The Project Management Function in a Joint Development Program

by

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

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Abstract

The management of large-scale system development has become increasingly difficult as the complexity of the systems has increased over time. The structure of the project team has become more complex as well with the increasing reliance on joint program structures. The helicopter industry provides two excellent examples that can be studied to understand the impact of complex program structures on project management. The RAH-66 Comanche is a new armed reconnaissance helicopter being developed jointly by Sikorsky Aircraft and Boeing Helicopter for the U.S. Army. The S-92 Helibus is a new medium civil transport helicopter being developed by Sikorsky Aircraft and five international partners. These two programs provide the frame of reference needed to study various methods of project management in a joint development program structure. A comparison of Department of Defense versus commercial joint programs identifies the challenges that are presented to an organization confronted with supporting both types of project structure. Particular emphasis is placed on global commercial projects, as industry trends indicate that this type of development will become increasingly prevalent in the future. A system dynamics model is used to introduce the concept that project management activities can be cost effective if they improve initial quality and reduce rework discovery time.

The project manager requires sophisticated methods to profitably develop new products to meet the requirements of a discerning customer. A functional decomposition is used to determine the requirements of project management. The functional decomposition identifies the highly coupled nature of the project management requirements. Current and proposed new methods are identified and compared with the functional requirements identified in the decomposition. An evaluation of the methods is performed to determine their suitability for meeting the identified project management requirements. The methods identified fail to address the coupled nature of the project management functional requirements. A dynamic business plan is proposed as the required project management method. The lack of project management method and skill development within the organization is identified as an inhibitor of the successful implementation of project management methods. A functional resource for project management is proposed as a means to overcome this limitation.

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I am indebted to Joyce Warmkessel, my thesis advisor, for her willingness to help me extract something meaningful from my work and school experience.

I would like to thank my children Christopher and Kate for giving me the inspiration that hope for the future brings. Having gone through this experience, I will be able to tell you to do your homework without any feelings of guilt as I lie on the couch watching ESPN.

I would like to express my appreciation to my parents for their love and support. Dad, you have always been a hero to me the way you have lived your life. Mom, you have always been there when I needed a new direction and I didn't want to admit it. I love you both very much. Thank you for being my biggest fans.

I cannot begin to describe the feelings of love, respect and admiration that I have for my wife Lori and what she has accepted so gracefully over these last two years. We started our adventure together in January 1997 driving around Back Bay on our fifth wedding anniversary trying to find take-out food. While attempting to open our celebratory bottle of wine without a corkscrew, we sprayed half the bottle on my shirt and all over the kitchen. Of course, it was all smooth sailing from there. I am still amazed and grateful that you agreed to go along with my insane plan for our family to be together during the semester in Boston. It made such a difference in our lives. Thank you for all of your support and for believing in me, I could not have done it without you. I'm sorry that you have to go back to work now.

I almost forgot to thank my dog Adelaide for sleeping so peacefully by my side through the entire two years. We've been through a lot together.

Lori, now that I am finished, I have one request. Can I please have a few weeks off before I have to start the next program?

Biographical Note

The author attended the University of Virginia where he received a Bachelor of Science in Mechanical Engineering in August of 1979. The author was awarded a Fellowship to pursue a Master of Science in Mechanical Engineering.

During the summer of 1979, the author was selected to participate in the summer program at the Boeing Commercial Aircraft Corporation where he contributed to the preliminary design of the Nose Landing Gear Steering Installation for the 757.

The author started work at Sikorsky Aircraft as a Rotor Systems Design Engineer in August of 1980. He was the lead engineer for the development of advanced composite rotor systems for two of Sikorsky's production line aircraft.

In January of 1986, the author transferred to the Advanced Design and Business Development Group working as a Preliminary Design Engineer. He was primarily involved with the preliminary design of the RAH-66 Comanche Helicopter and became responsible for overall design integration of this advanced attack helicopter which is being developed by a joint venture of major defense contractors including Boeing, Lockheed Martin and Westinghouse under contract with the U.S. Army.

In March of 1994, the author transferred to the S-92 Program where he is a product development team leader responsible for overall design integration of the S-92 Helibus, a medium civil transport helicopter being developed by a joint venture of five international partners for year 2000 certification.

The author has been awarded eight U.S. Patents relating to helicopter rotor systems and the overall design configuration of helicopters.

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Chapter 1 - Introduction

1.1 Introduction

Within the aerospace industry, the management of large-scale system development has become increasingly difficult as the complexity of the systems has increased over time. The structure of the project team has become more complex as well with the increasing reliance on joint program structures. Military programs now typically require 10 to 15 years from conceptual design to initial operational capability. A typical project manager's career will see only two or three new aircraft programs from start to finish. Unlike the prior generation, current product development leaders will be unable to build an experience base by designing and building a new aircraft every few years. Project managers will have to learn from new techniques developed in other industries, extract and apply new methods from the academic world, and carefully identify and preserve lessons learned from existing programs. The project manager requires increasingly capable methods to profitably develop new products to meet the requirements of a discerning customer.

Project management in the context of this research is defined to include activities within the project and between the project and the project environment, which includes the larger organization, suppliers and customers. This definition encompasses both technical and business functions and is defined broadly in order to capture all aspects of project management. The complex systems that the research addresses are systems comprised of components that are themselves systems and whose component interfaces and interactions are highly coupled. A joint program structure refers to projects that share development of the basic architecture of the product among partners as opposed to traditional program structures that consist of a primary product developer contracted with suppliers who develop components of the product. The difference between joint project partners and traditional suppliers is the complex nature of the partner products and the close coordination required between the partners. Thus, the development of complex products using a joint program structure represents a unique challenge for the project management discipline.

Sikorsky Aircraft has experience with the development of complex products using a joint program structure. The RAH-66 Comanche and the S-92 Helibus are the first new aircraft developed by Sikorsky in the last twenty years. These two programs share many common features but differ in important ways as well. While both are joint development programs developing new aircraft from a blank computer screen, the customers and the funding for these two programs present unique challenges. The RAH-66 Comanche is a Department of Defense (DOD) funded project developing an attack helicopter for the US Army. The S-92 is a company funded commercial venture to develop aircraft for a wide variety of international customers. By comparing and contrasting the Comanche and S-92 programs, insights can be developed leading to improvements in current project management methods which are effective in the context of joint projects.

With reduced funding available from the Department of Defense, companies are increasingly looking to international joint development programs as a method to develop complex and expensive new products. These project structures involve a lead developer teamed with a number of international partner companies that share non-recurring cost initially and revenue eventually. The customer relationship is also an important difference between commercial and DOD projects. While DOD projects develop a product for a single highly sophisticated customer, commercial projects must satisfy many different international customers with potentially widely different operational requirements. Thus, both from a project and a customer perspective, the international joint development project places unusual demands on the project management team. Supporting both joint development project structures within a single organization may represent a particularly difficult challenge given the organizational demands of each project type.

Improved project management methods are required to minimize time to market and product cost, while maximizing product quality even as product and project complexity increases. Typically, project management is viewed as a task that integrates the activities of other functional disciplines such as engineering, manufacturing and finance. This view has perhaps contributed to a reduced emphasis on the development of project management methods and skills as compared with the development of methods and skills that support the functional disciplines. Organizations are confronted with the challenge of introducing new methods addressing the increasing complexity of products and project structures into the organizational mix depicted in Figure 1-1.

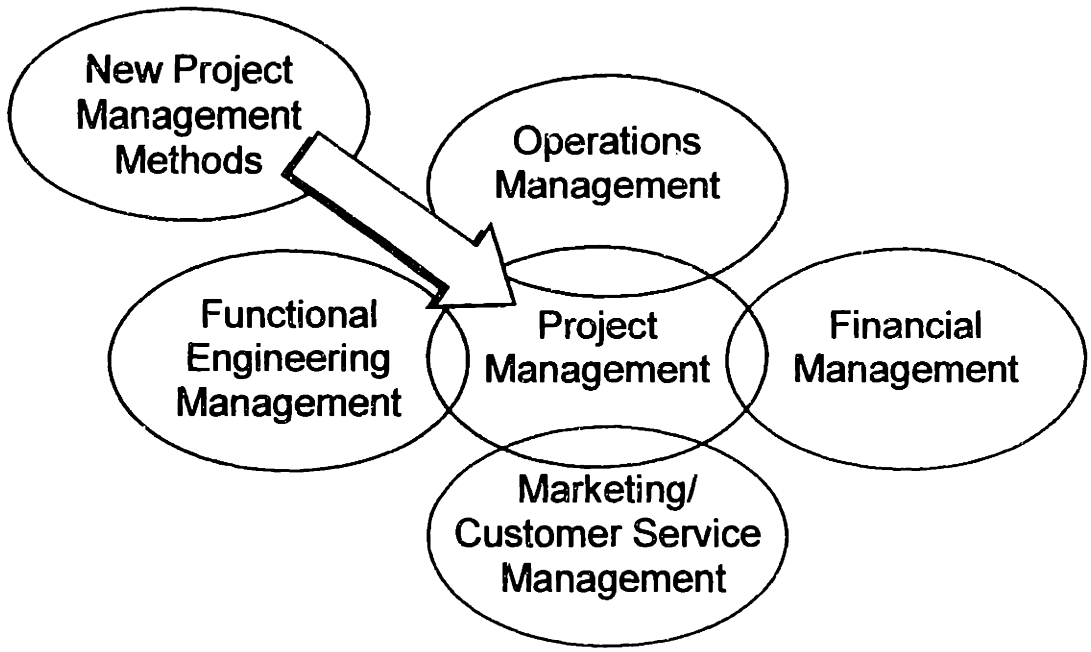
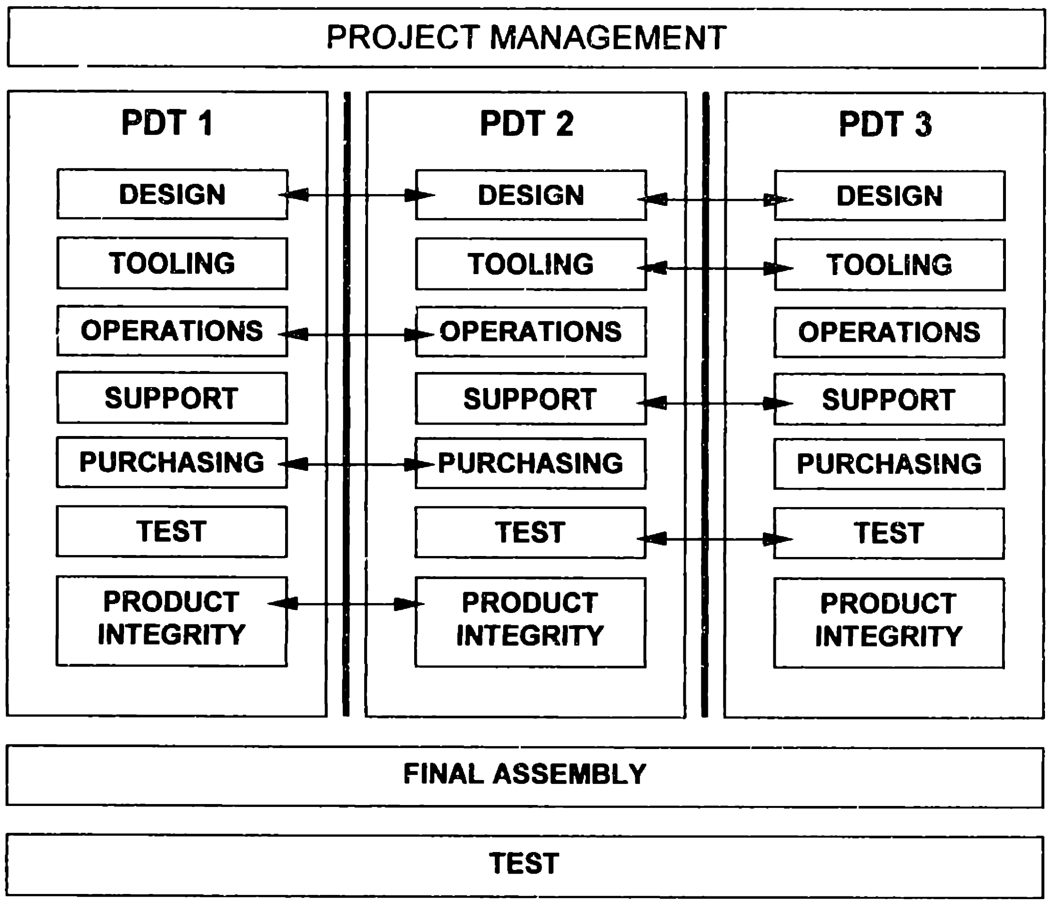


Figure 1-1. Introduction of New Project Management Methods.

The focus in much of the current product development literature concerns the implementation of Product Development Teams (PDT's) and better approaches for vertically integrating product development activities. Vertical integration in this case refers to concurrent design, manufacturing, and product support to ensure that the product is both producible and maintainable. On a complex product development program, PDT's can be extremely effective at executing the development of a well-defined product, which is actually a component within the complex system.

The PDT's can experience difficulty however when changes at the system level lead to changes in the product definition which are outside of the PDT's control. With the increasingly capable methods assisting the PDT, sources of costly rework as a percentage of total program cost can increasingly be a result of system definition issues that require the input to the PDT to change in a significant way. The interactions among PDT's require coordination between teams at multiple levels as shown in the figure below.

Figure 1-2. PDT Interaction.



While PDT's are effective at promoting communication within the team, significant interaction occurs between teams in a complex product development. These interactions can be a source of additional rework on the project. Therefore, it is appropriate to focus on a stronger project management function and evaluate what methods would enable the development of complex systems in a complex project structure for the minimum cost and schedule investment.

The thesis is organized as follows. Chapter 2 introduces joint development programs in the aerospace industry and reviews the RAH-66 Comanche and S-92 Helibus programs in detail. The complexity of the commercial international joint development project structure is evaluated using the S-92 Helibus as an example. Chapter 3 expands on the analysis of the joint program structure comparing and contrasting the DOD joint project structure with the commercial joint project structure. A project framework is introduced which allows the interactions between project phases and between PDT's to be identified as an interface that can have a significant impact on the success of the project. A system dynamics model is used to show the importance of project management activities focused on improved initial quality and reduced rework discovery time to the success of a complex project.

Chapter 4 includes a functional decomposition of project management and an analysis identifying the degree of interaction between the project management functions. Project Management methods are reviewed in Chapter 5 with emphasis on identifying which methods are effective addressing the functional requirements of project management. In Chapter 6, new project management methods are introduced and evaluated considering the shortfalls of the existing methods. An integrated method is proposed to address the inability of existing tools to effectively deal with the highly coupled nature of project management. Chapter 6 concludes with a suggested organizational structure that provides a functional resource home for the development of project management methods and skills, supporting the need for sophisticated project management in complex project structures. A summary is presented in Chapter 7.

Chapter 2 - Overview of Joint Development Programs

2.1 Joint Development Programs

In the aerospace industry, joint development programs are defined as projects that share the development of a complex product among project partners. The resulting aircraft establish new platform architectures that are the basis for many years of derivative development. Partners differ from suppliers in that the partners in a joint program structure develop products that are core to the basic architecture of the aircraft. Interfaces between partners tend to be highly coupled requiring close coordination among the partners. Joint development programs are typically undertaken when the magnitude of the project exceeds the resources (either human or financial) available within a single company.

Joint development programs are becoming more prevalent throughout the aerospace industry. This is particularly true for large development programs funded by the Department of Defense. Recent examples of joint military programs in the aerospace industry are listed in the figure below.

Figure 2-1. Department of Defense Joint Development Programs.

Program	Customer	Aircraft Type	Program Partners	
F-22	US Air Force	Air Superiority Fighter	Lockheed	Boeing
V-22	Marine Corp	Tilt Rotor Transport	Bell	Boeing
RAH-66	US Army	Armed Reconnaissance Helicopter	Sikorsky	Boeing

The joint structure of these programs has been required by the Department of Defense in an effort to maintain a broad development base for aircraft programs that are so large that they represent a significant percentage of the total new development in the industry. The partners on these programs are leaders in the industry who are fully capable of developing aircraft on their own. Typically, a Joint Program Office (JPO) is established to serve as the primary interface to the customer and to consolidate funding and technical issues. Employees from each of the prime contractors make up the JPO staff.

