Information Flow & Knowledge Capture
Lessons for Distributed Integrated Product Teams

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in Partial Fulfillment of the Requirements for the Degree of

Master of Science in Engineering & Management
at the
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January, 2000
[February 2000]

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ABSTRACT

Two major organizational tools, Integrated Process and Product Development (IPPD) and co-location, have been key initiatives in many corporate knowledge management and information flow strategies. The benefits of IPPD and co-location are well documented, and central to the success of these tools is the increased information flow and knowledge transfer across organizational boundaries. The fundamental knowledge management philosophy of IPPD is person-to-person tacit knowledge sharing and capture through the establishment of multi-disciplined Integrated Product Teams (IPT). Co-location of the integrated product team members has facilitated frequent informal face-to-face information flow outside of the structured meetings typical of IPPD processes.

In today's global environment, the development and manufacture of large complex systems can involve hundreds, if not thousands, of geographically dispersed engineers often from different companies working on IPTs. In such an environment, the implementation of IPPD is challenging, and co-location is not feasible across the entire enterprise. The development of a comprehensive knowledge capture and information flow strategy aligned to the organizational architecture and processes involved with proper utilization of available information technologies is critical in facilitating information flow and knowledge transfer between dispersed IPTs.

In this thesis we provide a case study of the knowledge capture and information flow issues that have arisen with the recent transition to the Module Center organization at Pratt & Whitney. We identify several critical enablers for efficient information flow and knowledge capture in a dispersed IPT environment by analyzing qualitative and quantitative survey data obtained at Pratt & Whitney, existing research in this area, and our own observations as participants in this environment. From this analysis, we identify key information flow and knowledge capture issues and provide recommendations for potential improvement. The Design Structures Matrix (DSM) methodology is used to understand the complex, tightly coupled information flow between the IPTs that exist at Pratt & Whitney. We build upon the previous Pratt & Whitney DSM work. The proposed DSM is not only a valuable tool identifying the information flow paths that exist between part level and system level attributes, but also can be utilized as an information technology tool to capture the content or knowledge contained in the information flow paths identified.

Acknowledgements

Obtaining the information for use in this thesis was a significant endeavor requiring help from many of our friends and coworkers. The raw data and many valuable insights came from dedicated employees willing to spend their valuable time supporting this effort and we wish to acknowledge their efforts, and thank them.

The authors recognize the recent thesis work of some of our Pratt & Whitney colleagues that have laid much of the groundwork for this thesis. Specifically, we recognize the work of two alumni of the System Design and Management Program.

> Mascoli, Gregory J., "A Systems Engineering Approach to Aero Engine Development in a Highly Distributed Engineering and Manufacturing Environment", MIT MS Thesis, 1999
>
> Rowles, Craig M., "System Integration Analysis of a Large Commercial Aircraft Engine", MIT MS Thesis, 1999

Special thanks go to Dan Whitney, our thesis advisor, for helping us mold our free flowing ideas into a singly focused and manageable thesis. Dan's ability to extract meaning from our discussions and pose poignant questions added greatly to our ability to focus.

We thank our many supervisors who continued to support our efforts in this distance learning program. Clearly, their understanding made this demanding program possible. Stephen Glynn specifically thanks Rich Hoff, Stacy Malecki, Ed Donoghue, Paul Smith, Frank Ello, Steve Gerber, and his original sponsor Carl Meece. Tom Pelland specifically thanks Paul Finklestein, Rob Archer, Phil Provencher, Dave Carter, Tom Davenport, and his original sponsor Vince Scaramella.

Finally, we thank our families who were exposed to as much, if not more, of the sacrifice during this two-year endeavor that absorbed much of our time. Thank you for continuing to support us even as the experience became more burdensome than exciting.

Table Of Contents

Chapter 1

Introduction and Statement of Problem

Over the past decade intense domestic and international competition has driven organizational and process change at many large engineering and manufacturing firms. Restructuring, Re-engineering, and the implementation of lean principles, such as the elimination of *muda* (waste) and Value Stream analysis[1], have become a part of corporate culture and landscape as companies strive to remain competitive. Companies effectively integrating lean techniques, such as cellular manufacturing and Just-in-Time in manufacturing operations have realized significant reductions in product and operating cost while improving quality and delivery performance. Motivated by the demonstrated success stories of implementing Lean manufacturing philosophies, corporations are now beginning to apply Lean principles to Engineering and Product Design and Development processes. To remain competitive, corporations realize that they must not only become lean manufacturers, but *lean enterprises*.

The product of a manufacturing system is generally thought of as piece of hardware or assembled component or physical entity, which can be viewed as it flows through the process. In Product Design and Development and Engineering processes, knowledge and information can be considered the "product" which flows through the process. From this perspective, effective knowledge management and efficient information flow are critical to the success of an Engineering or Product Design and Development organization and require significant focus as a corporation transitions to a lean enterprises.

Knowledge management is an extremely broad concept encompassing the identification of knowledge, knowledge capture, knowledge transfer, and information flow. In simple terms, businesses focused on developing knowledge management as a competitive advantage must

[1] For an complete review of Lean principles and successful application of Lean techniques, we suggest "Lean Thinking", by James P. Womack and Daniel T. Jones, Simon & Schuster, New York, 1996

"find and capture the knowledge they have, share it, and exploit it for commercial benefit."[2] A recent study of twenty Chief Knowledge Officers in North America and Europe stated that "[k]nowledge is a necessary and sustainable source of competitive advantage" and "[s]uccessful companies are those that consistently create new knowledge, disseminate it through the organization, and embody it in technologies, products, and services."[3] Corporations have begun to recognize that the knowledge possessed by their employees is a valuable asset to be managed and utilized for competitive advantage in today's fast paced, global market environment.

Two major organizational tools, Integrated Process and Product Development (IPPD) and co-location, have been key initiatives in many corporate knowledge management and information flow strategies. The benefits of IPPD and co-location are well documented, and central to the success of these tools is the increased information flow and knowledge transfer across organizational boundaries. The fundamental knowledge management philosophy of IPPD is person-to-person tacit knowledge sharing through the establishment of multi-disciplined Integrated Product Teams (IPTs). Co-location of the IPT members has facilitated frequent informal face-to-face information flow outside of the structured meetings typical of IPPD processes. In a co-located, IPPD atmosphere, knowledge can reside with individual technical experts because of the formal and informal communication network provided. Formal knowledge capture and sharing processes, such as Standard Work, existed but it was the IPPD structure and co-location that is central to knowledge management in this organizational structure.

Integrating the efforts of dispersed IPTs to achieve the desired system level requirements and corporate objectives requires a fundamental understanding of how information flows between the IPTs and how to effectively manage the subsystem component boundaries. The development of a comprehensive knowledge management strategy that is aligned to the organizational architecture and processes, and proper utilization of available information

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[2] Habbel, R., Harter, G., and Stech, M., "Knowledge-Critical Capital of Modern Organizations, Knowledge Management", White paper, Booz-Allen & Hamilton, Insights, October 1999
[3] Earl, M. J., Scott, I. A., "Opinion, What is a Chief Knowledge Officer?", Massachusetts Institute of Technology, Sloan Management Business Review, Winter 1999

technologies is critical for facilitating effective information flow and knowledge transfer between the IPTs.

