its employees to do things quicker and easier.

7.3.3. Defense driven compliance issues

In order to be competitive in the military helicopter industry, Sikorsky had to design unique management systems. For example, the management systems had to provide for the extensive qualification and documentation required by both the Federal Aviation Administration (FAA) and the military. This detailed documentation allows for a failed part to be traced to the specific production lot. In the event of a structural failure after production, the FAA or military service is able to identify production lots and serial numbered parts which may be defective. This is only one example of the many unique management systems required for defense contractors. These systems have traditionally been quite dissimilar to the commercial helicopter business and have become part of the culture within Sikorsky. Changing these systems to be more responsive to the commercial buyers will be a continual challenge within the organization.

7.4. Typical problems that teams encounter

For design-planning teams to be effective, a certain degree of commitment from senior management must be placed on the development and nurturing of teams. Restructuring trends in industry over the past decade have emphasized the importance of eliminating barriers through the formation of teams. Vast research has been done in the area of teaming, and much has been documented as to what makes teams successful and not so successful.

Hamel and Prahalad argue that much of the discontent within industry over the use of teams is founded in how teams are used by companies. Hamel classifies organizations into two basic corporate "orientations." These orientations correspond to the numbers above and below the line in any fraction:

The top number, the numerator, he claims is a company's potential for growth, expansion, core competencies, and new products. He calls this "profit by doing." The bottom number, the denominator, is the bottom line—cost containment, downsizing, flattening, delayering, and dehiring. He refers to this as "profit on paper."

Numerator companies have a vision of growing and creating something new that did not exist before. Denominator companies typically take a more limited view, a zero-sum picture of mature markets that can never be expanded. As such, numerator companies embrace teams as a way to leverage growth, while denominator-oriented companies use the idea of teams to trim the workforce.[34] Both numerator and denominator approaches are legitimate, since most companies pursue both all the time. Hamel argues, however, that problems arise with teams when they are used primarily as a cost-cutting tactic. No team thrives on being left to its own devices, and when they fail it is typically because companies have used them solely as a means of trimming middle management, without giving the new teams the attention, vision, rewards, or clarity that they need to succeed.

Significant research has been done in the area of teaming. Table 7-1 summarizes the research of Finley and Robbins and highlights some of the symptoms and possible solutions to common teaming problems.

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[34] Gary Hamel and C.K. Prahalad, Competing for the Future (Cambridge: Harvard Business School Press, 1994).

Problem	Symptom	Solutions
Mismatched Needs	People with private agendas working at cross-purposes	Get hidden agendas on the table by asking what people want, personally, from teaming
Confused Goals, Cluttered Objectives	People don't know what they're supposed to do, or it makes no sense	Clarify the reason the team exists: define its purpose and expected outcomes
Unresolved Roles	Team members are uncertain what their job is	Inform team members what is expected of them
Bad Decision Making	Teams may be making the right decisions, but the wrong way	Choose a decision making approach appropriate to each decision
Bad Policies, Stupid Procedures	Team is at the mercy of an employee handbook from hell	Throw away the book and start making sense
Personality Conflicts	Team members do not get along	Learn what team members expect and want from one another, what they prefer, how they differ, start valuing and using differences
Bad Leadership	Leadership is tentative or inconsistent	The leader must learn to serve the team and keep its vision alive or leave leadership to someone else
Bleary Vision	Leadership has foisted a bill of goods on the team	Get a better vision or go away
Anti-Team Culture	The organization is not really committed to the idea of teams	Team for the right reasons or don't team at all; never force people to team
Insufficient Feedback and Information	Performance is not being measured; team members are groping in the dark	Crate system of free flow of useful information to and from the team members
Ill-Conceived Reward Systems	People are being rewarded for the wrong things	Design rewards that make teams feel safe doing their job; reward teaming as well as individual behaviors
Unwillingness to Change	The team knows what to do but will not do it	Find out what the blockage is and eliminate it
The Wrong Tools	The team has been sent to do battle with a slingshot	Equip the team with the right tools for its tasks, or allow freedom to be creative
Lack of Team Trust	The team is not a team because members are unable to commit to it	Stop being untrustworthy, or disband or reform the team

Table 7-1: Problems that teams typically encounter.[35]

Several of these problems were felt within the DMC II at varying degrees—some obviously more serious than others. For design-planning teams to be effective, several of these issues should be addressed and acted on quickly and decisively by management.

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[35] Michael Finley and Harvey Robbins, Why Teams Don't Work (New Jersey: Peterson's/Pacesetters Books, 1995) 13.