The civil aerospace industry has also seen a recent trend towards joint development programs although these programs typically have a different structure and purpose than the DOD programs. Examples of joint development in the civil sector are listed in the figure below.

Figure 2-2. Commercial Joint Development Programs.

Program	Lead Developer	Aircraft Type
777	Boeing	Civil Airliner
S-92 Helibus	Sikorsky	Transport Helicopter
BA-609	Bell	Civil Transport Tilt Rotor
Global Express	Canadair	Business Jet

These programs typically adopt a structure in which one company is the lead partner and partner companies are selected to participate in the project to spread the development cost and assist with market entry. The joint structure can also minimize the peak manpower and resource requirements at a given company during the detail design phase of the project. These programs also have a distinct global aspect to them as many of the partner companies are selected to provide access to international markets since domestic markets are not large enough to ensure the success of the project.

Sikorsky Aircraft has experience with both DOD and commercial joint development programs. The RAH-66 Comanche program is typical of the DOD structure while the S-92 Helibus program is representative of an international joint development program in the civil aerospace sector. Project management in the context of a joint development program highlights the issues with the management of complex product development that are not so apparent in simpler program structures. The RAH-66 Comanche Program and the S-92 Program can provide a useful framework to evaluate modern project management techniques leading to recommended approaches for future implementation.

2.2 RAH-66 Comanche Program Overview

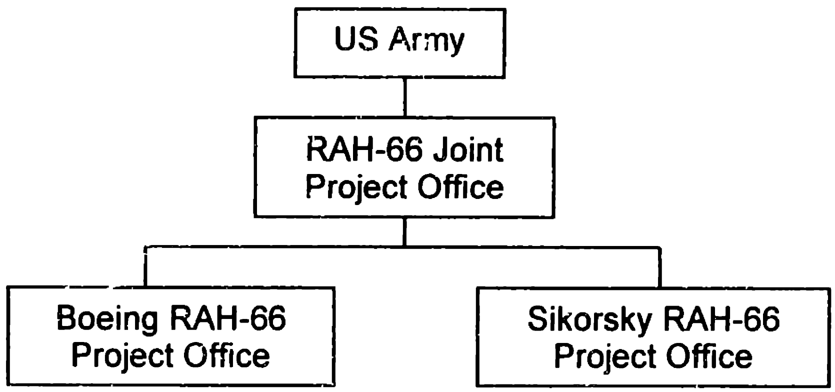
The RAH-66 Comanche Program is a US Army funded development of a new reconnaissance light attack helicopter which will replace the current light helicopter fleet which has now been in service for 20-30 years. This program is the first military helicopter development program since the AH-64 Apache which was designed in the 1970's. Originally, the program included the requirement for a utility transport helicopter as well as the reconnaissance/attack configuration. Total production was forecast to be over 6000 aircraft, easily the largest helicopter program ever. As a result of the enormous scale of the original program, the Army mandated a teaming arrangement among the four major US helicopter manufacturers. Boeing Helicopters and Sikorsky Aircraft joined together to form one competing team while Bell Helicopter and McDonnell Douglas formed the other team. Assessing the relative strengths of each team, the Bell and McDonnell Douglas team had produced between them virtually the entire light helicopter fleet as well as all of the attack aircraft currently in service. By contrast, thc Boeing Sikorsky team has produced almost exclusively larger transport aircraft, the smallest of which is roughly 50% larger than a typical light helicopter.

The program grew out of requirements definition studies that began in the early 1980's. Various configurations were developed at the conceptual design level in order to refine the operational requirements for the aircraft. The aircraft was originally designed to combat an invasion of Warsaw Pact forces into West Germany. This operational scenario drove many sophisticated aircraft requirements such as low observable signatures (radar, infrared, aural); survivability in nuclear, biological and chemical warfare environments; all-weather and day/night capability.

At the conclusion of the study contracts, a 16-month Demonstration/ Validation Phase contract was awarded to the two teams with final selection of a single team awarded based on competitive proposals. During this period, preliminary design for the helicopter was conducted based on the outcome of an elaborate trade study process which included operational effectiveness models that were used to select the optimal system within the stated cost and weight constraints. Contract award to the Boeing Sikorsky team occurred on April 12, 1991.

After contract award, a new phase of the program began, shaped by the contractual requirements imposed by the customer, which required the use of Product Development Teams (PDT's) to develop the air vehicle from the preliminary design configuration to the final production configuration. Also, at this time a Joint Program Office (JPO) was formed to be the collective interface between the customer and the Boeing-Sikorsky Team.

Figure 2-3. RAH-66 Project Structure.



Other important initiatives instituted by the customer included co-locating Army pilots and maintenance personnel on-site to provide the voice of the customer to the design teams. Another new concept introduced at this time was the extensive use of three-dimensional (3D) design based on solid modeling. A formal system engineering approach was also a contract requirement. This included elements of requirements definition and flowdown, the creation of weapon system segments and segment specifications, and a risk management program.

The prime contractors shared development of the aircraft by establishing lead responsibility for each aircraft system and statement of work item. Sikorsky was responsible for the forward and mid fuselage sections of the aircraft. Boeing was responsible for the aft fuselage, the rotor blades, and the Mission Equipment Package including the Target Acquisition System.

The Comanche Program followed a thorough product development process dictated by each contractual phase of the program. Conceptual design was performed during the early study contracts which selected the conventional helicopter as the best technical approach for the mission and established weight and cost targets for the aircraft. The preliminary design phase was conducted primarily during the DEM/VAL contract and during the first period following downselect up through the Preliminary Design Review in January 1992. The detail design phase followed PDR and the Critical Design Review was held in the spring of 1993. Component fabrication began concurrently with the completion of detail design and culminated in final assembly of the aircraft in the summer of 1995. First flight of the Comanche was January 4, 1996.

Designing a helicopter is by definition an exercise in compromise. In order to meet the performance objectives for the aircraft, a delicate balance was maintained between capability and the two primary constraints of weight and cost. The trade study process was adopted as a method for decision making and this proved particularly successful. Using this process, all approaches for meeting a requirement were considered equally and the approach that maximized the operational effectiveness of the aircraft after consideration of all weighted factors was selected.

A rigorous system engineering process was used to perform the flowdown and validation of technical requirements. Compliance with the aircraft system specification was a contract requirement. In order to ensure full compliance, each technical requirement of the system specification (literally thousands) was assigned an individual identification number and compliance with each requirement was verified throughout the detail design process. Air vehicle segments (Airframe, Mission Equipment, Armament, Flight Controls, for example) were established as lower tier elements of the weapon system and a matrix established the relationship of system specification requirements to the segments. Individual segment specifications were written and a weapon system design document was created which contained a description of the method of compliance with the segment specification requirements. At the critical design review, a complete assessment of all requirements was conducted identifying any areas of non-compliance and associated recommendations to gain compliance. As testing was performed, correlation between the testing and the requirements was maintained to systematically demonstrate validation. Another aspect of the system engineering approach was the risk management program that identified key areas of program technical risk and required detailed risk management plans for each area.

Overall, given the complexity of the product, the program has been relatively devoid of significant technical setbacks that have added significantly to the development cost and schedule. Final assembly and test of the product have been extremely successful to date. Due to financial restructuring of the program, certain sub-systems have yet to be developed and tested, so a final determination of the success of the project cannot be made at this time.

2.3 S-92 Helibus Program Overview

The S-92 Helibus is a twin engine, medium transport helicopter designed to meet the needs of a variety of commercial and military customers. The aircraft is to be certified to unified FAA and European JAA certification criteria. The S-92 architecture is adaptable to different customer configurations on a common assembly line.

The initial premise for the S-92 program was to marry the proven reliability and performance of the successful Sikorsky BlackHawk series of aircraft with the improvements available from state-of-the-art materials and manufacturing processes. The gains provided by these advances were targeted to provide a larger cabin aircraft capable of exceeding all customer expectations. A need existed for an aircraft that would be a force multiplier in regional conflicts, would meet the financial and regulation-driven requirements of a commercial replacement market, and would also be capable of entering the emerging markets of mass transit in the large formerly socialist countries.

Marketing studies in this time frame identified the need for replacement of the successful S-61 commercial helicopters that Sikorsky had produced in the 1960's and early 1970's. These aircraft, used predominately in offshore oil support missions were nearing the end of their useful lives, and new regulatory requirements were gong to make them financially unattractive to operate. Basic requirements for a replacement for the S-61 were identified with a panel of commercial operators. Parameters such as cabin size, range, baggage volume, operating cost, and price were defined. Customer involvement contributed to a design requirement characterized by lower acquisition cost, lower operating cost, and improved performance when compared to all currently available comparably sized aircraft. Marketing studies also identified a significant international market for an aircraft capable of performing military transport missions.

Preliminary design for the S-92 began based on the customer input. Marketing data continued to indicate that the S-92 market consisted of a wide range of potential customers each requiring unique option provisions on the aircraft. These requirements lead to the incorporation of "build to order" techniques that would enable a wide variety of S-92 configurations to be built on a single assembly line. This S-92 configuration received public program launch approval from the United Technologies Corporation Board of Directors in 1995.

The advent of three-dimensional digital design, proven on the RAH-66 Comanche program, enabled a project team structure that could design and build modules of the aircraft at widely spread geographic global locations. This capability allowed the formation of an international consortium to share the investment, which was an essential element of the business plan as there is no US Government funding of the program. Sikorsky, with its extensive helicopter experience, formed the nucleus of the international consortium of partners. All consortium partners share:

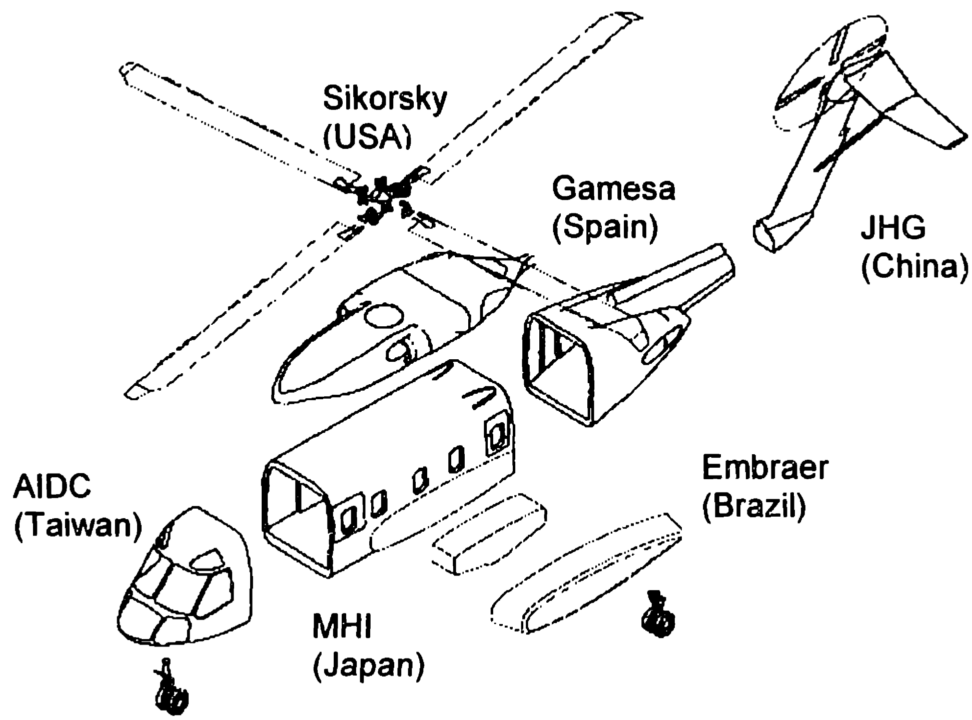
1) A commitment to fund the development activity assigned to them
2) A broad base of experience in developing and building aircraft
3) The ability to conduct the detail design in the three-dimensional electronic media.

All of 1994 and the early part of 1995 were spent in developing the partner relationships.

The S-92 Program partners are as follows. The figure below depicts the partner products.

- The Aerospace Industrial Development Corporation in Taichung, Taiwan, the Republic of China is responsible for the cockpit.
- Mitsubishi Heavy Industries, Nagoya, Japan is providing the main cabin.
- Gamesa Aeronautica, Vitoria, Spain is providing the tail cone/transition section, the top deck fairing structure including engine nacelles, and the composite interiors.
- Embraer, San Jose dos Campos, Brazil is providing the sponson structure complete with fuel system along with the landing gear.
- The Jingdezhen Helicopter Group, Jingdezhen, People's Republic of China is providing the vertical tail and horizontal stabilizer.

Figure 2-4. S-92 International Partners.

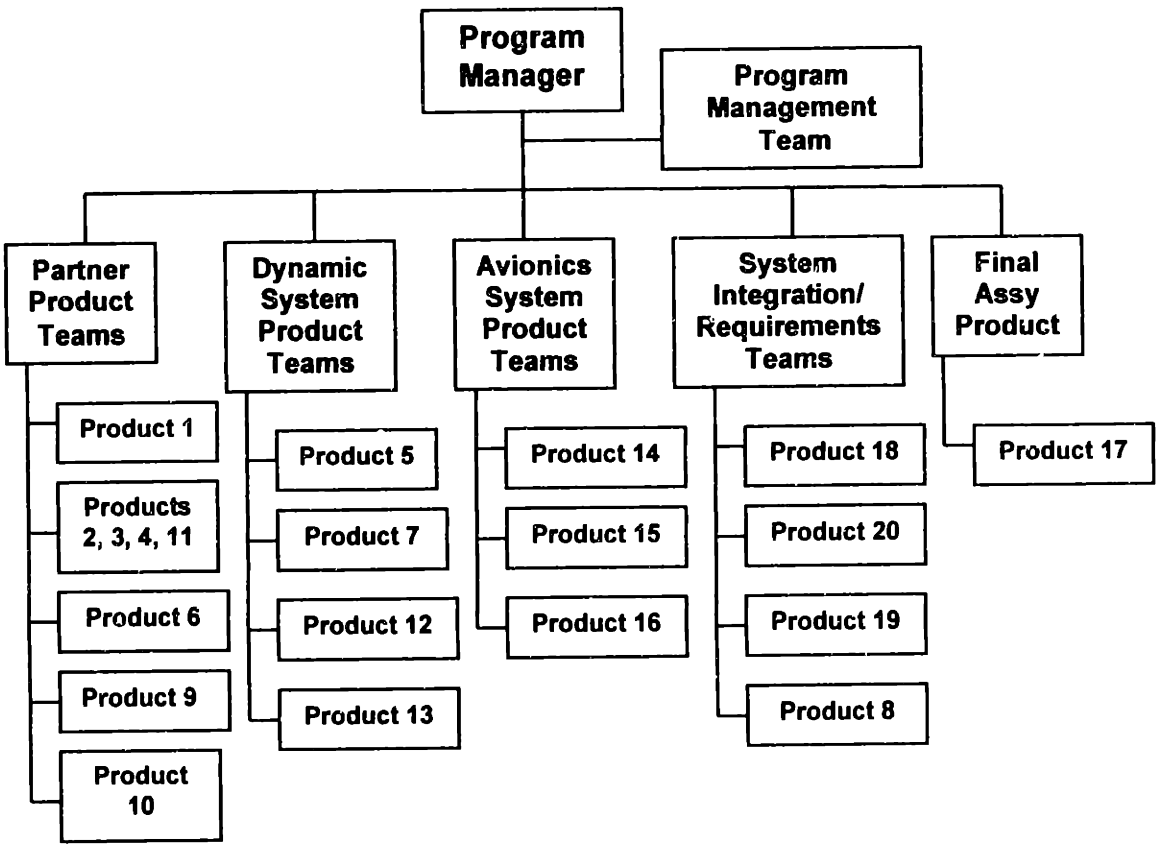


Sikorsky Aircraft will provide the avionics systems, and dynamic systems (rotors, transmissions) and serve as the system integrator and manager through final assembly, ground and flight test and certification by both the American Federal Aviation Association (FAA) and the worldwide Joint Aviation Authorities (JAA).