However, in today's global environment, the development and manufacture of large complex systems can involve hundreds, if not thousands, of geographically dispersed engineers often from different companies working on IPTs. In such an environment, the implementation of IPPD is challenging, and co-location is not feasible across the entire enterprise. Knowledge management strategies must become a conscious priority and focus on capturing and efficiently disseminating both explicit and tacit knowledge through the enterprise.

1.1 Thesis Scope

This thesis will present a case study of the most recent organizational changes implemented at Pratt & Whitney, a division of United Technologies Corporation, and the information flow and knowledge capture issues that resulted. Over the last decade Pratt & Whitney, like many other Aerospace companies, has gone through many organizational changes. Pratt & Whitney has evolved from a functional segregated vertical organization to a product aligned, integrated product team architecture. This study details, from an organizational and information flow perspective, the most recent change implemented at Pratt & Whitney that involved the dispersal of the engineering organization and the establishment of Module Centers.

Specifically, this research will investigate the information flow and knowledge capture issues that have resulted from the transition to Module Centers in the Pratt & Whitney IPPD culture. We also will also utilize and attempt to build upon the current SDM thesis works of Greg Mascoli[4] and Craig Rowles[5] that investigated the use of the Design Structure Matrix (DSM) in understanding the information flow between IPTs and the role of systems engineering at Pratt & Whitney.

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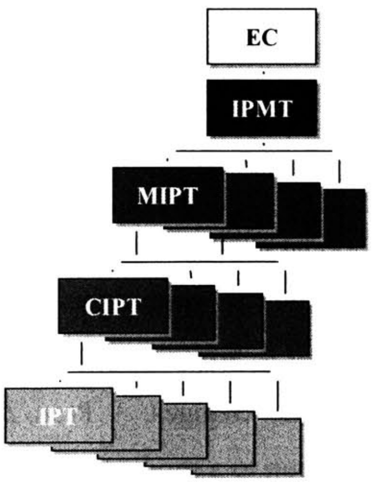
[4] Mascoli, G.J., "A systems Engineering Approach to Aero Engine Development in a Highly Distributed Engineering and Manufacturing Environment", System Design and Management Thesis, Massachusetts Institute of Technology, January 1999

[5] Rowles, C.R., "System Integration Analysis of a Large Commercial Aircraft Engine", System Design and Management Thesis, Massachusetts Institute of Technology, January 1999

Prior to the Module Center transition, the engineering organization at Pratt & Whitney was very centralized. All engineering disciplines (except manufacturing), product validation, program business office, and systems engineering organizations were co-located at the company's East Hartford facility[6]. The engineering organization was decomposed, by program and component, into a tiered integrated product team structure, as shown in Figure 1.1.



Executive Council (Enterprise level

Integrated Program management Team (Program level

Model Integrated Program Team (Engine model program level

Component Integrated Product Team (Sub-system level technical

Integrated Product Team (Part level technical

Figure 1.1
Pratt & Whitney IPD Structure

This co-located IPPD organizational architecture promoted a strong information flow and knowledge capture network for product design, development and validation, and systems integration through the formally structured IPPD methodology and informal information flow processes enabled with co-location.

The manufacturing organizations prior to the Module Centers, called Product Centers, were decomposed by part family (Cases, Rotors, Externals, ect.) and were geographically dispersed primarily in Connecticut. Each product center contained all required resources to produce and deliver hardware supporting production deliveries and customer requirements, but contained limited engineering discipline resources. The part family alignment of the Product Centers versus the program specific component focus of the engineering

[6] The scope of this thesis will focus on the commercial engine business at Pratt & Whitney

organization, along with the lack of co-location between the organizations resulted in weak manufacturing integration with design efforts. While product cost reduction and design for manufacturing has always been a Pratt & Whitney enterprise objective, it was often difficult to achieve in the Product Center and centrally located engineering organization. The integration link between engineering and manufacturing occurred at the part level IPT. Integration typically consisted of one manufacturing representative present at multiple IPT meetings, who was only a representative, not a integrated team member.

Beginning in 1999, Pratt & Whitney began the transition to the new Module Center organization to address the manufacturing integration issue. This transition has dispersed the centralized engineering organization and co-located engineering with manufacturing. The resulting Module Centers are each capable of designing *and* manufacturing each sub-system (module). The systems engineering, program business office, and customer engineering organizations remain in the East Hartford facility, while the Module Centers are dispersed throughout Connecticut. This new Module Center organization has strengthened the integration of manufacturing and engineering. However, the partitioning of the engineering workforce has made total systems integration and IPT information flow more challenging.

As the Pratt & Whitney organization has evolved into the Module Center architecture, the information flow and the knowledge capture processes have lagged behind. The primary method for cross sub-system and cross-module information flow is still meetings. Component system and IPT engineers are spending significant amounts of time traveling between plants for various meetings. The informal information flow network that was critical for systems and component integration and efficient information flow across IPTs in the previous co-located environment is no-longer present, and the need for a more structured process has developed. Knowledge capture and sharing methodologies also need to be addressed because the technical experts, who served as knowledge repositories, are also no longer co-located with the IPTs of other components.

In the highly coupled and complex design process of a jet engine, thousands of component interactions can affect system level performance. Management of these interactions and the efforts of the IPTs will require efficient and timely information flow between the Module Centers, system engineering, and the program office. The information flow and knowledge capture processes that existed at Pratt & Whitney prior to the transition of Module Centers need to be re-established to reflect the new organization.

1.2 Thesis Objectives

This thesis provides a case study of the knowledge capture and information flow issues that have arisen with the recent transition to the Module Center organization at Pratt & Whitney. We will identify the critical enablers for efficient information flow and knowledge capture in a dispersed IPPD environment by analyzing qualitative and quantitative survey data obtained at Pratt & Whitney, existing research in this area, and our own observations as participants in this environment. From this analysis, we will identify key information flow and knowledge capture issues and provide recommendations for potential improvement.

To fully understand the complex, tightly coupled information flow between the IPTs we will utilize the Design Structures Matrix (DSM) methodology and build upon the previous work completed at Pratt & Whitney[7]. We intend to show that the DSM can be a valuable information flow tool in the new Module Center organization by identifying the information flow paths that exist between part level and system level attributes. This part attribute to system effect DSM would provide a "road map" or link between part level design attributes and how they are coupled within the total system. Essentially, it would provide a new inexperienced part designer a guide to what parts of the system are effected by changing a specific part attribute. It would also provide a needed "directory" between the knowledge captured in the technical experts and the IPTs. The DSM tool is developed to provide not only the information flow paths between IPTs, but also to capture information content and knowledge along these paths.

The previous DSM work at Pratt & Whitney focused on the phases between preliminary design and product launch and investigated the use of the DSM methodology to map out the

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[7] Ibid., Mascoli and Rowles

information flow during this period. We will build upon this work by evaluating its DSM conclusions downstream of product launch for post-certification engineering change work, called PCE at Pratt & Whitney. Specifically, the Module Center organization, because it is relatively new, has only directly affected PCE efforts. We will analyze the conclusions reached through analysis of the previous DSM work and determine if they are valid for the PCE life cycle phase (see Figure 1.2).