8. The DMC II process and its applicability to the construction industry.

This section identifies policies and procedures that the DMC II has adopted that have proven successful for its development projects. These policies and procedures are founded on concurrent engineering principles and include: overlapping responsibilities, unit reward and feedback systems, physical layout changes, redesigned work procedures, and cultivation of a sense of collective responsibility. These same ideas have wide sweeping applicability to the construction industry in general.

8.1. Concurrent engineering principles

The DMC II has attempted to eliminate traditional functional silos and create a new organization—a process complete department—able to perform all of the cross-functional steps or tasks required to meet customer's needs. To date, the DMC II has proven successful in the form of lower costs, shorter cycle times, and greater customer satisfaction.

"Concurrent Engineering," "Design for Manufacturing," "Simultaneous Engineering," and "Design for Constructability," and other similar phrases have progressively been used to describe the process whereby organizations have sought to achieve world class performance in design and manufacturing. Conceptually, the process of ensuring all constraints are considered in order to achieve a perfect product is very simple. In practice, it is extremely difficult. Many factors act to resist the achievement of a perfect product. In an environment where technical complexity is increasing and development costs are rising, the importance of "getting it right the first time" is stronger and the pressures for alternative and more effective management of the development process is critical. The collaborative work environment within the DMC II offers the prospect of achieving these desirable objectives.

Research has proven the benefit of a design process with considerable concurrent activity. Conventionally, activities can be viewed serially with one stage being completed before the next stage begins. There is an implicit assumption that no downstream activity impinges on the preceding activity. Each department signs off and passes responsibility on in isolation from the remainder of the product development process. Often times, changes introduced later in the process due to unanticipated problems will require additional redesign thereby slowing the entire process.

Moreover, when the impact of change late in the product development process is considered, it can be seen that such change is extremely expensive as depicted in Figure 8-1.

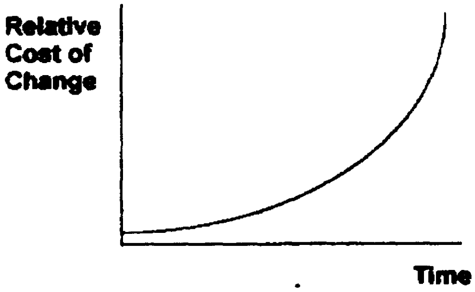

Figure 8-1: Cost of change profile for large projects.[36]

The logic for concurrent design is therefore one which, while promoting change and increasing management complexity during the early stages in the process, results in more robust designs with lower development costs overall. The research of Pearce and Bodnar has shown that, historically, some 85% of major design product programs have failed to meet their originally planned dates. And, of the 15% that do, some 80% of the changes occur in the last 15% of the planned program time.[37]

The purpose of concurrent activities is therefore to actually encourage changes to satisfy constraints from all interested parties early in the product development process. The total number of changes are likely to be the same in such a process, but the overall cost will be dramatically reduced as illustrated in Figure 8-2. More importantly, the resulting program is more likely to achieve its planned delivery date.

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[36] C.M. Pearce and A.A. Bodnar, "People and their Role in the Design Process," Transitions of Mechanical Engineering Vol. ME20 (1995): 261.
[37] Ibid. 262.

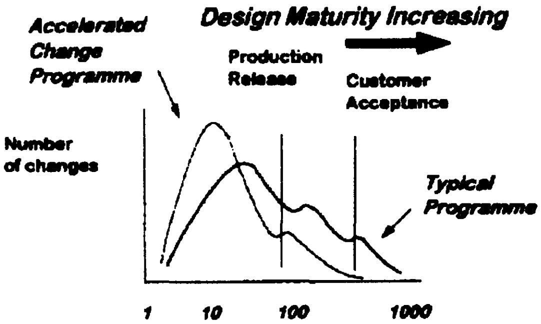

Figure 8-2: The effect of concurrent activities on overall project cost.[38]

This concurrent engineering process reinforces the notion of investing early to reap future benefits. This is a concept which is intellectually accepted by managers but which is not often accepted when faced with the reality of spend authorization and manpower constraints. Doing design concurrently can lead to higher up front design costs, although not necessarily more cost for the entire project. It is in the downstream processes that the benefits will occur.

In seeking to manage and introduce discipline to what could be considered an intrinsically ill-disciplined activity whereby all constraints are resolved simultaneously, the DMC II is taking on an enormously complex task—one that can be easily underestimated by someone not involved in the process. To aid them in accomplishing this task, the DMC II has attempted to build a collaborative culture among team members by focusing on overlapping responsibilities, team rewards, physical layout changes, and redesigned work procedures.