Sikorsky Internal Research and Development (IR&D) funds are assisting S-92 development. The S-92 will consume 80-90 percent of the company's IR&D funding from 1995 through 1999. The magnitude of this investment at the expense of improving other products makes the S-92 a significant undertaking for the company. The success of the S-92 would continue Sikorsky's global leadership position in the production of large helicopters. This position has been established through development efforts funded by government military contracts. The S-92 Program is unique due to the fact that the international partners are contributing approximately 25% of the development costs. The partners are interested in technology and skill acquisition as well as revenue from the sale of S-92 products. The contractual relationships with the partners are bilateral agreements between SAC and each investment partner and are not structured as a joint venture.

The S-92 Program is organized using Product Development Teams. The organizational structure is depicted in the figure below. The teams are grouped together into Partner Product Teams, Dynamic System Product Teams, Avionics System Product Teams, and System Integration Product Teams. These product team groups each report to a Deputy Program Manager who facilitates coordination among the teams comprising the product team groups. The Deputy Program Managers report to the Program Manager along with the Program Management Team. The Program Management Team includes representatives from various functional disciplines such as Manufacturing Operations, Customer Service, and Finance. These functional representatives provide senior leadership and a communication path to the functional department management. The Program Manager reports directly to the President of Sikorsky Aircraft.

Figure 2-5. S-92 Helibus Organization Structure.



The Partner Product Teams are located on site at the five international partners and each has responsibility for a section of the airframe structure along with varying degrees of installed subsystems (wiring and plumbing for example). A team leader for each partner resides at the partner facility and is responsible for all aspects of the interface with the partners including the technical and schedule performance along with negotiation of cost adjustments. Assisting the Partner Team Leader is a small team of Sikorsky personnel consisting of an individual from design, manufacturing, and product integrity.

The System Integration and Requirements Teams perform a collection of activities that span individual product teams. Examples of these activities include configuration management, system-level attributes such as weight and performance, test, and the partner interface function that includes the oversight of partner design and structural analysis. For each partner, the System Integration Team includes a point of contact responsible for coordination of the interface, ensuring the partners' voice is heard in daily interactions within the project office and ensuring that the communication from Sikorsky is effective and consistent. The Final Assembly Team is responsible for the activity associated with assembling the Partner products and installing the various subsystems to form the completed air vehicle.

The grouping of product teams under the Deputy Program Managers was designed to provide closer coordination among teams that interfaced frequently compared with the rest of the project organization. In order to identify the level of interaction among the various teams, the project teams are shown as both a row and a column in a matrix. The teams are grouped in the diagram according to the organization structure shown in the previous figure. The degree of interaction is reflected by a scale from 1 to 3, with 1 being the highest level of interaction. An empty cell reflects a lack of significant interaction. This matrix is shown in the figure below.

Figure 2-6. S-92 Product Team Interaction Diagram.

	Group	Partner								Dynamic Systems				Avionic Systems			Integration/ Requirements				
Group	Product Team	1	2	3	4	11	6	9	10	12	13	5	7	14	15	16	18	8	19	17	20
Partner	1. Cockpit			3	2		2					3	2			1	1	3		2	2
	2. ATT			3			2		2		3	3	3			2	1			3	3
	3. MRP	3	3				2				3	2				3	1			3	3
	4. Interior	3					2					3				2	1		2	3	3
	11. Horiz Stab								2								1			3	2
	6. Cabin	2	2	2	2			2			2	2	2			1	1	2	3	2	2
	9. Sponson/Fuel						2					1			3	3	1	3		3	2
	10. Tail Rotor Pylon		2			2					3		3			3	1			3	3
Dynamic Systems	12. Rotor Systems										1		2								
	13. Drive Systems		3	3			2		3	1		1	2								
	5. Propulsion	2	3	2	3		2	1			1		3								
	7. Hyd/Mech Controls	2	3	1			2		3	2	2	3									
Avionic Systems	14. AFCS														1	3					
	15. Avionics							3						1		1					
	16. Electrical	1	2	3	2		1	[illegible]	[illegible]					3	1						
Integration/ Requirements	18. Integration	1	1	1	1	1	1	1	1									1	2	2	2
	8. A/F Systems	3					2	3									1		3	3	3
	19. Requirements				2		3										2	3			2
	17. Final Assy	2	3	3	3	3	2	3	3								2	3			3
	20. Test	2	3	3	3	2	2	2	3								2	3	2	3	

LEGEND		
Relationship	Interaction	
Contractual Relationship Through Prime	1	High
Contractual Interface with Partners	2	Medium
Internal Interface Between PDT Groups	3	Low

Areas of the matrix are shaded to reflect the different types of organizational relationships within the S-92 organization structure. Areas along the diagonal represent areas of interaction that are grouped together under a single deputy program manager to facilitate communication. A high degree of interaction occurs within these groups with the exception of the partner group. While there is some interaction between partner products, this interaction is through Sikorsky. If a change proposed by one of the partners affected another partner, the change was coordinated by Sikorsky and distributed to the affected partners. Other shaded areas identify contractual relationships with the partners and internal PDT interfaces not coordinated through the PDT groups under the deputy program managers.

The level of activity that occurs across product teams, which is not captured in the organization structure grouping of partner, dynamic system and avionics teams is significant. This activity is represented on the matrix as the off-diagonal shaded areas. Also of interest is the interaction occurring across the contractual boundary with the partners. This of course is to be expected by the nature of the work being performed by the partners, which requires a high degree of coordination among the various PDT's. Only the Rotor System, Automatic Flight Control System (AFCS), and Avionics PDT's do not demonstrate substantial cross PDT interaction. The System Integration and Final Assembly Teams had significant interaction with virtually all of the product teams.

The interaction diagram supports the conclusion that on a complex product development program, the interaction among the PDT's is highly coupled. The joint program structure introduces a contractual relationship at the PDT interface, which is significant due to the high bandwidth communication required across the interface. In the next chapter, the impact of the joint program structure will be analyzed.

Chapter 3 - Analysis of Joint Program Structure

3.1 Joint Program Structure Analysis

Department of Defense and commercial joint development projects have different project structures that require a different mix of project management activities in each project type. As shown in the figure below, the customer in a DOD project structure consists of a number of different organizations that can have influence over the project.

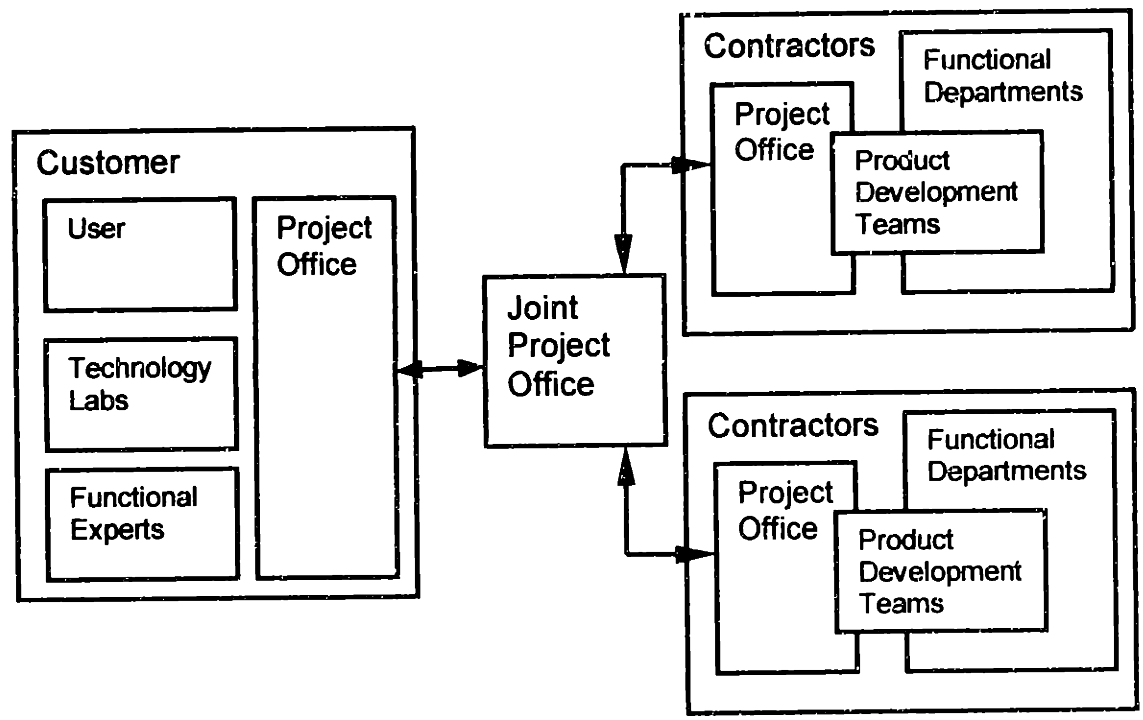


Figure 3-1. DOD Joint Project Form.

Typically, the DOD customer maintains a project office that provides a consolidated interface to the Joint Project Office representing the two prime contractors. The user community, representing the future operators of the aircraft, makes important contributions to the project along with the technology laboratories and functional departments. The technology laboratories conduct research on defense related technology with the objective of developing technology that can be inserted into defense products. The functional departments of the DOD customer effectively mirror the functional departments of the prime contractors providing informed oversight of the contractors.

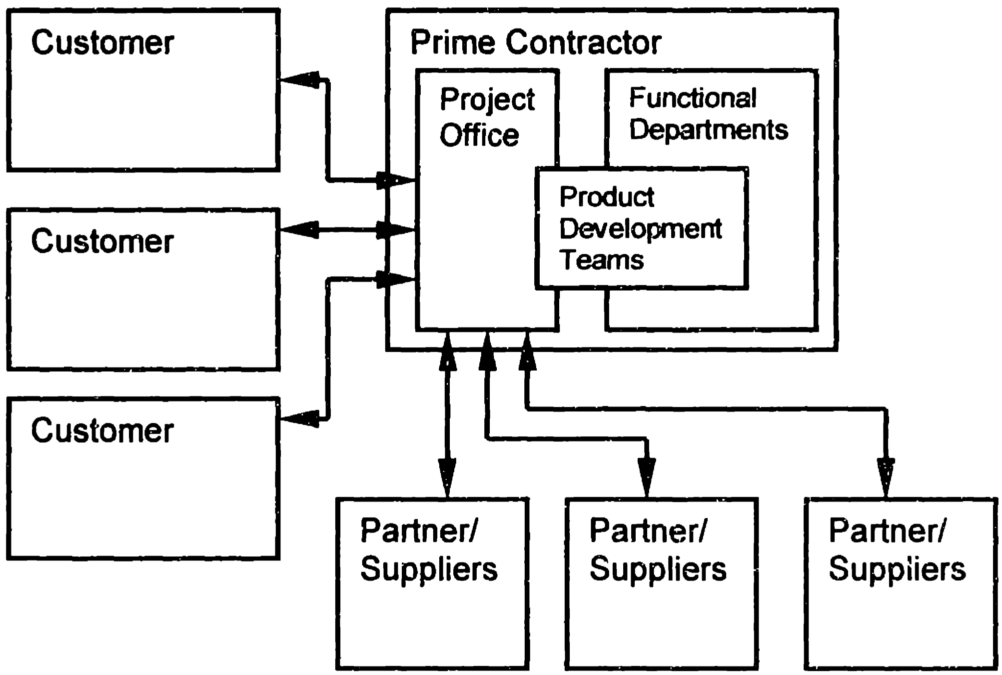
The DOD customer is an extremely complex and capable customer that shares the development responsibility with the contractors. The customer also takes responsibility for the front end of the development process by generating an operational requirements document which specifies how the aircraft will be used. The customer provides the technical specification to the JPO as part of the contract and implements a formal specification change process that permits the contractors to propose changes to the customer.

The Joint Program Office is also unique to the DOD project structure. The JPO is staffed with representatives from each of the prime contractors and provides the primary customer interface. The JPO attempts to integrate the inputs from each of the prime contractors and resolve differences between them. The JPO also provides an organizational home for a system integration function that maintains close ties to the user community.

In a commercial joint program, the customer composition is significantly different than in a DOD joint program. Typically, a commercial joint program must serve a wide range of prospective customers possibly with widely different operational requirements.

Compared with the DOD customer, the commercial and international military customers buy fewer aircraft of a given configuration so that the project must manage a proliferation of possible option combinations. Also, the emphasis on partner participation places extra demands on the project management team.

Figure 3-2. Commercial Joint Project Form.



In comparing the two project structures, it becomes clear that a significant coordination role is focused within the project management team of the prime contractor on the commercial joint project, combining functions that are shared among a number of different organizations in the DOD program structure. This may in fact be an advantage for the commercial program structure since a certain amount of inefficiency can result from addressing the competing interests in the DOD structure. In both cases, it is important to clearly understand the relationships among the participants in each project structure and ensure that the project management team is able to address the different responsibilities in each structure. For a company attempting to successfully undertake both project types, it is important to distinguish between the types and associated issues and ensure that functions performed by the customer in a DOD project are being addressed in the commercial project.

3.2 Impact of the Joint Program Structure

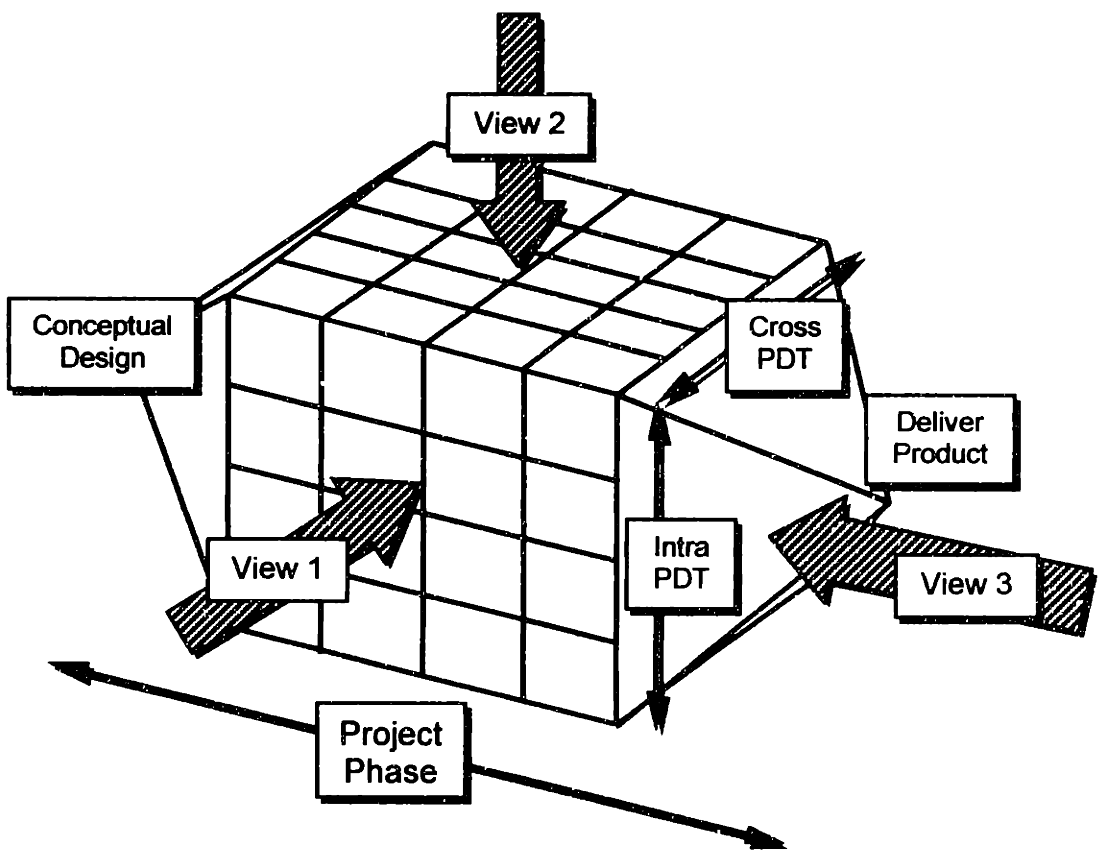
The joint program structure is chosen for reasons other than product development efficiency. In DOD programs, the joint structure is intended to preserve a distributed industrial base. In commercial programs, the primary purpose for a joint program structure is to spread development cost and avoid peak levels of employment which must be shed after the manpower intensive phases of the project are complete. Also, improved market entry is expected in countries whose companies are participating in the project. In some ways, the joint structure enables the project to proceed where other project forms could not.