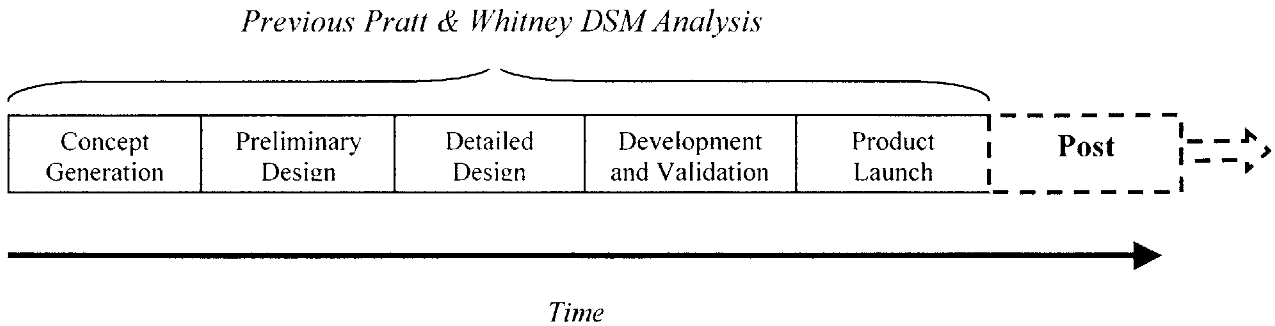

Figure 1.2
Product Life Cycle Phases

Following this introduction, Chapter 2 will provide a broad overview of Pratt & Whitney. It will include a description of the large commercial jet engine architecture and how it maps to the organizational architecture at Pratt & Whitney. The organizational change history at Pratt & Whitney will be discussed briefly, with a focus on the latest change from the Product Centers to Module Centers and the disbursement of engineering. Finally, the fundamental principles behind gas turbine engines will be provided.

Chapters 3 and 4 will cover in detail the Product Center and Module Center organizational architecture and the perceived strengths and weaknesses. The roles and responsibilities of the various integrated product teams will be outlined along with the primary information flow and knowledge capture processes used in each type of organization.

Chapter 5 will describe the data collection methodology used for this thesis, including the development of our survey, how the interviews were conducted, and the literature search. Also included will be the diverse backgrounds of the authors and the unique perspective it provides on the information flow and knowledge capture processes at Pratt & Whitney.

Chapter 6 will detail several tools used for Product Development knowledge capture and information flow. A broad overview of the Design Structures Matrix methodology will be provided, and the previous Pratt & Whitney DSM works reference earlier will be discussed.

Chapter 7 will detail each key information and knowledge capture issue we have identified through our research. Only the issues and their effect on information flow with Pratt & Whitney will be discussed.

In Chapter 8, we will present our conclusions and recommendations addressing the issues discussed in Chapter 7. We intend to show how the part attribute – system effect DSM should be utilized as an organizational "road map" capturing and facilitating required information flow between IPTs, systems integration, programs, and technical experts. We will also provide, based on our research, what critical enablers are needed for efficient information flow and knowledge capture in a dispersed IPT environment. Our intention is for these recommendations to become and integral part in the evolution of the Pratt & Whitney knowledge management strategy.

Chapter 2

Overview of Pratt & Whitney

Pratt & Whitney, a unit of United Technologies Corporation, is a leader in the design, manufacture, and support of dependable engines for commercial, military, and general aviation aircraft, and space propulsion systems. Pratt & Whitney's headquarters are in East Hartford, Connecticut. To help the reader identify with the size and scope of Pratt & Whitney this section contains some background information from the UTC-Pratt & Whitney Internet Website (May 1999)

Today, Pratt & Whitney engines power more than half of the world's commercial airline fleet. Every few seconds - more than 20,000 times a day - a Pratt & Whitney-powered airliner takes flight somewhere in the world.

Sales:
$7.87 billion in 1998

Employees:
About 30,000 worldwide

Customers:
More than 600 airlines operate with Pratt & Whitney large commercial engines in more than 150 countries. More than 7,400 regional airlines and other operators fly with engines made by Pratt & Whitney Canada. Twenty-seven armed forces operate aircraft powered by Pratt & Whitney and Pratt & Whitney Canada engines.

Engines In Service:
About 18,000 commercial engines and nearly 11,000 military engines supported by representatives in 76 cities in 47 nations. In addition, about 33,000 Pratt & Whitney Canada engines are in service around the world.

Business Units:
Pratt & Whitney's five business units are located in East Hartford, Connecticut; West Palm Beach, Florida; and Quebec, Canada.

Large Commercial Engines Headquarters:	East Hartford, CT
Engine Services Headquarters:	East Hartford, CT
Large Military Engines Headquarters:	West Palm Beach, FL
Space Propulsion Operations Headquarters:	West Palm Beach, FL
Pratt & Whitney Canada Headquarters:	Longueuil, Quebec

Manufacturing and Engineering Sites

Our engineering expertise and manufacturing capabilities come together at six facilities in four U.S. states where engines for commercial and military customers are designed, developed, assembled and tested, and spare parts are made.

East Hartford, Connecticut	Middletown, Connecticut	North Haven, Connecticut
North Berwick, Maine	Columbus, Georgia	West Palm Beach, Florida

Service Sites

Pratt & Whitney Engine Services operates overhaul and repair facilities for large commercial and military engines across the United States, with joint-venture locations in Europe and Asia.

East Hartford, Connecticut	Cheshire, Connecticut	North Haven, Connecticut
East Windsor, Connecticut	North Berwick, Maine	Columbus, Georgia
San Antonio, Texas	Dallas, Texas	Tulsa, Oklahoma
Springdale, Arkansas	Singapore	Tapei, Taiwan
Dublin, Ireland	Kiev, Ukraine	

Pratt & Whitney, like many large corporations, is always working to develop efficient organizational strategies for the existing market environment. Forces in the market have clearly changed from where they were even just a decade ago. Specifically, in the large commercial aircraft engine arena, the evolution to three dominant engine producers, UTC-Pratt & Whitney, General Electric & Partnerships, and Rolls Royce ILC, has resulted in fierce competition not just on the engine selling price, but also on full service deals, which include engine support services and maintenance contracts. These market forces and the direction of competition places a premium on the ability to bring engines and upgraded components to market faster, with higher quality and for lower cost. Certainly these three dimensions -- speed, quality, and cost -- are ones that are familiar to all companies with competition. This fiercely competitive market environment is what has driven Pratt & Whitney to take their next bold reorganization.

2.1 Engineering Organization at Pratt & Whitney – Background

The jet engine is a technical marvel and clearly a large complex piece of machinery. It is a cornucopia of many complex sub-systems all operating together in harmony to satisfy the requirements of the overall propulsion system. In order to execute the design, manufacture, and integration of all these sub-systems, a vast amount of engineering input is required. The technical expertise that is brought to bare on a jet engine for design, manufacture, and test include: Aerodynamics, Thermodynamics, Structural Dynamics, Materials, Design, Drafting, Fracture Mechanics, Controls, Software, Acoustic, Heat Transfer, Project, and Manufacturing.

From the inception of Pratt & Whitney in 1925 until approximately 1990, the engineering organization was a classic vertically integrated collection of single-discipline focused groups. The dynamic nature of a developing technology required heavy focus on a workforce with a deep breadth of technical knowledge, which this organizational structure would promote. The structure was truly one of a classic craft industry, with mentoring of the workforce up through the functional chain of command and promoting technical excellence within the discipline.

While this type of organization has a clear advantage for the *technical* needs of the product, the advantage comes at the expense of several other *product* needs, such as manufacturing integration and continuous improvement. When jet engines were in their earliest development, the focus on the product need was limited to the technical performance of the product. This narrow focus continued even as the product need evolved into specific customer needs.