8.2. Overlapping responsibilities

The DMC II made responsibilities overlap by designing jobs with a relatively broad range of duties and by having a relatively small number of job titles. Moreover, it attempted to breakdown boundaries between positions by assigning people to multiple teams, by rotating assignments within teams weekly, and by holding unit wide meetings to discuss improvements to the process. Over time, I would expect virtually every DMC II Core Member to be able to perform most of the department's functions.

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[38] Ibid. 262.

Designing jobs so that employees can at least partially perform most of the functions assigned to a department helps create a shared sense of responsibility because people understand one another's work and thus share a common language and similar constraints and objectives. More important, if a process-complete department does not make responsibilities overlap, it will end up with a set of specialized jobs by default and may inadvertently re-create the same coordination problems and high overhead that challenge organizations with functional departments.

8.3. Rewarding team performance and providing constructive feedback

Rewards in the DMC II take the form of bonuses, raises, or nonfinancial recognition. Rewarding unit performance is important because it prevents team members from placing their individual or functional needs above customers' needs. For example, if employees are rewarded for reducing processing times at their individual work stations, they will probably not feel compelled to examine ways of reducing cycle times at the places between or outside their workstations. In contrast, employees rewarded for achieving high levels of customer satisfaction or reduction in the department's total cycle time are more likely to be motivated to solve what they traditionally would consider other people's problems.

Progress measurement and sharing were key items that kept the team spirit alive within the DMC II and formed a common language for measuring effectiveness. Everyone within the organization concentrated on what was measured, therefore it was important for management to carefully select those metrics which were relevant both to the team players and to the customer. Since changes initiated before hardware was committed was so much cheaper in overall terms to the program, emphasis was placed on the number of design changes as a key criterion to be measured. This obviously had a direct impact on the magnitude of rework and how frequently work iterated through the "Rework Cycle."

8.4. Changing the physical layout

The layout of a work site can either inhibit or promote collective responsibility. Layouts can encourage people to share information about one another's work and try out new ideas openly. Special areas for continuous improvement and places for teams to sit and discuss problems were crucial to team interaction within the DMC II. Such areas contained data relevant to all the projects, as well as the tools for documenting, analyzing, designing, and sometimes even building prototypes. This type of area made it easier for people to analyze problems together, build prototypes, and discuss their individual and group-developed ideas.

Besides making changes in the physical layout of the facility, the DMC II made significant use of information technology to coordinate the activities of group members. Automated mail systems, calendars, and shared databases made for the timely and efficient transfer of critical information.

8.5. Redesigning work procedures

It was critical that the manager of the DMC II asked employees what they needed in order to work well together. Moreover, it was equally as important for management to recognize the constraints and possibilities provided by the existing technology, the work process, the existing organizational culture, and the organization's strategic mission. The DMC II's formal and informal work procedures encouraged team members to do the following three things: share ideas for improvement with people in other disciplines, involve everyone affected by a decision in making that decision, and help others to do their work even if it caused their own productivity to suffer. Overall, management made themselves readily available for informal discussions on improvements to work procedures, and team members generally felt as though they could discuss problems freely with management.

8.6. Cultivating a sense of collective responsibility

The future success of the DMC II, will be strongly tied to how well managers create a collective sense of responsibility. Restructuring by process can lead to faster cycle times, greater customer satisfaction, and lower costs, but only if the organization has a collaborative culture. Combining the boxes on the organizational chart alone will not create such a culture. Overall, within the DMC II, the message came through clearly that management considered collaboration extremely important, however, cultivating a sense of collaboration with employees accustomed to their functional lifestyles remained challenging.

Today, as the DMC II continues to grow, it is confronted with how to socialize new workers into the DMC II process to ensure a sense of collective responsibility within the organization. Moreover, as the size and complexity of the DMC II grows, key engineering team leaders are forced to spend more time managing and less time on value added engineering tasks. A key determinant of the future success of the DMC II will undoubtedly be its ability to quickly socialize new members into the collaborative culture within the DMC II. It is crucial that management does not underestimate the actions required to transform the way employees behave and work with one another. Simply changing an employee's work location from a functional unit to a process-complete department will not cause them to shed their functional mind-sets and integrate them into a team intent on achieving common goals.

Sparing, but thoughtful use of training had a beneficial effect within the DMC II and proved to employees that they were valued by the organization. Training also helped to break tensions by establishing stronger relationships among new and existing team members. Platform leaders played a crucial role in the DMC II process and the organization recognized the importance of developing their skills to manage projects more effectively. The organization also recognized that there could be no substitute for experience in the platform leader role and made every effort to develop young leaders by rotating them through these positions. Company financial incentives to pursue advanced management and engineering degrees were also used as a means to encourage self-development and improve the overall competitiveness of the organization.

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