The impact of the joint structure results primarily from the introduction of contractual, time and distance barriers into the project team structure. While the project team would ideally be co-located in one facility to improve communication that occurs between individual product teams, on joint projects the team can only participate in a co-located fashion for relatively brief periods of time. Thus, other forms of communication become significant in this type of program structure. These forms of communication include written communication (including e-mail), telephone and video-conferencing, and exchange of digital design data. In an international joint project, the communication is further impacted by cultural and time zone differences which tends to favor forms of communication which is asynchronous and picture based rather than text based. The contractual boundaries between project participants can delay the transmission and also the response to shared communication. Contractual boundaries typically reflect a more formal communication style than communication across product teams within a given company.

When viewed in the context of a complex product development, these barriers to high bandwidth communication will result in increased time to exchange information, process the information and respond. Given the highly iterative nature of product development, this can be a significant effect. Perhaps a more significant effect occurs if changes in program input to the PDT's occurs during the development process. In a joint project structure, the introduction of design changes during the product development process can have a much more significant effect if the cycle time for communication is increased effectively delaying the introduction of the change across the project team.

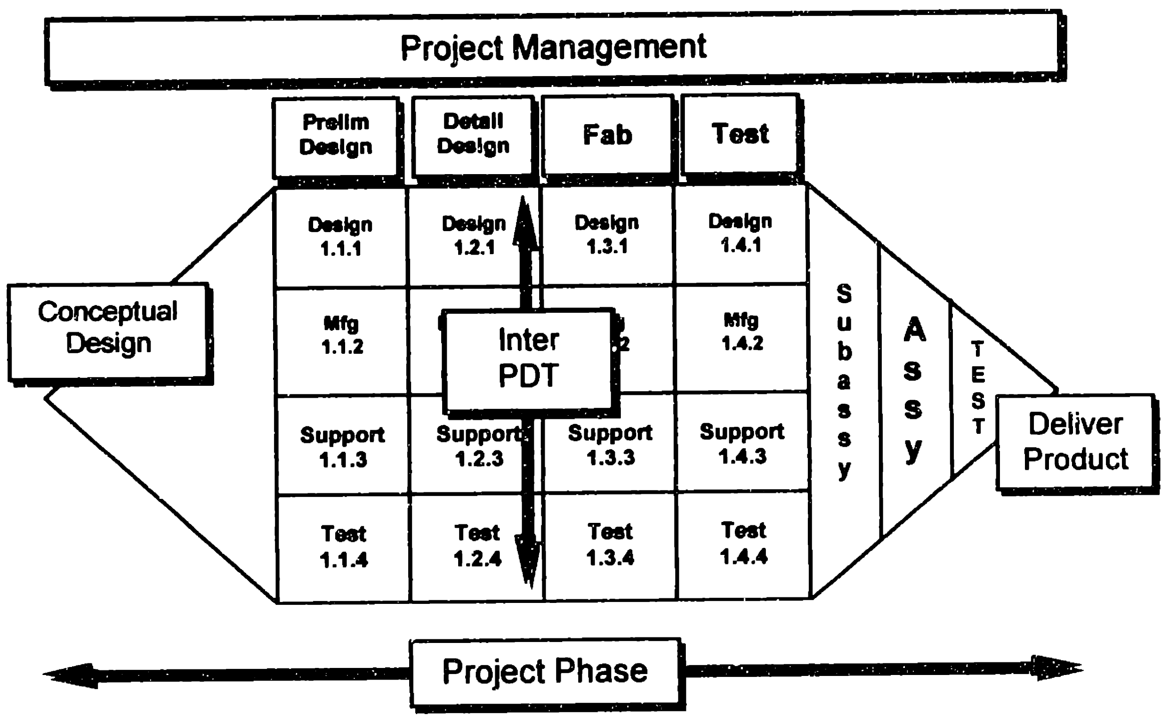
If the project is viewed as a whole as shown in the following figures, the issues associated with the joint program structure become more apparent. In the figure below, the product development framework is depicted using three dimensions. The first dimension is the project phase dimension, which reflects the progression of the project from the conceptual design phase through product delivery. The second dimension reflects the vertical integration of functional disciplines represented by the integrated product team structure. The third dimension represents the multiple PDT's on the project and is labeled in the figure as the "Cross PDT" dimension. Different views of this simplified structure are presented in the following figures.

Figure 3-3. Product Development Framework.



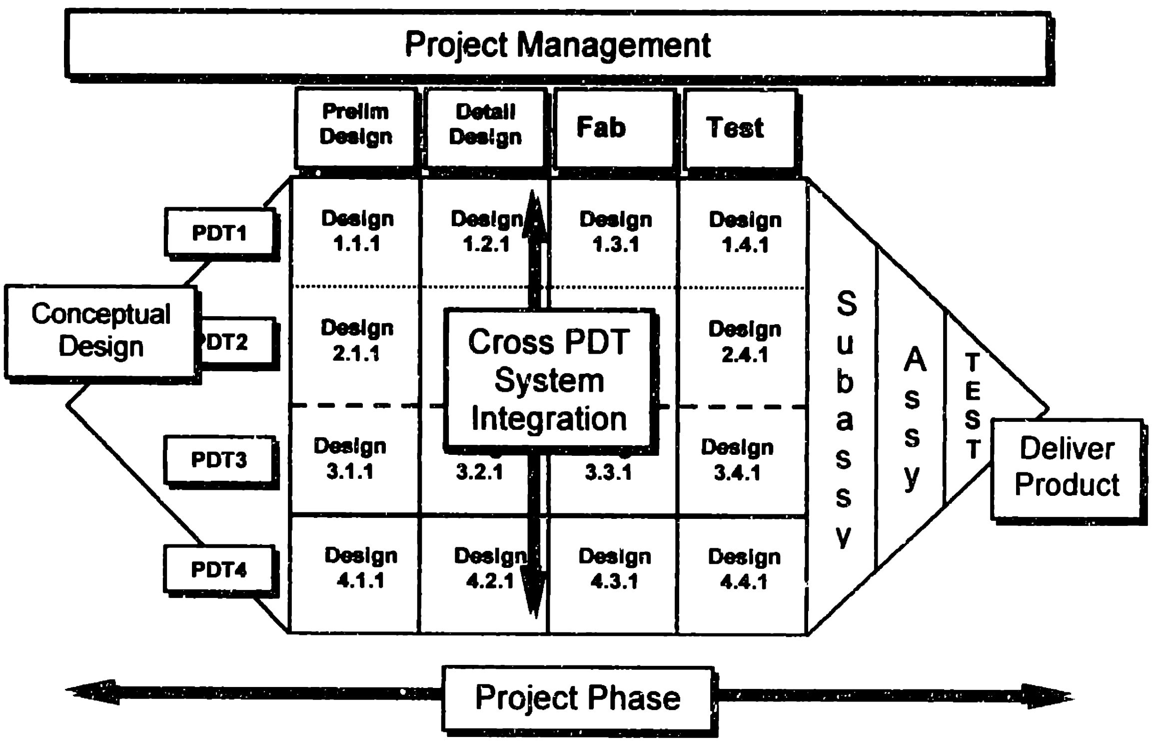
Much of the recent analysis of product development tends to focus on the activity within a given PDT as the project advances through the various project phases. This analysis would apply to the view labeled View 1, which shows an individual PDT's activities over the various phases of the project. The PDT is comprised of various functional disciplines such as design, manufacturing, test and customer support. In a complex product, the components developed by an individual PDT are eventually assembled into an integrated product and tested.

Figure 3-4. View 1 of PDT1.



For a complex project, the communication between PDT's becomes significant and View 2 and View 3 require more attention. View 2 shows the relationship among PDT's for a given activity such as design. As shown in the interaction analysis of the S-92 Program, a significant amount of communication is occurring across PDT's on a typical complex project. This communication becomes particularly significant when the communication is across contractual boundaries. The formal communication style required in these situations coupled with the physical barriers of time zones and distance in the case of the international partners amplifies the effect of changes on the significance of rework. Even communication within Sikorsky but among different groups of PDT's can have significant consequences which the PDT's have difficulty addressing. The iterative nature of design in a complex product requires changes initiated by one PDT affecting other PDT's to be designed and re-designed until the design of the components in both PDT's are stable.

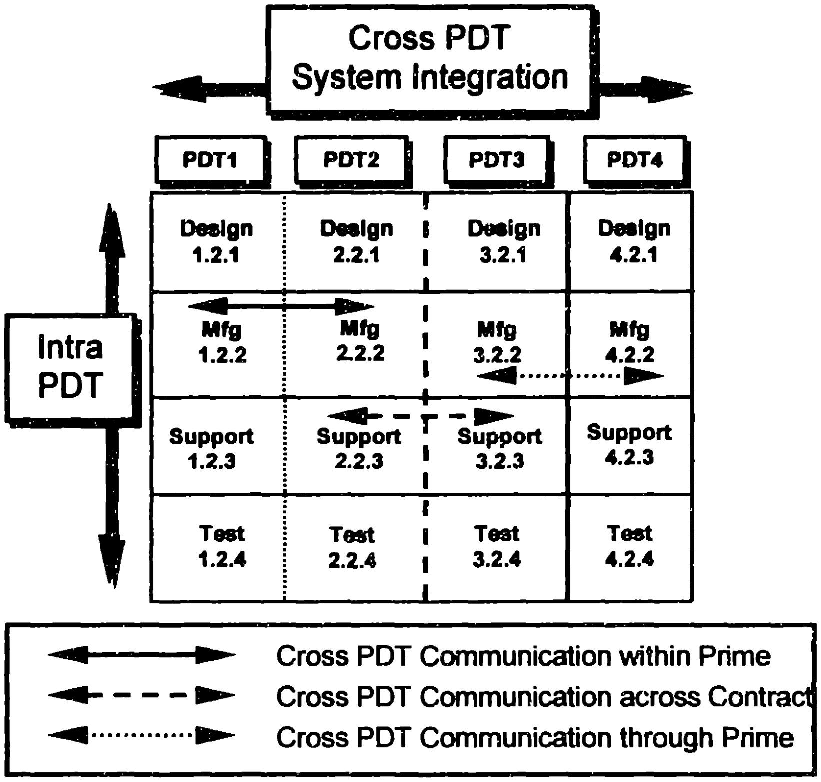
Figure 3-5. View 2 of Design.



View 3 illustrates that within a given phase of the project, considerable communication occurs among all functional disciplines comprising the PDT's across PDT's. In a DOD joint project, the two prime contractors must share information across a contractual boundary. In this structure, there tends to be more tightly integrated activities within the prime contractors. The interfaces occur across significant and recognizable parting lines.

In an international joint project, two distinct forms of communication occur. One form is the communication between the prime and the contractor, which is across a contractual boundary. The second form of communication is between contractors, which typically must pass through the prime, in effect crossing two contractual boundaries if the communication originates with one contractor and affects another contractor.

Figure 3-6. View 3 – Detail Design.



The joint program structure introduces a number of challenges compared with a traditional development program. While the introduction of Product Development Teams and digital design data have improved the quality of the product of an individual product team, the joint program structure introduces barriers to communication across PDT's which make this dimension of the project more critical than on traditional development programs. On the S-92 Program, partner interface consumed a significant portion of the program management team's attention since the program placed a premium on keeping the partners on track. This attention would ordinarily be focused on other issues in a traditional development program. Decisions could take longer to make within the joint program structure. While Sikorsky contractually was in a position to dictate to the partners, this avenue was rarely pursued due to a desire to maintain constructive relations.

The overall effect was reduced efficiency of project execution and an increased need for coordination among the various project participants as compared with traditional project structures. The effects of changes in this project structure are amplified requiring improved inputs to the development process. The joint program structure places additional challenges on the project management team compared with traditional programs. Succeeding within this complex program structure requires the most capable methods to assist the project manager.

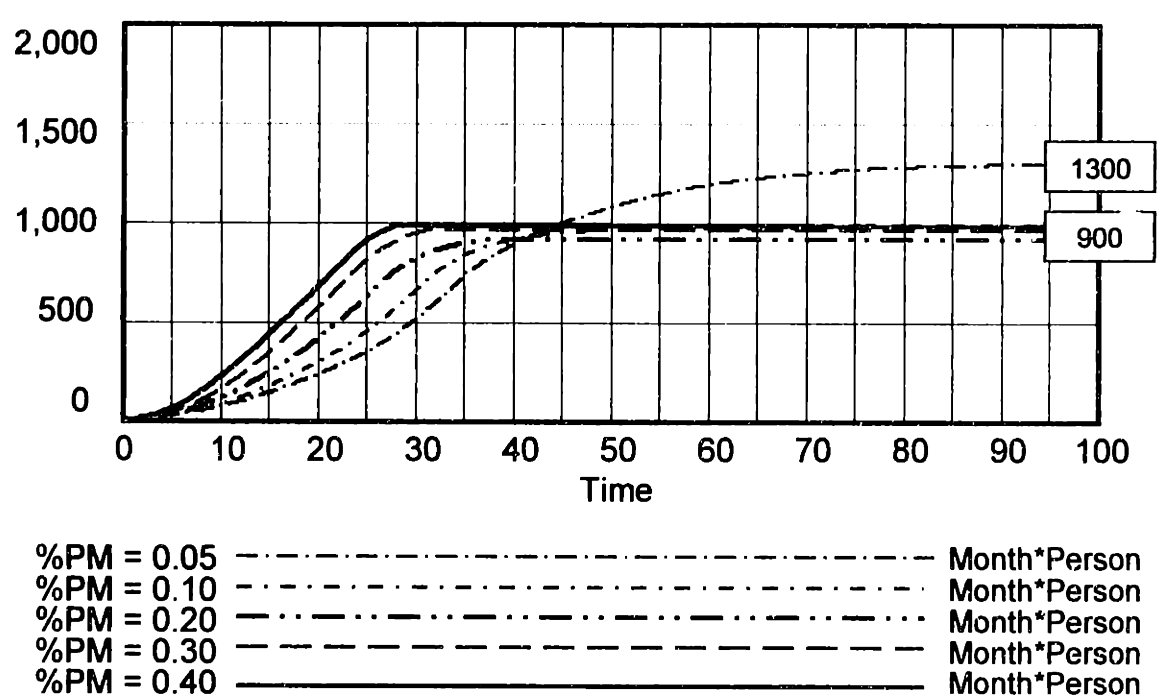
3.3 System Dynamics Model of Joint Program Effects

The effect of a joint program structure on the project can be modeled using System Dynamics. These models are useful in this context because they allow the effects of delayed discovery of rework to be evaluated in a dynamic simulation. More specifically for the joint development project, the effect of the contractual relationships between program participants on overall project parameters such as project cost and completion date can be represented. Project management activities are modeled as having an effect on rework discovery time and rework generation. While the joint program structure can increase the time to discover rework and dilute project management activities that improve the initial quality of the design tasks, additional project management resources are modeled as counteracting these effects. Increased project management activity affects staffing level as increased project management decreases staff available for productive work. The percent of effort expended on project management accounts for both dedicated, full-time project management personnel and time spent by functional personnel performing project management tasks.

One effect that is common in complex systems is the effect of redesign on previously completed work. This is a category of rework in which work has been successfully completed at full quality and this work must be redone as a result of rework introduced into the process. The effect on completed work can be relatively small in the early phases of a project, but as the project nears completion, this effect typically becomes more extensive as the product has been more completely defined. A diagram of the system dynamics model is included in the appendix for reference.