Other downsides of the vertically integrated organizational structure include long cycle time and high product and development costs. The cycle time tends to increase due to sequential execution of tasks[8]. Costs increase because the product definition is not aligned with manufacturing capabilities until very late in the process. As the aerospace industry declined

[8] While vertical integrated organizations do not a priori lead to sequential activities, it does typically evolve to that type of flow, as has been the case within Pratt & Whitney.

in the late 1980's and competition intensified, Pratt & Whitney recognized a great need to implement an organizational change[9].

In 1990, recognizing this need for change, Pratt & Whitney began to align its engineering organization responsibility more toward the product need from design concept throughout the product life, with a great emphasis on a parallel design process through Integrated Product and Process Development (IPPD). The IPPD process moves the design, development, and manufacturing responsibility to cross-discipline teams focused on the product need. By 1993, engineering teams were fully distributed, and Component Centers were formed. Component Centers aligned all teams related to various engine components across product lines. The Component Centers were Compression Systems, Turbine Systems, Electrical and Mechanical Systems, and Combustor/Augmentors/Nozzles. At this time, manufacturing had representatives on teams, but responsibility still reported through an Operations organization.

With engineering now more focused on the product needs through IPPD in the Component Centers, better manufacturing integration on teams began. In 1995, the next organization change, Product Center Engineering, started with the deployment of engineers to the manufacturing sites. After two years, Systems Engineering Organizations were formally established to centrally retain some aspects of engineering disciplines that spanned the product. Systems Engineering encompassed not only Engine-System groups, but also included centrally located functional disciplines, such as secondary flow systems.

Chapter 3 will provide an in-depth look at the Component / Product Center organization in terms of the roles, responsibilities and the operational aspects of the information flow. This organizational structure of Component Centers and Product Centers has run its course through the end of 1998. In 1999, Pratt & Whitney embarked on a strategy, which more fully integrated manufacturing and engineering through creation of Module Centers. Chapter 4 will provide an in-depth look at the organizational changes and challenges as Pratt & Whitney is deploying this organizational structure.

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[9] James P. Womack and Daniel T. Jones, Lean Thinking, New York: Simon & Schuster, 1996, pages 159-165

The organizational changes made in 1993/1995 and again in 1999 have significant alignment with the architecture of the product. As such, we believe that it will be of benefit to first review at a high level the architecture of the jet engine, which brings us to the next chapter.

2.2 Overview of Product / Organization Architecture

The architecture of a product is the scheme by which the functional elements of the product are arranged into physical chunks and by which the chunks interact.[10]

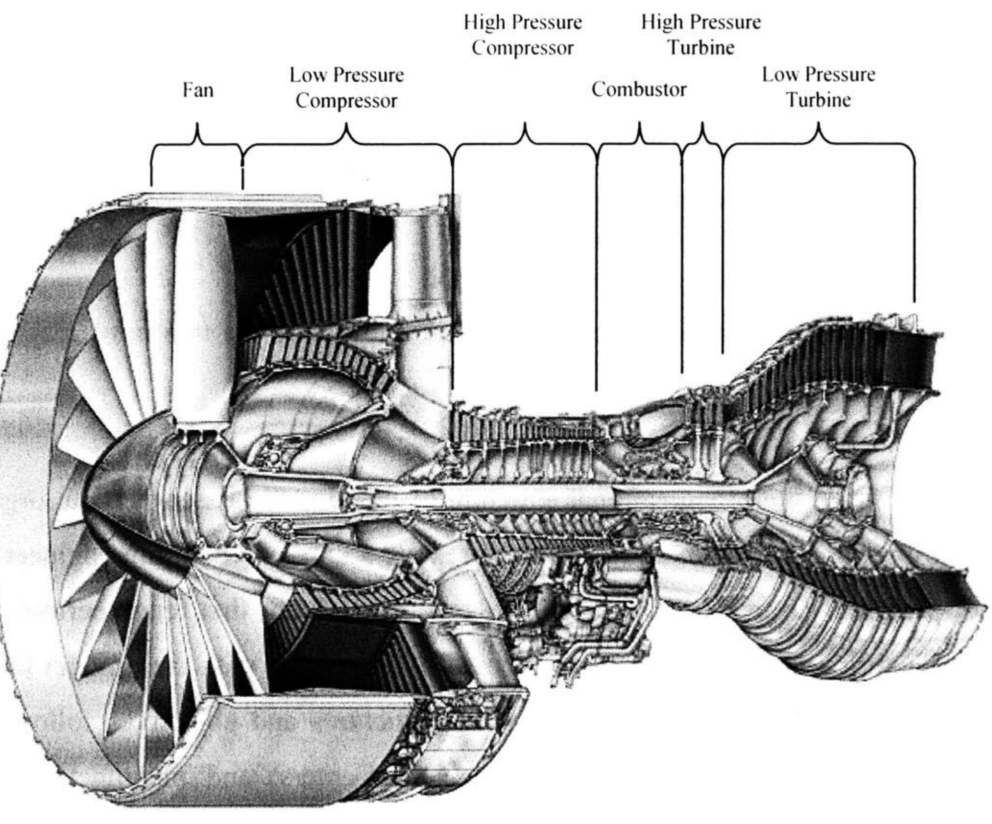

Figure 2.1: Aero Engine Cut-Away

There are many ways to decompose a complex product into simpler chunks. One way is to define the physical attributes of chunks and group them into *part or product families*. For a jet engine, as shown in Figure 2.1, the major product families moving from the engine centerline out are:

[10] Ulrich, Karl T. and Eppinger, Steven D., *Product Design and Development*, McGraw-Hill, Inc., New York, 1995, page 132

- Primary engine shafts
- Rotating disks and hubs
- Rows of airfoils
- Major engine cases
- Engine externals[11]

Another way to decompose the product is to define the functional attributes of the chunks and group them. For the case of the jet engine, shown in figure 2.1, the high level functional chunks from front to rear are:

- Fan
- Low Compressor
- High Compressor
- Diffuser / Combustor
- High Turbine
- Low Turbine
- Gearbox and Accessories
- Engine External Fuel, Air, and Oil Systems

These two decomposition strategies were used to define the two most recent organizational structures.

Coming out of the organizational structure of functionally based vertical organization, Pratt & Whitney recognized that more program focus was required within engineering and formed the program aligned IPD teams. Concurrent with that engineering alignment, the manufacturing organization was re-focused by alignment with the product families. A more in depth description of the organizational structures and objectives follows in Chapter 3. This engineering-program focus (Component Centers) and manufacturing-product focus (Product Center) organizational structure was in place from 1993-1998. In 1999, Pratt & Whitney realigned the engineering and manufacturing organizations into Module Centers, where all engineering design, manufacture, and field support reside within part family focused Business Centers. In many ways, this Module Center is a homogenization of the previous manufacturing and engineering organizations. A more in-depth description of the Module Center structure and discussion of its impact on information flow follows in Chapter 4.

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[11] Externals typically refer to all the tubes and wires on the outside or *exterior* of the engine

As discussed in the introduction, the key focus of this thesis is the review of the impact that the organizational structure has on the information flow during the design, manufacture, or field support for the engine system, component, or individual part. To facilitate this discussion, a brief description of gas turbine fundamentals is included. If the reader would like to find out more about the fundamentals and operation of a jet engine, we recommend *Jet Engines: Fundamentals of Theory, Design and Operation,* by Klaus Hunecke, Motorbooks International, 1998.

2.3 Gas Turbine Fundamentals – A Coupled System[12]

Jet propulsion is the propelling force generated in the direction opposite to the flow of a mass of gas or liquid under pressure, which is escaping through an opening. Since the force generated is proportional to the mass times the acceleration, the approach can be to accelerate a small mass to a large acceleration or a larger mass to a smaller acceleration. A pure turbojet operates with the former approach – small mass / large acceleration while, a turbofan operates with the latter approach – large mass / small acceleration to produce the propulsive force.

This force, or thrust, is produced within the jet engine whenever the momentum of the air or gasses passing through the engine is increased. To create this situation of increased momentum, large quantities of air enter the engine and are compressed to increase the pressure. The compression process is accomplished by passing the air through a series of rotating blades and static vanes that incrementally decrease the air velocity and increase the pressure. This increase in pressure is required so that the fuel addition and resulting combustion process can expand enough to do useful work.

The expanding gas exiting the combustion chamber passes through the turbine section causing the turbine rotors to rotate. The power that the turbine rotors extract from the gas stream is used to drive the compressor through shaft horsepower. If this compression - combustion - expansion system can be executed in a manner with efficient components, then

[12] This section is developed from a Pratt & Whitney internal document "The Aircraft Gas Turbine Engine and its operation" P&W part number 182408, 1988.

enough energy remains to perform useful work. In the case of a pure turbojet, this useful work is to have enough velocity left in the gas stream to provide thrust to the engine. In the case of a turbofan, this useful work required is to have enough energy to drive a secondary turbine, which in turn drives a fan, which accelerates a large volume of air to provide thrust to the engine.

In an effort to increase the efficiency of a gas turbine it is desirable to utilize as high a turbine inlet temperature as possible, but only to a level that the exposed hardware can reliability withstand. In order to withstand these high temperatures, air is bleed off the compressor for use in cooling some of the turbine hardware. The resulting system efficiency is a balancing act between the efficiency gains of increased operating temperatures and the efficiency losses of extracting and distributing air for cooling. The convergence on the overall system performance is an iterative-based process of assumption and feed forward of information and then calculation and feedback of information. This coupled nature of the engine systems leads to the great complexity of the overall system. Also, having greater than 50,000 parts certainly impacts the complexity of the system as well.

Depending on the specific sub-system under review, components can have multiple dimensions and system interactions. A simple high level example, in the turbine, defines four distinct areas where system interaction plays significant role in the detail component design efforts.

1. Mechanically the turbine rotors are connected to the compressor rotor through a shaft.
2. The operating environment of the turbine requires a cooling system, with obtained by bleeding air off the compressor.
3. Turbine efficiency is heavily dependent on blade tip / flow path clearance. Methods employed to control this clearance include active cooling of the engine case structures, which position the outer diameter of the flow path, with air also obtained by bleeding air off the compressor.
4. Design for some turbine hardware is based on a sub-system failure limiting operating condition, where the limiting sub-system may be in the Fan section.

While this view started with hardware and worked upstream to find the source of the coupling, another way to look for the coupling in a jet engine is to perform a variation on the decomposition, described earlier in this chapter. The previous decomposition dealt with aggregating the hardware into similar part families by the functional sections of the engine. Another way to decompose the jet engine is to first recognize the need for air management, and then decompose the engine into two sub-systems: the physical hardware and the *air* [13]. This cooling air, also referred to as secondary air,[14] is the lifeblood of the engine and creates many of the system level interactions between hardware components, which otherwise share no mechanical interactions. Two high level examples were provided previously. In practice, there are hundreds of sub-systems in a jet engine linked to one another by way of the secondary air interaction.

[13] In this context, we are referring to the cavities created by the physical hardware as the portion which is *air*

[14] In a jet engine, the air which is in the gas path providing thrust is referred to as *primary* air, and the required by non-thrust producing air is referred to as *secondary* air.

Chapter 3

Component/Product Center Organization

3.1 Background

This chapter is intended to provide a detailed background on the organizational structure that existed at Pratt & Whitney prior to the transition to the Module Centers. This background information will provide a better understanding of the knowledge capture and information flow issues that resulted during the transition to Module Centers which will be discussed in detail in later chapters.

By 1998, the Integrated Product Team (IPT) methodology was part of the corporate culture at Pratt & Whitney. All sectors of the company including strategic planning, program management, engineering product development, and customer support had adopted organizational structures and processes consistent with what Pratt & Whitney designated Integrated Program Deployment (IPD). The overall organizational architecture of Pratt & Whitney at this time consisted of centralized co-located engineering, systems integration, customer support, and program management organizations focused on product design, development, and field support. The manufacturing organization was decomposed into Product Centers that focused on producing a specific family of parts across multiple programs. These product centers were not only primarily geographically dispersed from the engineering organizations but also dispersed relative to one another.

In this chapter, we review the Pratt & Whitney organization as it existed prior to the implementation of Module Centers. Roles and Responsibilities of each organization and the methodology used for communication and information flow will be described.

The overall organization at Pratt & Whitney consisted of several additional organizations not listed above, including Human Resources, Financial, Advanced Programs, Marketing, and Management Information Systems. For simplicity throughout this thesis, these organizations will be mentioned in context with membership on various IPTs but will not be specifically addressed. The authors' intent was not to lesson the importance of these organizations, but to simplify the analysis of the communication and information flow issues that resulted in the transition to Module Centers.

3.2 The Pratt & Whitney IPD Organization[15]

The complexity and high degree of system coupling in jet engine design, development, and support results in a tiered, hierarchical IPT structure at Pratt & Whitney, as shown in Figure 3.1. This section describes the structure of the IPT architecture at Pratt & Whitney and provides a summary of the roles and responsibilities of each of the integrated product teams. The organizational representation and reporting structure will also be discussed.

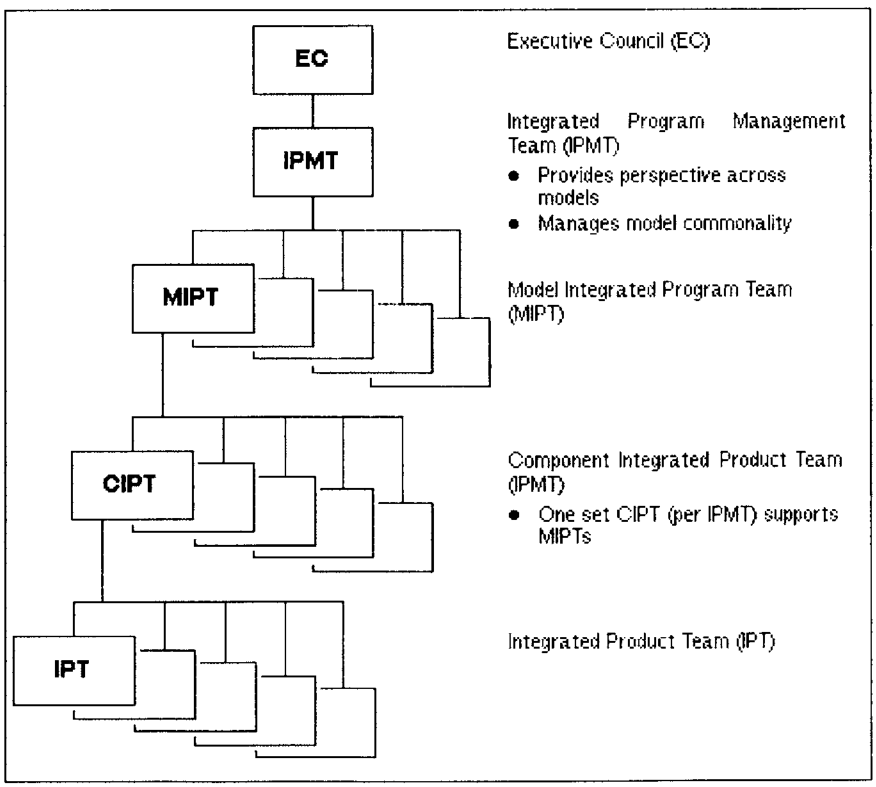


Figure 3.1
Integrated Program Deployment Team Relationships[16]