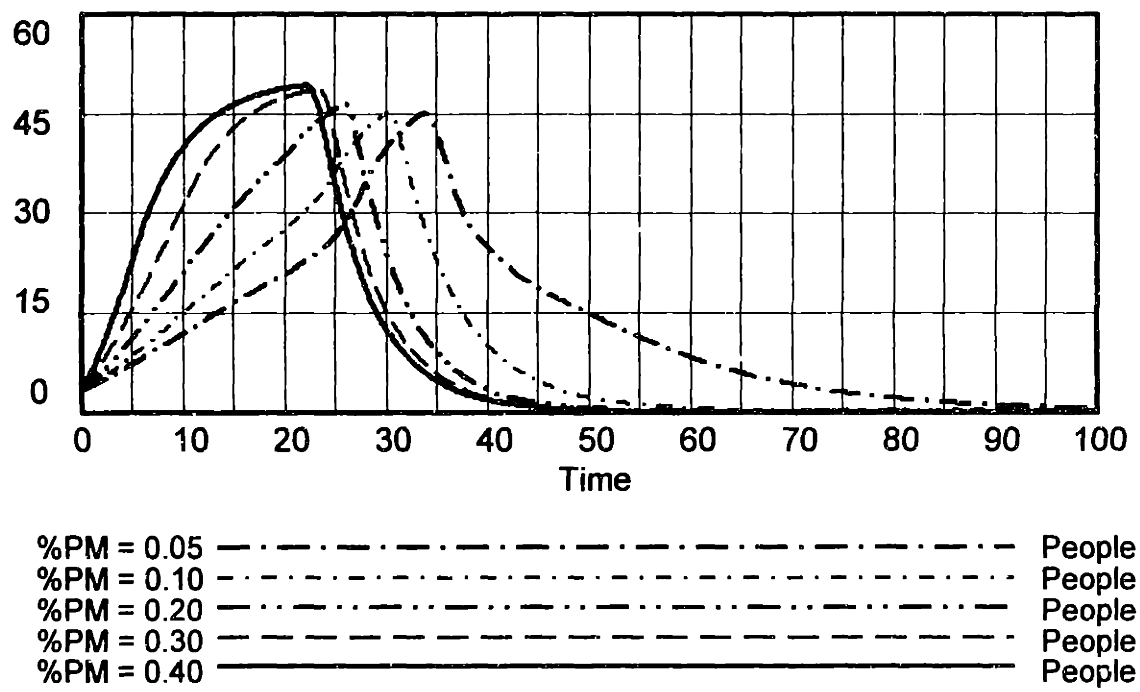
The results in the figures below show the effect of increasing levels of project management activity on key attributes of the model. The model was run at five levels of project management activity as a percentage of the total effort ranging from as low as 5% up to 40%. At the lower limit, the project generates a significant amount of rework and cannot complete in the 100-month window established for the model. At the upper limit of 40% project management activity, the project is completed in the shortest time period, but the additional cost of the project management activity results in the second highest level of cumulative effort expended (total person-months) which corresponds to a higher total cost for the project. Optimum total cost is achieved when 20% of the effort is directed towards project management activities. This level of activity could correspond to 5% of the staff comprised of dedicated project management personnel and the remainder of the staff spending 15% of their time performing project management tasks. While this level of project management exceeds current levels, it still represents a reasonable level of support. As shown in the figure below, the 20% level of project management results in a 30% reduction of overall cost as compared with the 5% level.

Figure 3-7. Effect of Project Management on Cumulative Effort.



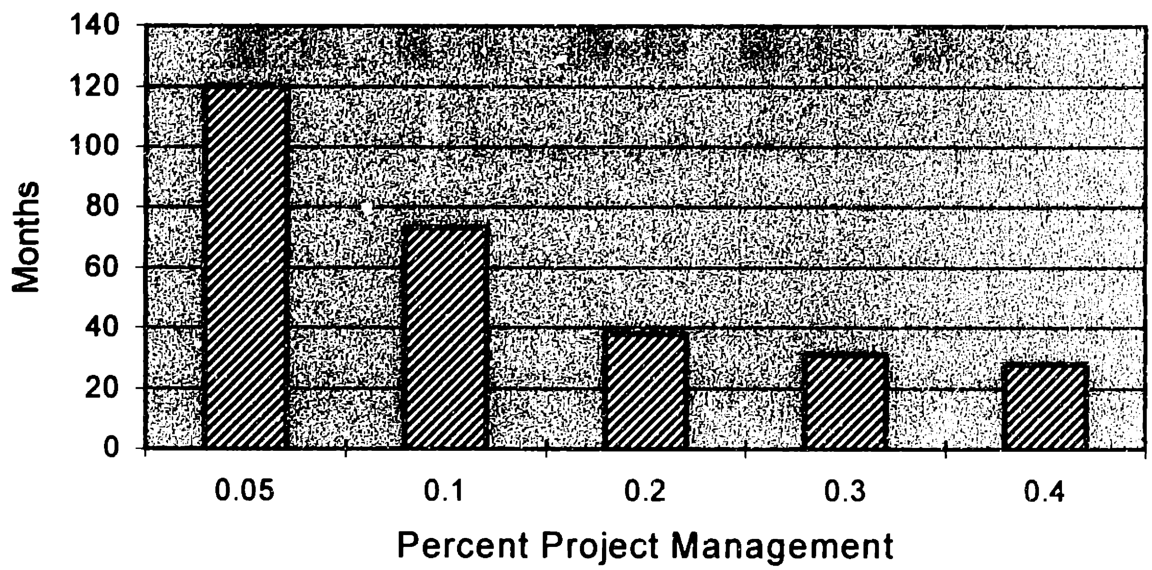
Examining the actual staff level profiles as shown in the figure below explains the overall effects noted in the cumulative effort expended curves. As the percentage of project management increases, the staff ramps up more quickly and the rework discovery time is reduced. Since the rework discovery time is reduced, the rework cycle is highly damped and the feedback effects of undiscovered rework are minimized. As the level of project management activity drops below 10%, the rework has the effect of retaining staff and extending the duration of the project. One relationship that may need to be represented more realistically is the rate at which staff can be added to the project. Because this is not limited in the model, having a high percentage of project management staff does not significantly impact the completion date.

Figure 3-8. Effect of Project Management on Staffing Level.



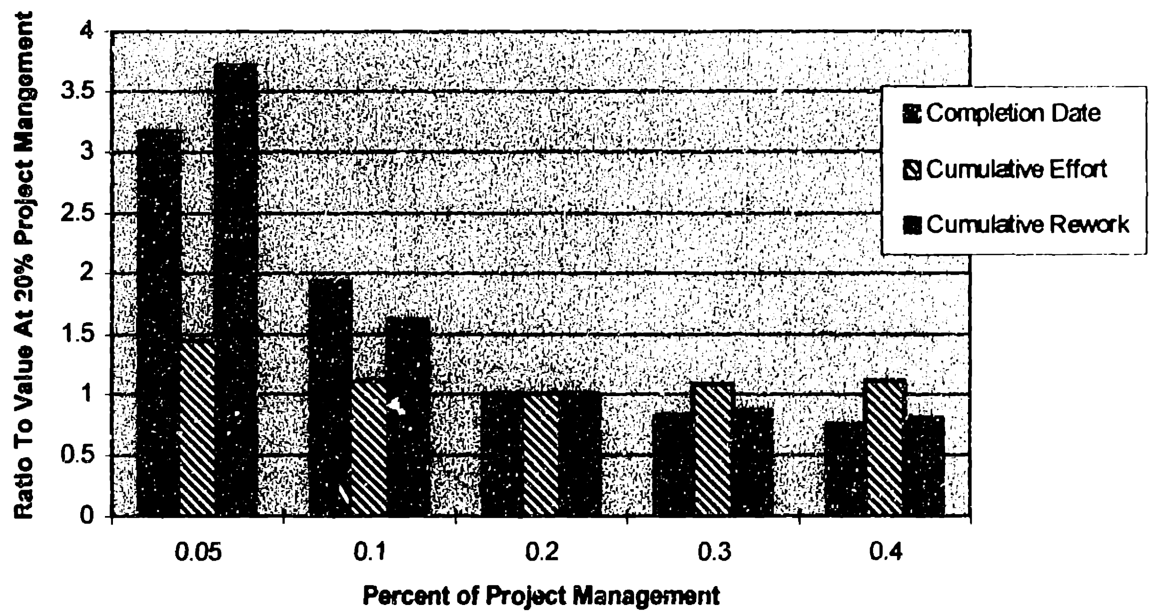
Considering the effect of project management percent on the duration of the project, a 20% level of project management results in a 300% schedule improvement as compared with a 5% level. The trend of completion date as a function of project management percent shows that the 20% level represents a point of diminishing returns related to completion date. Beyond 20% project management, the project duration can still be reduced significantly (from 39 to 23 months) but as described above, the modeling of a more realistic hiring rate would begin to impact the completion date as the percent of project management exceeds 20%. This savings in completion date is at the expense of the cumulative effort (project cost). A return on investment analysis including the effects of lost market opportunity could be used to weigh the project cost versus time to complete.

Figure 3-9. Effect of Project Management on Completion Date.



Adding a project management function to the model provides the opportunity to explore the benefits of different levels of activity on key program attributes such as overall cost and schedule. The optimum level of project management activity based on overall cost is approximately 20%. Increasing the level of project management activity above 20% does continue to reduce overall project duration but at the expense of higher overall costs.

Figure 3-10. Summary of Project Management Effect.



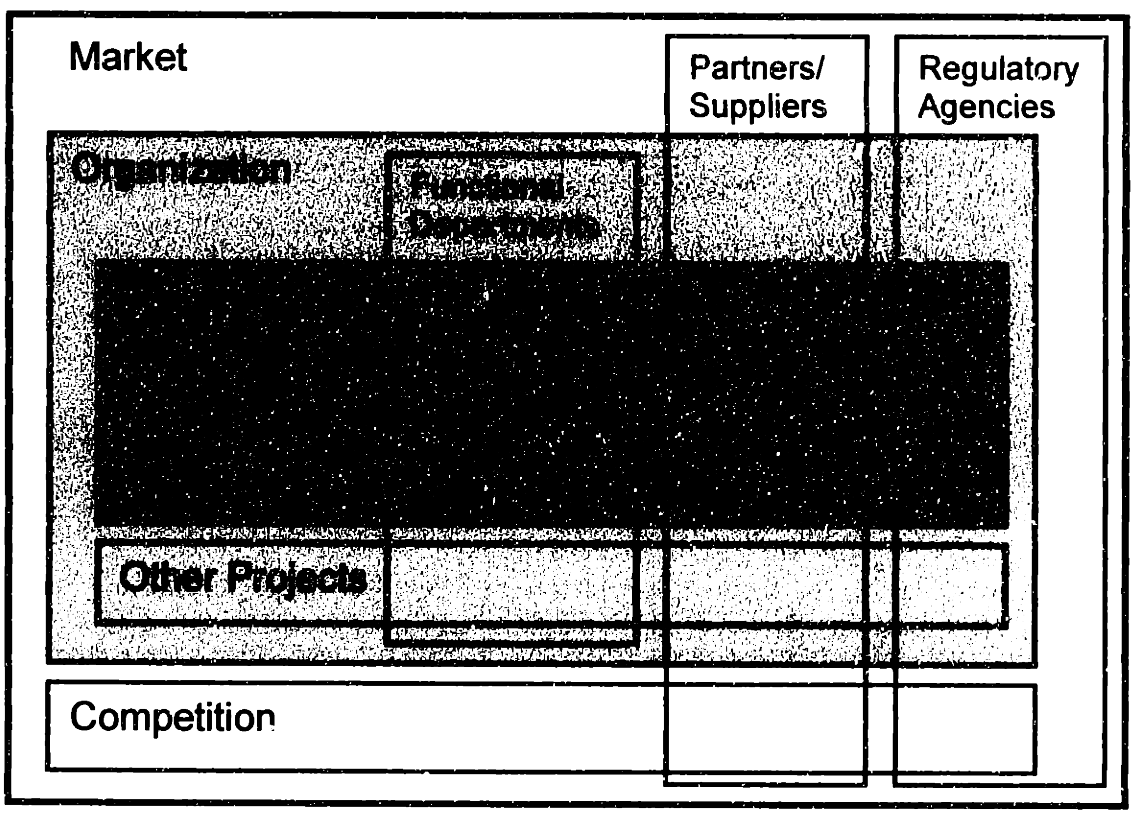
Considering the trends displayed by the model, it is important to recognize that implementing activities and methods that result in the effects represented in the model is not straightforward. Careful implementation of project management activities must be coordinated to ensure that time invested in these activities actually results in improved initial quality and shortened rework discovery time. In the context of a joint development project, an increased level of project management activities can be justified based on the cost savings and schedule benefits associated with the reduced impact of rework.

Chapter 4 - Analysis of the Project Management Function

4.1 Project Management Functional Decomposition

Given the complexity of project management in a joint development program structure, an evaluation of project management methods must begin with an understanding of the project management functions that the methods address. Once the project management functions are identified, project management methods can be evaluated against the functions to determine whether the methods are effective and whether new methods are required. The functions of project management can be viewed in terms of the relationship between the project and the product development and between the project and its environment. A set of relationships can be identified when the project is shown in the context of the organization, the market, and the industry as shown in the figure below.

Figure 4-1. Project Relationships.

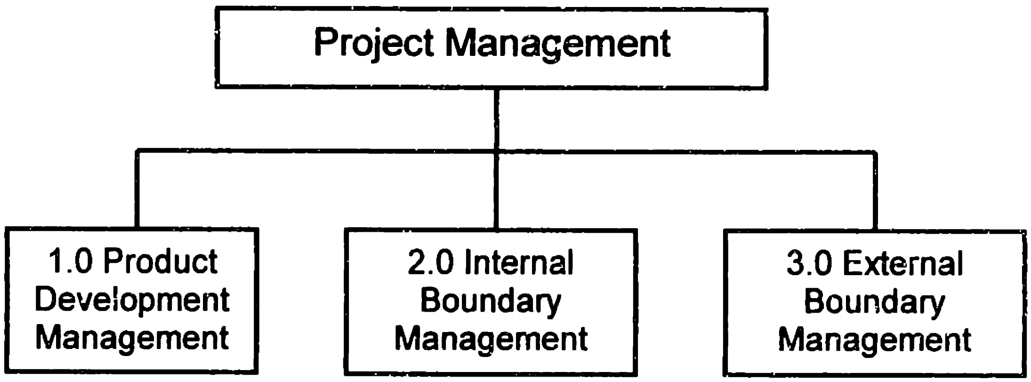


The project management team must address each of the relationships represented above for the project to be successful. Relationships external to the organization include interactions with regulatory agencies, partners and suppliers, the competition and the market for the product which may include a number of different customers. The details of these relationships can take many forms depending on the nature of the product and the contractual nature of the relationships with partners and suppliers, which of course can vary from supplier to supplier. Within the marketplace, competitive products will influence the success of the product since customers compare the relative value offered by competing products in making a purchase decision. Partner and supplier relationships are significant since the success of the product depends on the performance of the constituent components. Within the organization, the relationship with functional departments and with other ongoing programs can have a significant effect on project success depending on the availability of skilled personnel to staff the project. Funding availability is central to the success of the project. The relationships shown in the figure encompass the activities of project management by identifying the stakeholders in the process.

The next step is to develop a functional decomposition of the project management functions, which allows the elements of project management to be identified in a systematic way. As shown above, project management functions can be decomposed into functions which relate to the product, functions which relate to the organization within which the product is developed, and functions which relate to the environment within which the organization exists.

As a result, the first level functions of project management can be grouped into product development management functions, internal boundary management functions, and external boundary management functions as shown below.

Figure 4-2. Project Management First Level Decomposition.



Once the first level functions are identified, these functions can in turn be decomposed to yield the next level of functional requirements. For instance, the product development management function can be decomposed into performance-, cost- and schedule-related requirements. Internal boundary management functions include functions that address interfaces with the organization including staffing, funding and the development of skills, procedures and technology which can be used on other projects. External boundary management functions are concerned with the interfaces with customers, suppliers, competitors and regulatory agencies. Other external relationships can be identified such as interactions with unions, the media, or professional societies. These relationships are judged to be less pertinent to project management and are not included in the decomposition. A detailed functional decomposition of project management functions is provided in the figure below.

Figure 4-3. Project Management Functional Decomposition.

- 1.0 Develop product
  - 1.1. Meets performance requirements
    - 1.1.1. Competitive with available products
    - 1.1.2. Meets regulatory requirements
    - 1.1.3. Meets availability requirements
    - 1.1.4. Utilize appropriate technology
  - 1.2. Meets acquisition cost
  - 1.3. Meets operating cost
  - 1.4. Meets schedule
  - 1.5. Meets non-recurring funding requirements
  - 1.6. Utilize efficient development processes
    - 1.6.1. Effective communication
    - 1.6.2. Efficient organization
    - 1.6.3. Minimize rework
    - 1.6.4. Risk mitigation
- 2.0 Internal Boundary Management
  - 2.1. Maintain funding
  - 2.2. Maintain staffing/skill mix
  - 2.3. Acquire assets
  - 2.4. Develop follow-on capabilities
- 3.0 External Boundary Management
  - 3.1. Interface with Customers/Create Demand
  - 3.2. Interface with Suppliers
  - 3.3. Interface with Regulatory Agencies

4.2 Project Management Functional Decomposition Analysis

Once the project management functions have been identified, it is possible to determine the degree of interaction among the functional requirements. Project management methods that address individual lower level functions and do not address the coupling between functions could be of limited usefulness to the project management team. Understanding the coupling between functions helps determine the degree to which the existing and potential new methods can improve the success of complex product development in a joint program structure.

The following is a matrix that identifies the degree of coupling between project management functions defined in Figure 4-3. The degree of coupling is determined through a consideration of the impact of a change in one functional dimension on the remaining functions. If the functions are relatively de-coupled, actions addressing one project management function will have little effect on other project management functions. Conversely, a high degree of interaction is indicated by a relationship in which actions in one functional dimension have a significant impact on many of the other functional dimensions. Each of the second-level functions is arranged as a row and a column in the matrix and the degree of interaction between the functions is represented as a scale from 1 to 3 with 1 representing the highest degree of interaction and 3 representing the lowest degree of interaction. The lower half of the matrix is symmetric since only the degree of interaction and not directionality is considered. An empty cell in the matrix indicates an insignificant degree of interaction.

Figure 4-4. Project Management Functional Requirement Interaction Diagram.

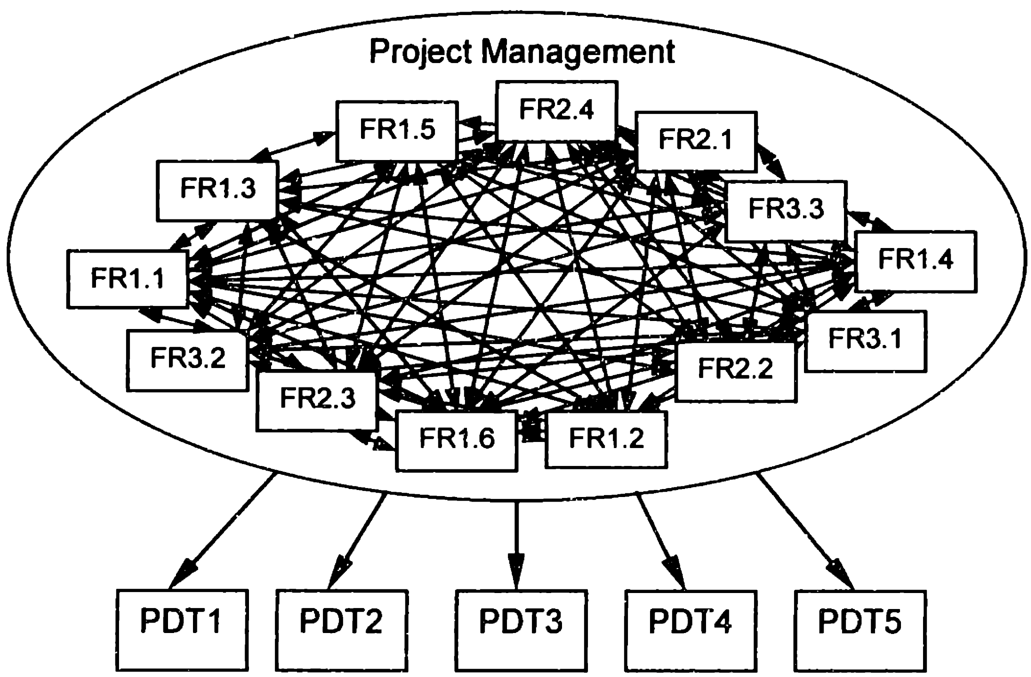
	1.0	1.1	1.2	1.3	1.4	1.5	1.6	2.0	2.1	2.2	2.3	2.4	3.0	3.1	3.2	3.3
1.0 Product Development Management																
1.1. Meets performance requirements			1	1	1	1	3		1	2	3	3		1	2	3
1.2. Meets acquisition cost		1		1	2	2	2		2		3	3		1	2	
1.3. Meets operating cost		1	1		2	2	3		2		3	3		1	2	
1.4. Meets schedule		1	2	2		1	2		2	2	3	2		1	2	1
1.5. Meets non-recurring funding requirements		1	2	2	1		2		1	2	2	2		2	2	1
1.6. Utilize efficient development processes		3	2	3	2	2			2	2	2	2		3	2	2
2.0 Internal Boundary Management																
2.1. Maintain funding		1	2	2	2	1	2			1	2	3		2	3	2
2.2. Maintain staffing/skill mix		2			2	2	2		1		3	3		3		2
2.3. Acquire assets		3	3	3	3	2	2		2	3		3		3	3	
2.4. Develop follow-on capabilities		3	3	3	2	2	2		3	3	3			2	2	2
3.0 External Boundary Management																
3.1. Interface with Customers/Create Demand		1	1	1	1	2	3		2	3	3	2			2	2
3.2. Interface with Suppliers		2	2	2	2	2	2		3		3	2		2		3
3.3. Interface with Regulatory Agencies		3			1	1	2		2	2		2		2	3	

The matrix demonstrates that the functions are highly coupled as indicated by the significant number of off-diagonal interactions. For example, project management actions addressing program schedule will impact program cost. If one assumes that a single schedule can be optimum for overall development cost, then schedules which are either shorter or longer than the optimum schedule will more expensive to implement. Other examples of the coupling between functions include the relationship between performance parameters and non-recurring, recurring and operating cost. Typically actions to improve performance and functionality will come at some fixed or recurring expense. Additional levels of performance, depending on the point at which they are introduced, may affect overall schedule for the project. The functions of meeting performance requirements and maintaining program funding are also highly coupled since a project that is not meeting performance requirements is subject to cancellation.

Commercial programs are subject to funding reductions if the program does not demonstrate competitive performance compared with other company projects that are pursuing company funding.

The effects that the product development functions have on the boundary management functions are particularly interesting. In a complex product development program with a joint project structure, the interactions between the suppliers are a concern. With partners developing sections of the basic structure of the aircraft, interactions between the management of the product development functions and the management of the partner-related functions are significant due to the contractual nature of the relationship. A representative depiction of the coupling between project management functions is shown in Figure 4-5 where each arrow indicates a coupled relationship between the functions.

Figure 4-5. Project Management Functional Requirements Coupling.



In this view, a large number of complex interactions among project management functions are integrated at the project management level. Below the project management level, the requirements and tasks are distributed to the individual PDT's for implementation. The project management team has the responsibility to trade-off the various implications of the different functions, selecting an approach that represents the preferred direction for the program to take.

Given, the highly coupled nature of the project management functions, it is important to consider whether alternate functional decompositions would yield a simpler and more de-coupled arrangement or grouping of requirements. However, this implies that the coupling is related to the arrangement of the functions rather than to the underlying function itself. Performance, cost and schedule are highly coupled since in many cases, increases in performance affect cost and schedule on the project. This is not always the case and certainly the project is always in search of new approaches which improve value to the customer with minimum impact to the various cost attributes or schedule.

Another perspective on the project management functional requirements would consider these requirements as attributes of the product rather than independent functions. For example, cost and schedule would be considered attributes of the product rather than functions. This is perhaps more consistent with the customer's perspective since the customer tends to think of the product in a more integrated way than the project management team. The objective of the project management team in this view is to balance the various attributes of the product in such a way as to maximize the value of the product as perceived by the customer. Depending on the project management requirement or attribute, a further decomposition by component is possible. An example of this type of requirement in the aircraft industry is aircraft weight in which the total weight of the product is simply the sum of the individual constituent components. Other product attributes are difficult to decompose below the system level. Aircraft performance parameters such as range or speed can only be evaluated when a system level analysis is performed.

Cost requirements or attributes must be considered together in order to avoid trading one attribute at the expense of the other. This is a consideration for acquisition cost relative to operating cost. By establishing a desired break even point; it is possible to amortize acquisition cost into an operating cost parameter. Also, non-recurring development cost can be amortized into acquisition cost. As a result, efforts to minimize acquisition cost may have an effect on development cost or operating cost. Unless all three parameters are considered together, it is possible to shift costs from one area to the other without increasing value to the customer. Whether the decomposition of the product functions are considered attributes or functions, they remain coupled such that only an integrated evaluation of these functions has the potential to effectively increase customer value.

Given the highly coupled nature of the project management functions as an intrinsic feature of the functional requirements, project management methods that recognize and address this coupling would be of most value to the project management team. In a joint development program, the sensitivity to rework places a cost and schedule premium on improved project management methods. The next chapter considers the relationship of project management methods to the project management functions in order to make an assessment of the effectiveness of current and potential methods in the context of a joint development program.

Chapter 5 - Assessment of Project Management Methods

5.1 Project Management Methods

A broad spectrum of project management methods have been employed by Sikorsky on the RAH-66 Comanche and S-92 Helibus development programs. In the context of this research, project management methods are defined as activities and tools that support the project management functions identified in the previous chapter. This definition includes methods that address the development of the product along with methods that manage project boundaries internal and external to the organization. Comparing the project management methods to the project management functional requirements will help to evaluate the effectiveness of the set of project management methods. A list of current project management methods in use at Sikorsky is provided in Figure 5-1. With the exception of the business plan, the methods apply to both the RAH-66 Comanche and the S-92 Helibus Programs.

Program Milestones

Program milestones such as design reviews are a method to ensure that the performance objectives of the system and constituent components are being met. Typically design reviews are placed at key points in the project as gates to ensure that as commitments of resources are increased, the design of the components is mature enough such that significant redesign and rework will not be required. For example, it is extremely inefficient for a program to begin the detail design phase of a project when changes to the basic design configuration are still frequent. Unnecessary design changes during the detail design phase render expensive detail design definition obsolete. Similarly, once fabrication begins, changes in the design definition can obsolete not only the design, but tooling and fabricated components. Effective design reviews are an important component of project management and can be helpful maintaining support for the project both internally within the organization and externally with customers and suppliers.

Figure 5-1. Current Project Management Methods.

1. Program Milestones
    1.1. Design Reviews (PDR, CDR etc.)
2. Organizational Structure
    2.1. Product Development Teams
    2.2. System Integration
3. Cost/Schedule Performance
    3.1. Network Scheduling
    3.2. Budget Allocation
4. Manpower/Resource Allocation
5. System Specification
    5.1. Technical Performance Measures
    5.2. Flowdown of Requirements
6. Trade Studies
7. Digital Mock-ups/Shared Design Database
8. Prototyping/Risk Reduction
9. Configuration Management
10. Interface Management
11. Business Plan

Organizational Structure

The use of Product Development Teams is an effective project management method. This organizational design is a method to facilitate coordination among groups that must interface frequently. PDT's facilitate the interface of functional disciplines organized around a product. The creation of a System Integration activity addresses the interfaces between the PDT's. Effective organization design can affect the communication between teams resulting in improved initial quality, reduced rework discovery time and increased efficiency.

Cost/Schedule Performance

Cost/schedule performance tracking enables the project management team to establish the planned cost and schedule for the project and to monitor the performance of the project against the plan. PDT's are provided a budget allocation, program milestones, and a statement of work that must be accomplished for the budget within the milestones. In order to add new tasks, PDT's are required to get project management approval. Network scheduling is a method that allows the linkage between project tasks to be represented so that the effect of early and late task completion can be determined. Cost/schedule performance is important to boundary management since it is an indicator of the cost and schedule efficiency of the program. Programs with poor cost and schedule performance risk cancellation.

Manpower/Resource Allocation

Manpower and resource allocation is a project management method that affects the rate of task completion and spending on the project. This method is closely related to cost and schedule performance monitoring since manpower resources are presumably available when budget is allocated. Manpower allocation can have a significant effect on project success if the correct skill mix of personnel is not available. This method is related to internal boundary management but can affect product development management as well.

System Specification

A system specification is used to define the technical performance parameters of the system. Once system level performance parameters are determined based on customer requirements, they must be analyzed to determine the individual contribution of PDT's towards meeting the system level requirement. This is accomplished via the process of requirements flowdown. Typically, a procedure is used to provide a linkage between system level and PDT requirements. The result of the requirements allocation process is the segment or product specification which is the expression of the customer's requirements as applied to an individual PDT. As a minimum, these requirements are reviewed at PDR and CDR by the project management team in order to verify that the customer requirements are being met. To the extent that the program does not clearly define these requirements permits ambiguity to exist as to which PDT is responsible for meeting customer needs. Requirements flowdown is clearly a project management function since individual PDT's are not in a position to determine the optimum approach to allocating system level requirements. Poor initial definition of system level requirements can be particularly costly in a joint development program due to the impact of the partner relationships on program cost and schedule.

Technical Performance Measures (TPM's) are specific performance parameters that are selected by the project for monitoring on a regular basis. These are usually parameters that are of particular importance to the customer. TPM's are typically plotted over time relative to the system requirement to show status and trends. TPM's that are over limits or exhibit a trend that is undesirable require corrective action by the project.

Simulation of the overall performance of the system is an important method and is related to requirements analysis and flowdown. Prior to the fabrication and test of the system, it is essential to establish through analytical means a model of the system performance that can be used to project the performance of the system relative to the customer requirements. The more reliable the analytical prediction, the less rework will be required following system level testing to meet customer requirements.

Trade Studies

Trade studies are an essential tool of project management. Often, system level design decisions can only be made through a detailed study comparing the attributes of alternate approaches. In a trade study that cuts across multiple PDT's and sub-systems, the project management team with the assistance of the affected PDT's develops a series of options for meeting a customer need. Through layouts and analysis, attributes of performance, cost and schedule are developed with the purpose of developing an objective comparison. Depending on the weighting of different attributes established by the project, (e.g. non-recurring cost vs. weight) a desired configuration can be selected. Trade studies are related to requirements flowdown since one result of the trade study is the allocation of performance requirements to individual PDT's.

Digital Mock-ups

The use of digital mock-ups allow designs of individual components to be brought together as a system in order to evaluate issues such as proper interface, maintainability and human factors. While digital design is important within a PDT to improve communication between design, manufacturing and supportability representatives, it is equally valuable in order to communicate interface between PDT's. Considerable efficiency in the design process is achieved through the use of a common design database that allows each PDT to design in the context of the existing design definition.

Early identification of physical conflicts is essential to the minimization of rework later in the project when costs impact is considerably higher. In a complex product such as an aircraft, this effect can be significant. Therefore, an important project management activity is the maintenance of the common design database and constant review of the database for physical conflicts. This method is also effective addressing internal and external boundary management functions. The partner interface is aided significantly as the digital data represents a common design language for the program. Customer interface can be improved through the use of fly through visualization of the aircaft.

Prototyping/Risk Reduction

Risk reduction activities are an important project management technique employed at Sikorsky. At the system level, risk reduction activities are an important method to establish that interfaces among components are well understood and that performance of the system will be as predicted. Risk reduction took the form of proof of concept testing which used prototype components to represent the performance of the system. One example of a system level risk reduction activity on the S-92 Program is the system integration lab which allowed avionics and flight control systems to be operated in a simulated aircraft installation. This activity allowed interface issues to be uncovered early in the design and fabrication process.