[15] Section 3.2 and subsection contain information developed from the unpublished "Operating Guidelines for Integrated Program Deployment at Pratt & Whitney", Pratt & Whitney, June 25,1998
[16] Ibid, pp 26

The high level engineering organizational decomposition at Pratt & Whitney is by engine family, then by module or component within a specific engine family. The overall discussion of the IPD organizational structure a Pratt & Whitney will be modeled after the PW4000 family of engines, but should be considered representative for all engine families.

3.2.1 Integrated Program Management Team/Model Integrated Program Team (IPMT/MIPT)

The IPMT is an integrated senior level management team responsible for ensuring all programs and customer requirements are satisfied. The cross-functional IPMT is led by a Program Vice President and has representation from Design Integration, Systems Analysis, Product Validation, and Customer Support. The IPMT provides direction, budget, scheduling, system level requirements, and organizational goals to the CIPTs and Manufacturing Operations. The IPMT is authorized to make all engine configuration decisions based on recommendations from the CIPT.

Typically, engine programs have multiple models that are managed by individually by Model Integrated Program Teams (MIPT). The MIPTs report directly to the IPMT and have the identical team membership as the IPMT. The MIPT manages the day to day activities of the CIPTs and Customer Support to ensure all program objectives (i.e. cost, weight, performance, schedule, and budget) are satisfied. The MIPT also determines the priority of all CIPT tasks and provides funding for the completion of these tasks that is consistent with the overall program financial plan and actively manages these task funds to meet the determined plan.

3.2.2 Component Integrated Product Team (CIPT)/Component Center

The CIPT, as a delegate of the IPMT/MIPT, leads the IPTs within a given module and engine program to ensure all program level objectives are met. The CIPT is responsible for the integration of all their respective IPT efforts at the component system level. The CIPT interfaces with System Design and Component Integration (Systems engineering) and manages the component system boundaries to ensure the total engine system requirements are met or not adversely effect by any component system changes or issues. The CIPT is responsible for obtaining necessary funding from the MIPT/IPMT and managing these funds to the schedule and objectives agreed to with the MIPT/IPMT.

The CIPT serves as the primary technical interface with the customer and the MIPT focal point for dealing with all Post Certification Engineering (PCE) efforts. The CIPT leader is responsible for assembling and leading all necessary IPTs during field issue investigation and resolutions. The CIPT model mangers are responsible, through the work of the IPTs, for determining root cause and corrective action of all field issues involving their component.

A representative CIPT exists for each module (component) of the engine; Fan, Low pressure compressor, High pressure compressor, High pressure turbine, Low pressure turbine, Externals, Controls, and Mechanical Systems. The core CIPT management team consists of component design, project, structures, aerodynamics, secondary flow systems, manufacturing, and performance disciplines.

3.2.3 Integrated Product Team (IPT)

The IPT is responsible for all aspects of designing, developing, and validation detail parts or groups of parts, such that, all component level requirements established by the CIPT are satisfied. The IPT membership consists of engineers from component project, design, systems, structures, supplier management, customer support, repair support, and manufacturing.

Based on the IPT membership, this level is where Manufacturing and Supply Management is integrated into the IPD process. The IPTs are not only responsible for the design of hardware at a part family level, but also for the integration of manufacturing and supply management to ensure the manufacture, tooling development, and production incorporation of new configurations.

The complexity of a jet engine has resulted in the formation of a large number of integrated product teams, as shown in Figure 3.2.

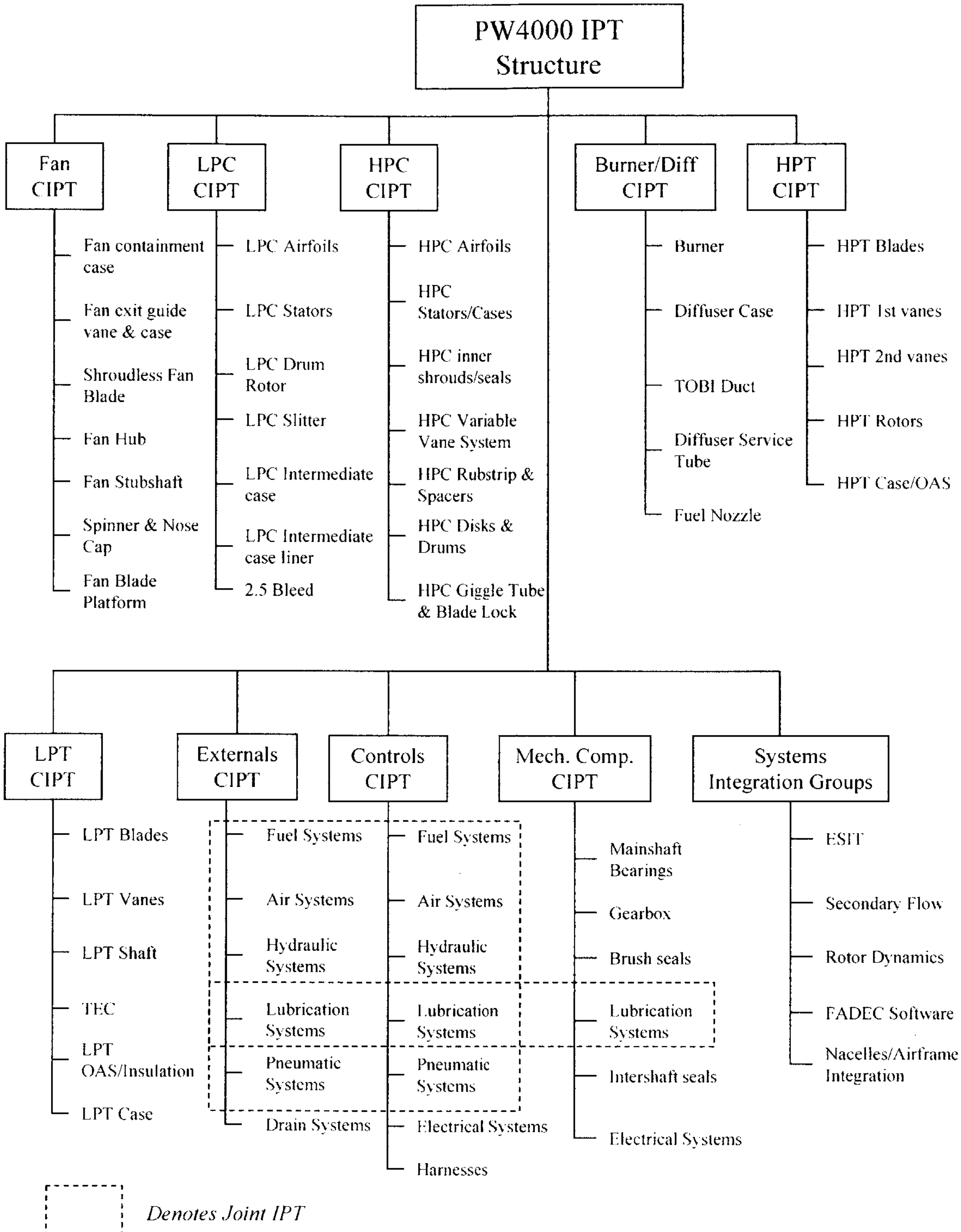


Figure 3.2
PW4000 Pratt & Whitney Integrated Product Team Structure (1998)