Configuration Management

Configuration management is an important project management method because it enables interfacing departments to determine the validity of the design and manufacturing data. Configuration management also allows the project management team to create procedures which define which types of configuration changes are within the responsibility of an individual PDT to authorize and which changes require project management approval. Configuration management is important to both the customers and regulatory agencies since it is essential that the aircraft configuration is controlled relative to the certified configuration.

Interface Management

Concerning the external boundary management functions, specific methods were introduced to address the issue of partner interface on the S-92 Program. In order to convey requirements to the partners, a product specification was developed for each of the partner products. This technical specification comprised a section of the contract with the partner. Interface Control Drawings (ICD's) were created to identify all of the physical interfaces between products developed by different partners. Over 300 ICD's were created on the S-92 Program to define these interfaces down to individual clamp locations for electrical harnesses. Interface Memorandums were created and tracked to ensure that communication with the Partners received management visibility. In addition to the teams that were resident at the partner's facility, a dedicated point of contact was established at Sikorsky to be the focal point for communication between Sikorsky and each partner. Finally, a system for managing contract-level change with the partners was instituted. These Change Notices (CN's) identified to the partner when changes were being proposed which were a modification to the original contract. These changes could be statement of work changes or changes in the technical requirement specified in the product specification.

Business Plan

The primary purpose of the business plan is to gain funding from either the corporation or outside investors. A secondary use for the business plan is to convince potential suppliers and partners that the program is viable to secure their involvement. A third purpose is to establish a business scenario under which the program will be successful. As a result, the business plan includes marketing projections, price projections, competitive assessments, non-recurring cost estimates, schedule, product features and more. It could be argued that the business plan addresses all three of the first-level project management functions to some degree since it is in effect an integrated summary of all the success factors, including product.

As described above, complex product and project structure requires a significant number of project management methods to properly coordinate the activities of the project. These methods require significant management effort and skill to implement. The methods identified above are designed to address specific management functions as perceived by the project management team on a given project. A number of the methods are particularly effective addressing issues encountered on the joint development programs.

5.2 Assessment of Current Methods

In order to evaluate the effectiveness of the project management methods, the methods can be compared with the project management functions identified in the previous chapter to determine the degree to which the methods satisfy the functional requirements. At first, it may seem logical that the project management methods could be mapped directly to the project management functions. In other words, a single project management method would address a single project management function. In this case then, it would be possible to organize the methods in Figure 5-1 into methods that address product development and methods that address internal and external project boundaries. In the table below, the rows represent the project management methods and the columns represent the project management functional requirements addressed by the methods. The strength of the method-to-function mapping is indicated by a 1 for a strong relationship and 3 for a weak relationship. Empty cells indicate an insignificant relationship between the method and the function.

Figure 5-2. Project Management Functions Versus Methods

Function / Method	1.0 Develop Product						2.0 Internal Boundary Management				3.0 Ext Boundary Management		
	1.1	1.2	1.3	1.4	1.5	1.6	2.1	2.2	2.3	2.4	3.1	3.2	3.3
1. Program Milestones	3	3	3	2	3	2	2	3			3	2	2
2. Org. Structure				2	2	1		3		3			
3. Cost/Sched Performance				2	1	3	2	3	3				
4. Resource Allocation				3	2	2		1	2	2			
5. System Specification	1	2	2	3	3	3					2	3	3
6. Trade Studies	2	2	2	3	3						3		
7. Digital Mock-up	3		3	3	2	2	3			3	2	3	3
8. Risk Reduction	3			3	2	2	3			3	3		3
9. Configuration Management	2	2	3	2	2	2				3	3		2
10. Interface Management	3	3		3	2	2						1	3
11. Business Plan	3	1	2	2	1	2	1	3	2		3	2	

The table indicates that the project management methods typically address a number of different functions to some degree. For example, the system specification is useful for tracking performance parameters including acquisition and operating cost through the allocation of technical performance metrics among the various products. The system specification is also useful in creating an efficient development process since the product development teams must clearly understand the performance metrics for the products under their responsibility. The system specification is useful for boundary management particularly with customers and suppliers who need to understand what the technical objectives of the project are in order to judge the potential for the project's success relative to the competition. Success at meeting technical specification requirements is also important to maintain support internally for the project since the project can be subject to reduced support or cancellation if the project is falling short of required performance parameters. Finally, a technical specification is useful for follow-on development since it represents a benchmark starting point technically for follow-on projects of a similar nature.

It is apparent that the methods for project management support the functions of project management in a complex and highly coupled way. To the extent that the functions are highly coupled with themselves, this is not necessarily a surprising conclusion. While the methods address different aspects of the project management function, it is fair to say that the methods do not synthesize the disparate functions into a framework that allows the project management team to address the coupled nature of the functions.

Section 5.3 Inhibitors of Current Methods

The current project management methods identified above are not always successfully implemented on each program. Given the number and scope of the project management methods, considerable effort and attention on the part of the project management staff is required to effectively implement the methods. Some of the inhibitors to the implementation of these methods in a complex joint development project are listed below. A better understanding of why project management methods are not fully implemented can lead to better implementation of existing methods or the development of new methods which address these inhibitors.

- Project management requires an uncommon level of understanding of a wide range of technical and business disciplines.
- Project management overlaps with functional management and roles and responsibilities are not clearly defined.
- Customer interface evolves over time and is difficult to define. The complexity of multiple customers on a commercial project is difficult to manage.
- Project Management maintains a strong dependency on deep knowledge within individual functional disciplines.
- New methods are typically implemented for the first time on a program.
- The time and effort required to perform project management activities in a thorough way exceeds perceived benefits.
- The time frame between receipt of Request for Proposal (RFP) to proposal submittal prohibits thorough application of project management methods without investment prior to receipt of the RFP.

Many of the inhibitors of effective project management are related to the magnitude of the task relative to the time and resources available to perform the task. The tendency to attempt to limit project management activities on a project is related to a fundamental issue. The fundamental issue is whether additional project management activities have the effect of reducing or increasing important project parameters such as overall cost and schedule. The system dynamics model supports the conclusion that there is a potential minimum cost and schedule project that includes increased levels of project management activities. The activities must result in greater savings from improved initial quality and reduced rework than the activities themselves cost. The challenge for the organization is to identify project management activities that meet this criteria and to develop an approach for implementation of new project management methods so that these savings can be realized.

Chapter 6 - New Methods for Project Management

6.1 New Project Management Methods

A number of project management methods are available which would be new to the Sikorsky Aircraft project management process. New management tools that are capable of addressing the issues identified in the review of current project management methods will offer the greatest value. Candidate new methods, which can supplement existing methods, include System Dynamics, Critical Chain, Design Structure Matrices, Quality Function Deployment and Virtual Design Teams. These methods are summarized below.

System Dynamics

System Dynamics is a modeling and analysis method that can be used to understand the behavior of complex systems as they change over time. System Dynamics can be used to evaluate many different types of systems including physical, organizational, economic, and social systems that have the characteristic of changing behavior over time. System Dynamics has been successfully used to analyze and predict the behavior of complex product development projects through the consideration of effects on productivity, quality and rework.

Critical Chain

Critical chain is a project management technique, developed by Eli Goldratt, which emphasizes the use of teams to identify a development effort's resource constrained critical path that is described as a "critical chain". All critical chain tasks are scheduled for a time to complete which represents the time corresponding to a 50% probability of completing the task on time. The traditional safety time built into individual tasks is aggregated in a buffer for the complete project. This aggregation of safety time results in an overall reduction in project safety time resulting in a decrease in projected completion time.

Teams working critical chain tasks are expected to be completely focused on completing the critical chain tasks and handing it off to the next team as soon as the information meet predetermined targets. This emphasis on focus while on critical path tasks acknowledges that a day lost on the critical path is a day lost by the program forever. Multi-tasking while assigned a critical path task is prohibited. This method has been successfully implemented in several industrial settings in both development efforts and job shop applications. Significant reductions in project schedule and cost have been obtained with this technique

Design Structure Matrix

Design Structure Matrix (DSM) techniques permit identification of interactions between components of a system. Once identified, these interactions can be reconfigured to optimize system performance. DSM has been used in the architecting of new products to optimize the "chunking" of components by minimizing information flow between chunks, to model project schedules based on inter-task information flow, and to define organizational structures based on information flow between groups.

Quality Function Deployment

Quality Function Deployment (QFD) is a technique that maps customer requirements to technical performance parameters. Also displayed in the matrix is the performance of competitive products along the same performance dimensions. Weighting of customer requirements can be included along with the interaction of technical performance parameters.

In the absence of other techniques to capture customer requirements and translate them into technical specifications, QFD represents a structured approach to dealing with a difficult problem for complex product development. While the matrix can be time-consuming to create, the risk of developing a non-competitive product that does not meet customer requirements is of greater concern. Fortunately, once the relationships are developed for one project, many of the relationships remain relatively stable on new projects. The structured nature of the method allows an editing approach to be used on related projects. Commercial joint projects are particularly in need of a tool like QFD since the input of the customer is less structured than in DOD programs.

Virtual Design Team

The Virtual Design Team (VDT) method models the relationship between organizations and tasks in order to gain understanding of how coordination affects overall project parameters such as cost and schedule. VDT uses a computational model of an organization as processing information to characterize activities, communication and organization design. The model can represent the interaction among resources by addressing issues such as attention allocation and capacity allocation. Dependency among tasks is represented and activities are broken down into production work and coordination work. The model helps identify where coordination bottlenecks occur within the organization so that organizational and resource allocation changes can be made. VDT is a tool that has particular usefulness on joint project structures due to the complexity of the interaction between the prime contractor and the partners.

6.2 Assessment of New Project Management Methods

The new project management methods all appear to offer promising capabilities that can be helpful to improved management of complex product development. Unfortunately, all of the tools require additional allocation of resources in order to implement and benefit from the new methods. The inhibitors of the current project management techniques relate primarily to a lack of project management resources to fully implement the techniques. Adding additional activities, while potentially beneficial, seems counter-productive while the current approach to project management is in place.

When the requirements of project management are considered in the context of a complex system development, it is clear that successful project management extends well beyond the coordination of functional disciplines. In the absence of a structured customer such as a DOD customer, the project management team takes on additional responsibilities that are critical to the success of the project. In a complex project structure such as a joint program, the project management team must split its attention among customers, internal development activities and partner activities. Methods to structure and analyze these relationships are important to the current and future success of the project.

The new methods however still do not address the central issue associated with the complexity of project management. The central issue as described previously is the highly coupled nature of the various functional requirements. The new methods identified still do not assist the project managers in making decisions choosing among a number of coupled parameters. A method that integrates the different functional requirements would be of value to the project management team to ensure that decisions were made based on balanced criteria that can be communicated to the project team.

A Pugh Matrix is effective for evaluating various configuration combinations in order to identify potential improved configurations that are yet to be understood. In this case, a Pugh Matrix is used to evaluate the new project management methods introduced in the previous section. Given the complexity of project management, it can be concluded that different tools address different aspects of the process and the optimal approach is some combination of tools which address the various gaps in the current process. The significant need which has not been addressed is the need to not only fill gaps in the current process but to integrate these various tools into an overall model of the product and project. A Pugh matrix allows the best features of available methods to be identified and combined in such a way that allows new methods to be conceived. The figure below shows the Pugh matrix for new project management methods. The methods are evaluated relative to the functional requirements of project management. The matrix assumes that the new methods are combined with current methods. A "+" in the matrix indicates improvement over existing methods and an "S" indicates no improvement compared to current methods.

Figure 6-1. Pugh Matrix of New Project Management Methods.

	Current + SD	Current + CC	Current + DSM	Current + QFD	Current + VDT
1.0 Develop Product					
1.1 Meets Performance Requirements	S	S	+	+	S
1.2 Meets Acquisition Cost	S	S	S	+	S
1.3 Meets Operating Cost	S	S	S	+	S
1.4 Meets Schedule	+	+	+	+	+
1.5 Meets Non-Recurring Funding	+	+	+	+	+
1.6 Utilize Efficient Development Processes	+	+	+	+	+
2.0 Internal Boundary Management					
2.1 Maintain Funding	+	+	S	S	+
2.2 Maintain Staffing/Skill Mix	+	S	+	S	+
2.3 Acquire Assets	+	S	S	S	+
2.4 Develop Follow-on Capabilities	+	S	+	S	+
3.0 External Boundary Management					
3.1 Interface with Customers	S	S	S	+	S
3.2 Interface with Suppliers	S	S	+	+	+
3.3 Interface with Regulatory Agencies	S	S	S	+	S
Sum of +	7	4	7	9	8
Sum of S	6	9	6	4	5
Ranking	3	5	3	1	2

The new methods offer the potential to improve the performance of project management functions. QFD in particular appears to address a number of important functions that are particularly challenging for the commercial joint program structure. QFD is more useful addressing the front end of the technical performance specification process, which is currently not well supported. VDT has the potential to identify project bottlenecks and can be successful addressing improved project management functions relating to interface and communication among the project team.

Section 6.3 Integrated Business Plan

In considering the needs of the project manager, the missing tool or method is one which integrates all aspects of the project into an overarching model which assists the project manager in performing the myriad tasks involved in managing the project. Following Goldratt, the single metric that integrates other metrics and can provide an overall measure of effectiveness for the project is profit as a function of time. This metric is useful since it translates value as perceived by the customer and costs as incurred by the organization into a single attribute. No other single attribute can accomplish this objective.

Products that have high value to the customer will generate more revenue than products with lower value. The difference between the price (reflecting customer value) and costs incurred by the organization is profit retained by the organization. Products that generate significant profit for the firm will be considered successful. Products that lose money for the firm will not be offered. The flaw in attempting to establish a metric that represents customer value is that this metric ignores the cost associated with developing the product as if improving customer value at any cost is a reasonable objective.

Using profit as a metric is hardly a new concept since the entire business community revolves around maximizing value in the form of higher profit. This metric is not typically found on a project, however, as other more specific metrics such as Design to Cost, weight, and various performance metrics are the subject of project management tracking. Of course, using surrogate metrics can lead to sub-optimal results as the quote from Eliyahu Goldratt indicates, "Tell me how you will measure me and I will tell you how I'll behave". Establishing metrics and using them to make decisions is an important aspect of project management. It is clear that careful choice of the metrics used on a project can be important to the overall success of the project.

Looking back at the list of current methods used by the project manager, the business plan comes closest to providing a profit perspective on the project. The business plan typically identifies level of investment, expected return on investment and rationale for the business case analyzed including market analysis and describing key discriminating features of the product which ensure the market penetration assumed in the business case.

The existing business plan is disconnected from the project manager's real time decision making concerning the development of the product. What is required is an integrated business plan in which all aspects of the project including external influences are fed into the business plan on a real time basis so that the incremental impact of changes on profit or rate of return can be determined. The implicit assumption underlying tools like QFD is that by doing a better job of capturing the customer needs in the design, the design will be more successful and ultimately, the project will be profitable. By focusing on the relationship between successfully meeting customer needs and profit, the objective of improving rate of return becomes explicit in the modeling tool rather than implicit. The advantage of the integrated business plan is that issues such as schedule impact, level of investment required, and impact on sales can be properly evaluated and traded off. The integrated business plan can also identify when changes have no impact on the profitability of the project and these are changes that can be avoided.

Implementing an integrated business plan is far from a trivial task. Deriving the relationship between performance attributes and profit is extremely difficult. Cost and schedule parameters are of course easier to integrate. The point of establishing an integrated business plan as a project management method is not to replace the program manager or to think that decisions which have been arbitrarily quantified are somehow better than decisions which are based on judgement. The advantage of establishing an integrated business plan is to keep this underlying motivation in front of the project management team and the larger project so that the teams explicitly understands how their activities can directly affect the success of the project. Tracking Design to Cost for instance can lose significance if this parameter is not related in some way to sales and profit. Encouraging a better understanding of these relationships makes the team more effective by unifying the focus of the team around a common metric.