3.2.4 System Engineering Organizations (1998)

In 1997, the System Engineering organizations were created at Pratt & Whitney. The complexity and coupled nature of jet engine design, development, and manufacture drove the implementation of the systems engineering process. The systems engineering processes at Pratt & Whitney are rigidly structured and detailed throughout the product development life cycle. Each phase of the product development cycle, from customer requirement definition to in-service support, is decomposed into system level engineering tasks. Each task has defined information inputs and outputs, similar to the DSM methodology, and assigned systems engineering owner.[17]

The high level objectives of the systems engineering organizations at Pratt & Whitney is best described in the UTC Systems Engineering Definition and is captured in Figure 3.3:

"Systems Engineering is the process which rigorously translates customer needs into a structured set of specific requirements, synthesizes a system architecture that satisfies those requirements, allocates them in a physical system, meeting cost, schedule, and performance objectives throughout the life cycle."

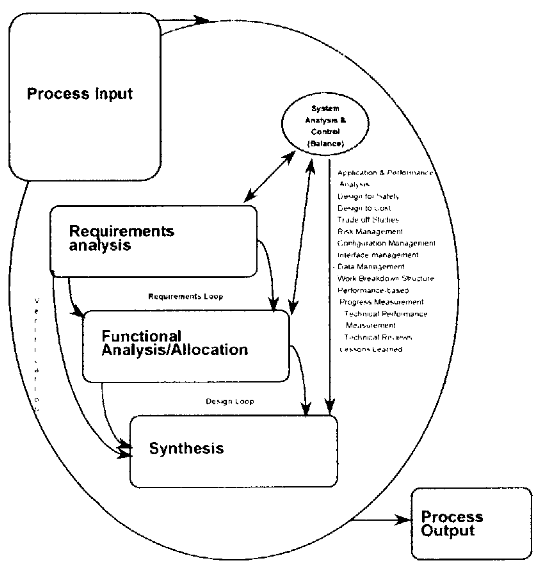


Figure 3.3
UTC Systems Engineering Process[18]

[17] The detailed Pratt & Whitney systems engineering process is proprietary
[18] "PW Systems Engineering Process", Unpublished, June 1998

The systems engineering organizations are responsible for the integration of the individual CIPT and IPT efforts to ensure the engine level metrics (weight, cost, performance, etc) are satisfied. Several systems engineering organizations at Pratt & Whitney are represented on the IPMT/MIPT. These Pratt & Whitney system engineering organizations are:

- Systems Design and Component Integration (SD&CI)
- Propulsion Systems Analysis and Integration (PSAI)
- Product Development and Validation (PDV)
- Manufacturing Systems Engineering and Integration (MSE&I)

3.2.5 Systems Design and Component Integration (SD&CI)

The SD&CI organization is primarily responsible for the management of the design integration between components (CIPT/IPT) and, with the MIPT, all engine level metrics, such as weight, cost, and performance. The SD&CI engineers work closely with the CIPTs and IPTs to understand how their component design effects other components and the engine systems as a whole. SD&CI's main responsibilities also include the management of the secondary flow and thrust balance systems.

SD&CI manages engine configuration and control through the chief design engineer who leads a cross-functional Configuration Control Board (CCB) that is responsible for the approval of all engine design configuration changes. The CCB process ensures all engineering changes have gone through the proper level of substantiation and have completed the proper steps to establish production drawing, engine manual updates all with program management approvals.

The SD&CI Conducts the formal design review process at Pratt & Whitney that ensures the design, and ultimately, the product is mature enough to progress to the next product development phase or introduction into service.

3.2.6 Propulsion Systems Analysis and Integration (PSAI)

The PSAI organization is responsible for the interpretation of customer requirements into systems level engine performance characteristics. These system level requirements are then decomposed by PSAI engineers into component level requirements, in the form of design tables, and assigned to the CIPT organizations for design, fabrication, and validation.

PSAI completes all engine simulations and modeling to aid SD&CI through conceptual and preliminary design trade studies. PSAI analyzes all engine test data during product development testing and flight testing. PSAI develops and validates all engine systems software, which is critical to satisfying all system level and organizational requirements. Additional responsibilities of PSAI include:

- Engine Cycle definition
- Engine Systems Analysis
- Performance & Operability Components Requirements Tracking
- Inlet Engine Compatibility
- Systems Level Root Cause Analysis
- Mission Analysis
- Propulsion & Aircraft Systems Integration
- Noise and Emissions Analysis

3.2.7 Product Development and Validation (PDV)

The PDV organization is responsible for the development and validation testing required to substantiate a new engine configuration or part design. The PDV organization is considered the traditional Engine Test organization that coordinates and designs the overall test and validation programs, which results in the optimized test sequence for cost, schedule, and customer (CIPT/IPT/MIPT) requirements satisfaction. The PDV engineers conduct the actual engine test ensuring all critical data is obtained, complete the post test analytical tear down inspections, prepare build, test, and tear down report summaries for distribution to the CIPT's. PDV also coordinate the completion of all necessary Federal Aviation Authority (FAA) validation reports to obtain engine certification and support engine flight test programs.

3.2.8 Manufacturing Systems Engineering & Integration (MSE&I)

The MSE&I is responsible for the integration of new development programs into manufacturing. MSE&I has representatives on the MIPT/IPTM. Its primary functions include assisting Program Management and the CIPT's in source selection and coordination, product scheduling, supply chain interfacing, product cost, and manufacturing technology readiness. MSE&I also develops tooling development and integrates best practices such as Quality Control Process Charts (QCPC) in the production of hardware to ensure a quick learning curve, process standardization, and the implementation of "lessons learned".

3.3 Product Center Organizations

The Pratt & Whitney Product Center organizations were centralized manufacturing facilities that contained all necessary resources for the production of part families. Each Product Center organization consisted of procurement, financial, manufacturing engineering, tooling design, human resources, business unit leadership, and manufacturing hourly functions. The Product Centers were cost centers responsible for meeting production hardware deliveries within an agreed upon budget and schedule. Limited design or systems engineering resources were located in the Product Centers[19].

The Product Center organizations were aligned along a part family decomposition of the jet engine. Each Product Center produced a specific family of parts across multiple engine programs to take advantage of the similar manufacturing processes utilized to produce similar parts. This part family decomposition was significantly different from the program specific modular decomposition of the design and systems engineering organizations detailed previously. The Product Center organizations and their locations in 1998 included:

- Cases & Combustors — Middletown, CT.
- Rotors & Shafts — Middletown, CT.
- Turbine Airfoils — North Haven, CT.
- Externals and Mechanical Systems — East Hartford, CT.
- Stators — North Berwick, ME.
- General Machining — East Hartford, CT.
- International Partners Procurement — East Hartford, CT.
- Small Parts Procurement — Middletown, CT.