The profit metric is useful mainly within the context of commercial programs. Of course, this is a result of the relationship the project has with the customer. In the case of DOD Programs, the customer is ultimately responsible for funding and establishes the parameters under which the program is considered successful. The customer also is responsible for establishing the performance requirements and maintains a technical organization and project management team, which mirrors in many ways the structure of the contractor team. Given that the customer is so heavily involved in the project management, this in effect augments the management efforts by the contractor. On commercial programs, this relationship with the customer is significantly different. Thus, it becomes more important on commercial programs to establish a clear focus in the absence of the customer relationship present on DOD programs. The profit metric is helpful in this regard.

6.4 Steps to Implement New Project Management Methods

Any of the methods identified above have the potential to significantly improve the success for project management particularly in the context of a complex joint development effort. Unfortunately, it is difficult to implement new methods into an on-going project without any understanding of the details of the method or what its likely benefit will be. How does the project management team become educated about the various methods and how can an organization promote the development of new methods such that a program can utilize the appropriate techniques when the opportunity calls for it? These questions are difficult to answer without attempting to answer some more basic questions.

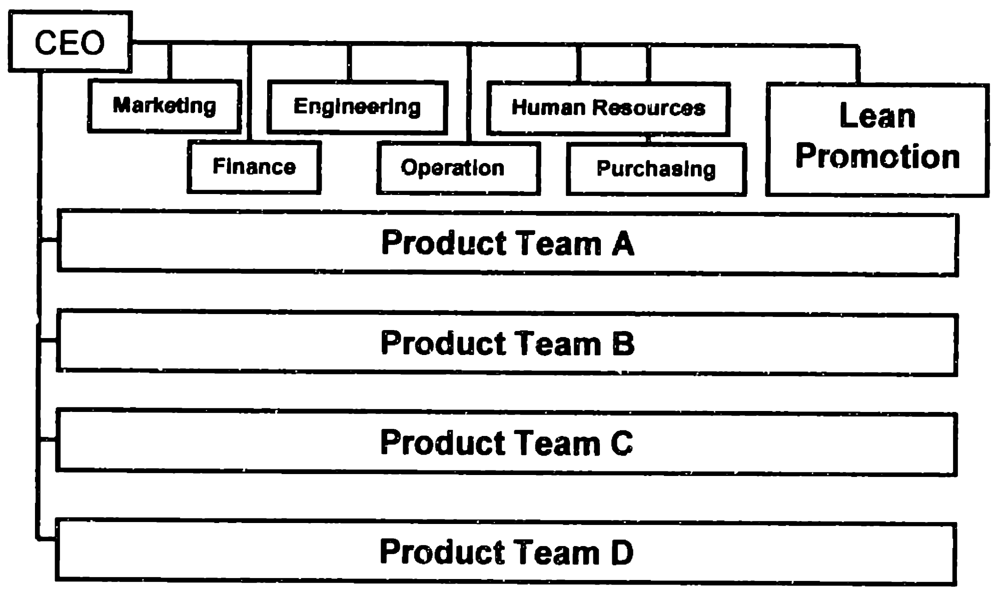
On DOD Programs, the customer conducts research into project management techniques and can impose techniques for use on the project by making these techniques a contractual requirement. Experience on related programs can be helpful in establishing which techniques are effective and since the DOD can span many programs, this can be a useful method for determining which techniques have been effective for use on the next program. Such was the case with the use of PDT's, Requirements Analysis, CSCS, and network scheduling on the Comanche program.

For a commercial program, the method for selection and implementation is less clear. In fact, there is a tendency to reject the project management methods imposed on the DOD programs as being overly burdensome to the program without associated benefits to be gained. In fact, due to the complexity of the programs, it is difficult to determine even approximately what the true benefits of any project management method might be since a control case for comparison does not exist.

It is reasonable to conclude that methods that are truly within the domain of the project will not necessarily be developed by any of the traditional functional organizations if they are not in a position to appreciate the potential benefits of the method. Project Managers must balance the requirements of a multitude of disciplines as established previously. Thus it seems logical to conclude that one reason why methods have not been successfully developed and introduced is that the equivalent of a project management resource to develop new methods is missing within the organization.

In Jones and Womack's book Lean Thinking, the recommendation is made to make the product family the primary organizational structure with dramatically reduced functional organizations in a supporting role to the products. In addition to the functional organizations, a new function called Lean Promotion is created to assist in the implementation of lean practices across the organization. See the figure below.

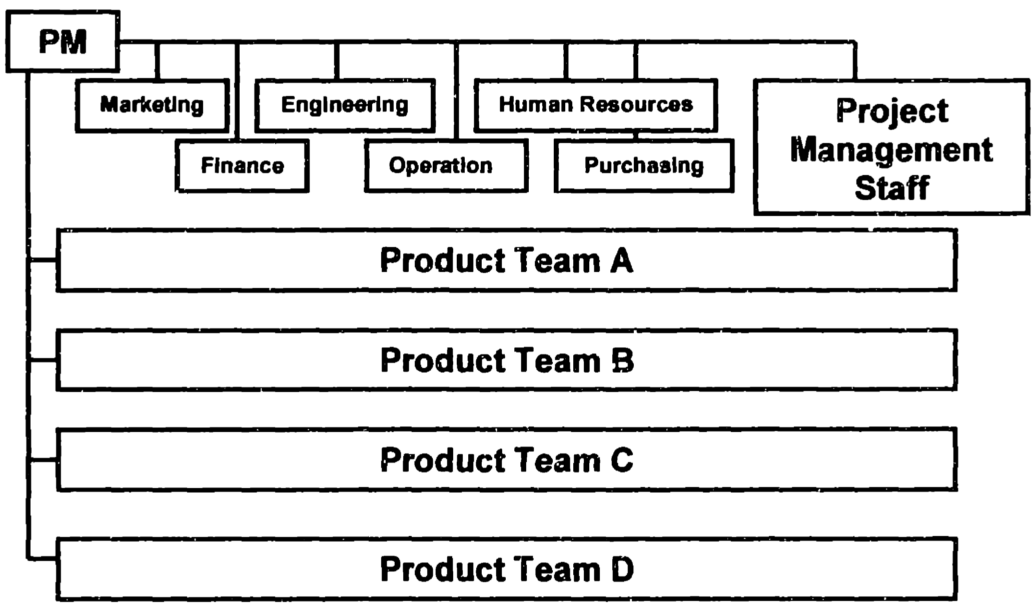
Figure 6-2. Prototype Lean Organization.



An interesting variation on this concept is the modification of Lean Promotion to Project Management Promotion. The role of this function would be to promote the development of methods and skills for use on the projects. Activities which have been previously organized under functional disciplines but which were really more project oriented (Configuration Management, Digital Mockups) can now be reorganized within the Project Management functional home.

The individual projects would mirror this organization structure as shown below. The project manager would be supported by a staff of personnel from the project management functional resource who would be responsible for implementation of the various project management methods. This arrangement also allows these individuals to be evaluated based on their real value to the organization, which is the extent to which they address and improve the total project management function.

Figure 6-3. Proposed Prototype Project Organization.



This organizational design would provide the foundation for improved project management methods to be implemented within and across different projects in the organization.

Chapter 7 - Summary

7.1 Summary

A review of recent complex product development activities underway at Sikorsky Aircraft has identified the importance of project management as a focal point for translating customer requirements into a successful product. Increasingly complex products and project structure places more demands on the project management team. In particular, the commercial joint development program represents a significant challenge due to the complex relationship with both customers and project partners. A system dynamics model is used to introduce the notion that increased project management activity on a commercial project can be cost effective if initial quality and rework discovery are improved such that overall project cost and schedule are improved.

A functional decomposition of project management identifies the highly coupled nature of the main functional requirements of project management. Current project management methods do not successfully address the coupled nature of the requirements. New methods are available which offer potential benefits with Quality Function Deployment and Virtual Design Team being particularly well suited to the commercial joint development project. An integrated business plan is proposed as a means to combine the disparate metrics used to aide decision making in project management on a commercial project and to help focus the entire project team on a consistent metric.

A principal inhibitor to successful implementation of project management methods is the lack of a project management functional resource, which is responsible for developing new methods and skills. Without the consistent support of a project management resource, the potential for successfully applying existing methods and introducing new methods will be impacted.

The challenge remains to determine the optimum set of project management methods and resources required to achieve the minimum cost and schedule performance while simultaneously maximizing customer value as embodied in the product. With a clearer understanding of the nature of the challenge enabled by the project management functional decomposition, new methods can be developed which approach the theoretical ideal project performance.

Appendix

Figure A-1. System Dynamics Model of Project Management Effect (Figure continued on the next page).

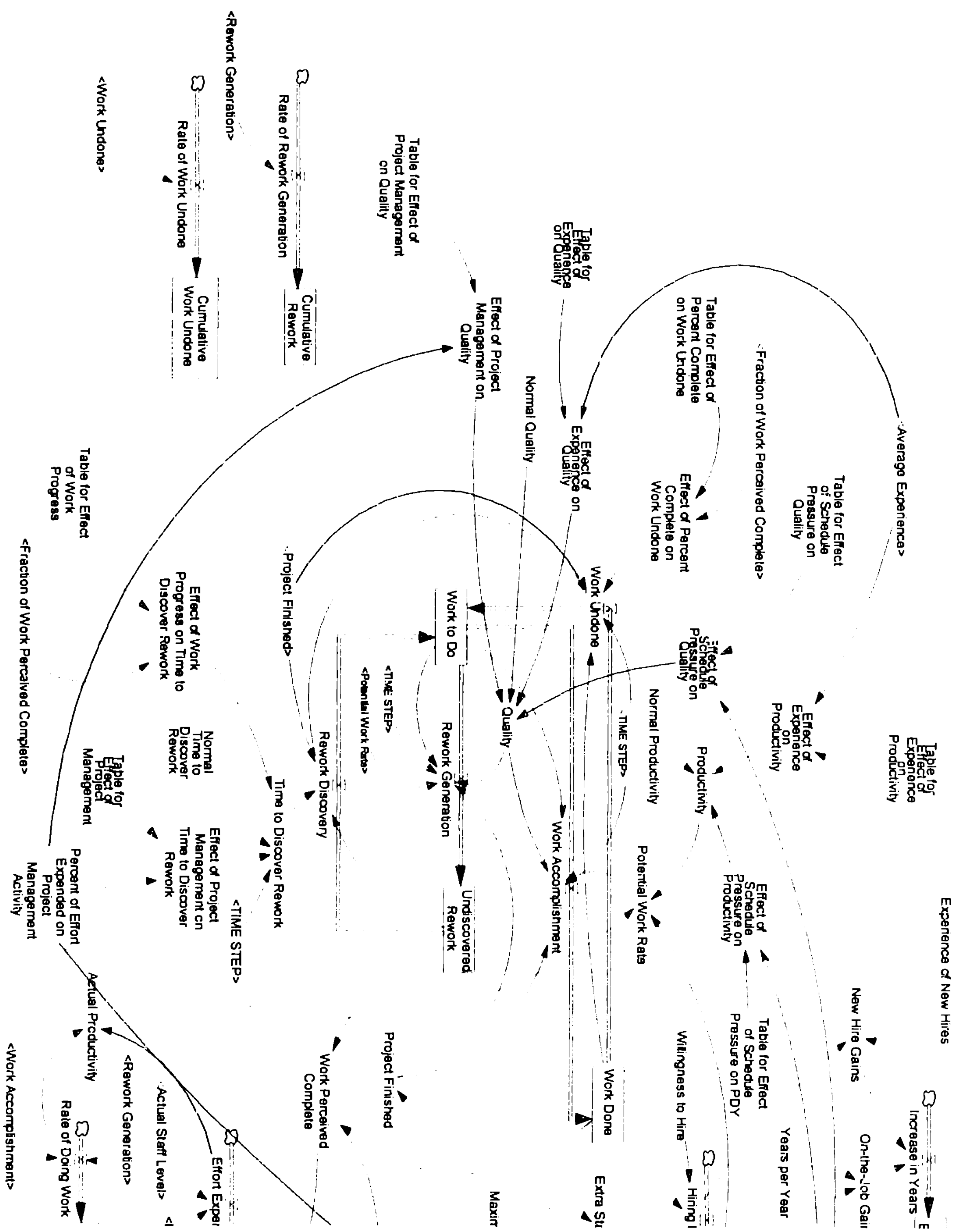
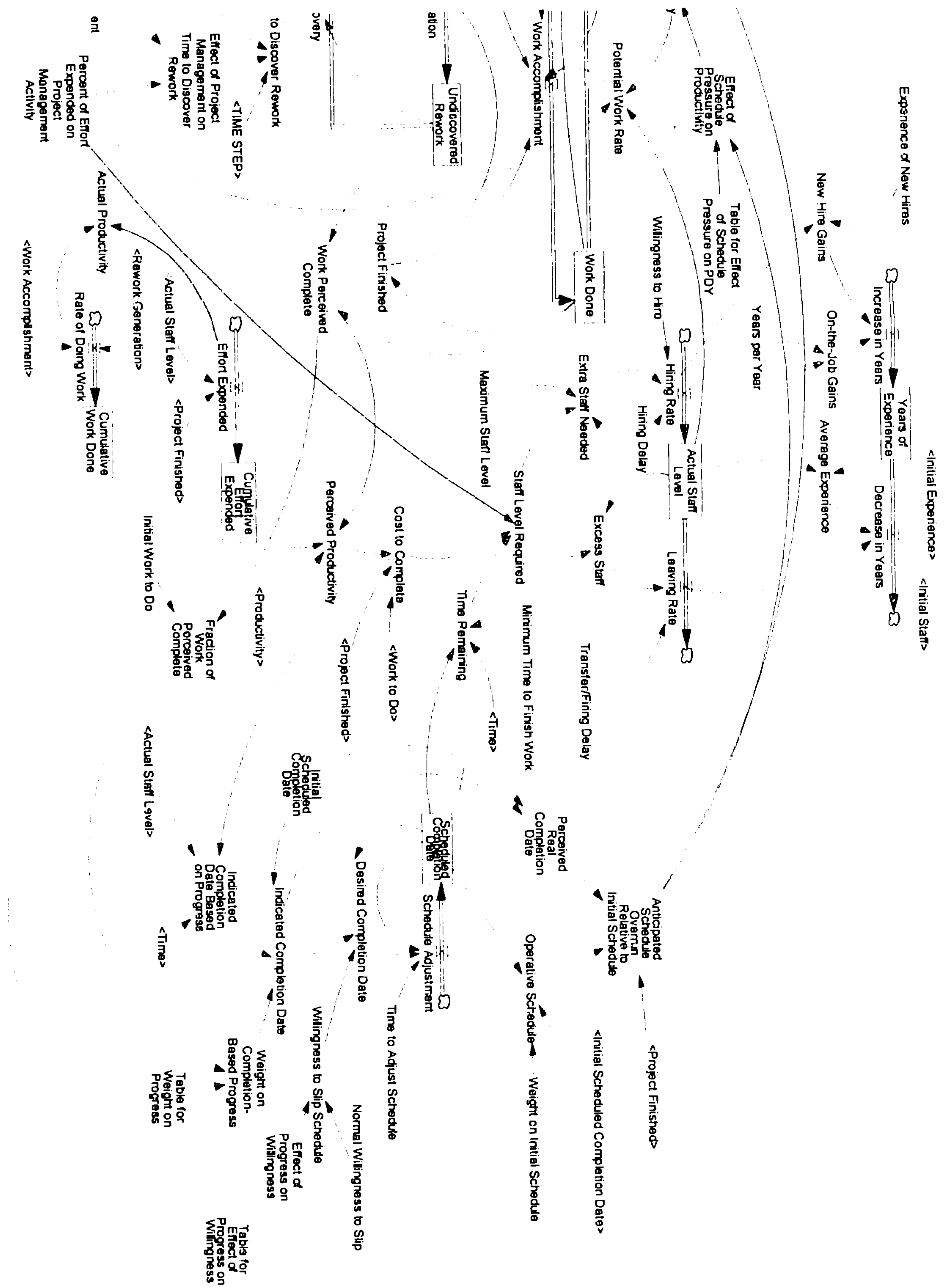


Figure A-1. System Dynamics Model of Project Management Effect (Figure continued from the previous page).



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