[19] The Turbine Airfoils Product Center (TAPC) was the exception. In 1995, some design engineering functions were co-located in TAPC. The CIPT and project functions remained in East Hartford. This partial co-location was a precursor to the transition to Module Centers.

The typical organizational structure within a Product Center consisted of multiple business units that utilized cellular manufacturing techniques to product specific part families with separate functional groups reporting to the product center general manager.

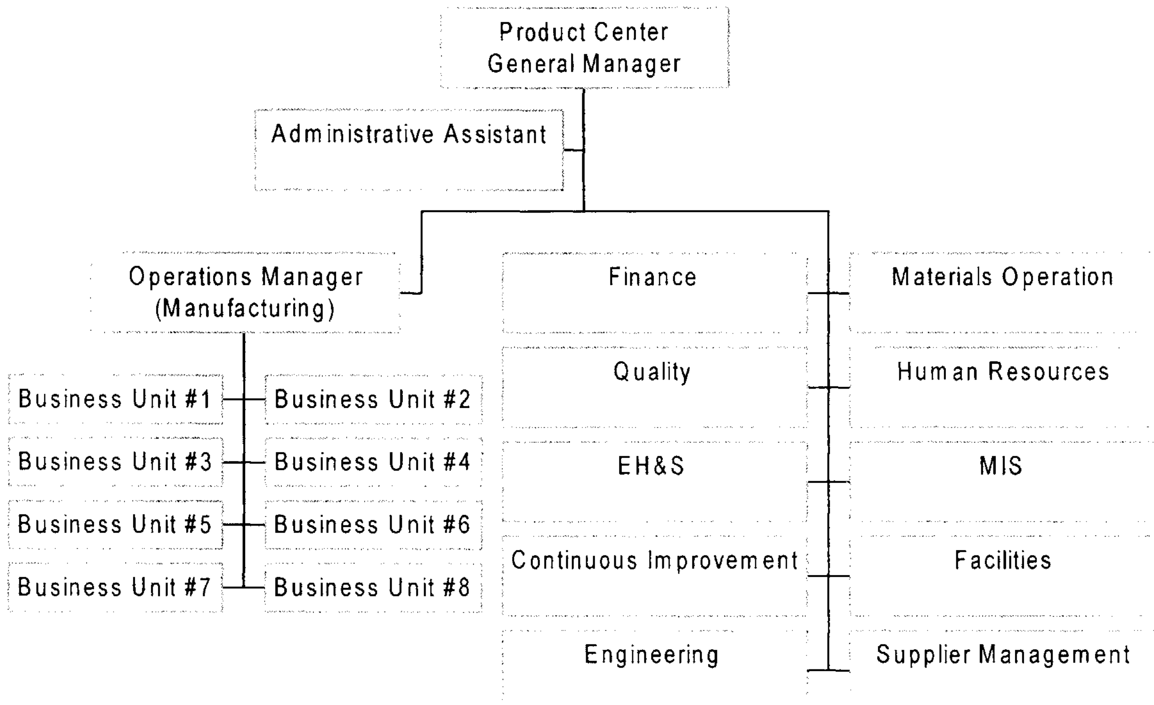


Figure 3.4
Product Center Organizational Structure (typical)

International Partners and Small Parts Procurement Product Center organizational structure differed from Figure 3.4 because it did not contain the operations branch. All hardware was purchased from outside vendors or partners in these Product Centers.

3.4 Organizational Reporting Structure

One of the significant changes that resulted in the reorganization to Module Centers was the reporting structure of the engineering organization. A multiple branch reporting structure existed at Pratt & Whitney prior to the transition to Module Centers that included separate Operations, Engineering, and Programs branches. The breakdown of each of these branches is pictured in Figure 3.5.

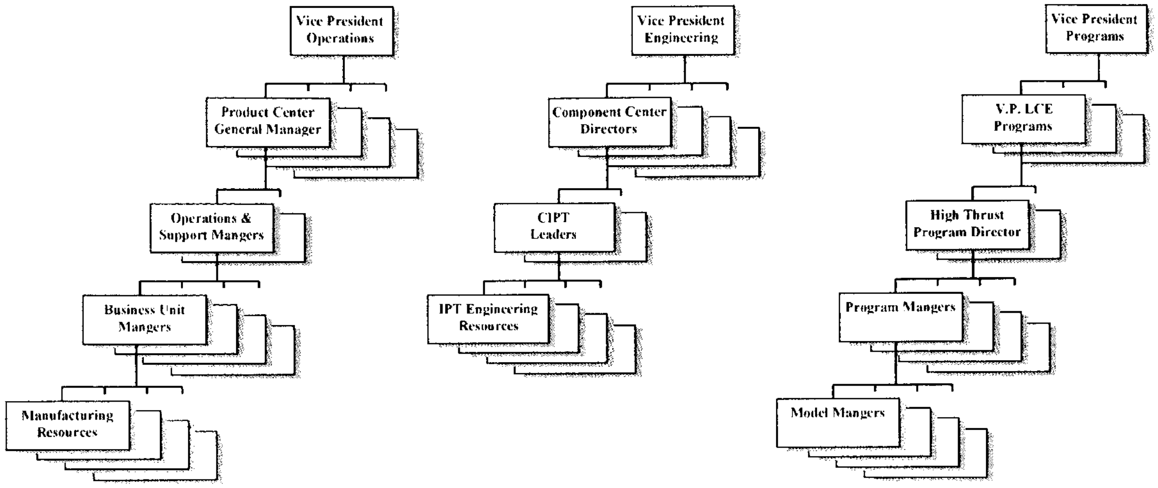


Figure 3.5
Pratt & Whitney Reporting Structure

The difference between the hierarchy of IPTs from Figure 3.1 and the actual reporting structure is significant. While the CIPT took direction, obtained funding, and worked closely with the IPMT/MIPT they were only considered a "delegate" of the IPMT/MIPT and did not report directly to the Program Business Office Vice President (IPMT). The IPMT did have considerable input, as a customer, in the performance review of the CIPTs, but it was not a direct reporting link.

Conversely, the engineering resources including structures, aerodynamics, project, and design that were core members of the individual IPTs did report directly to the CIPT leader, who reported to the Component Center director. This reporting structure allowed the CIPT's, with priorities established by the IPMT/MIPT, to actively manage all engineering resources required their specific module. The flexibility or resource allocation was critical in dealing with field issues and post certification engineering activities that required quick response and dedicated efforts from the CIPT/IPTs. The control of these resources is an important attribute in the organizational structure at Pratt & Whitney.

The Product Center organizations reported directly to the Vice President of Operations. The only link to the engineering organizations was the manufacturing engineering and procurement representation on the engineering IPTs. Because the manufacturing representatives were not reporting directly through the CIPTs, influence on their priorities was limited.

3.5 *Knowledge Capture and Information Flow Processes*

In the Integrated Program Deployment (IPD) environment at Pratt & Whitney, meetings are the primary method of knowledge and information flow between the various integrated product teams. In the co-located engineering structure that existed prior to module centers, these meeting were typically face-to-face meeting with all stakeholders present, and information technology needs were limited. The information flow and communication initiated during the face-to-face meeting were significantly augmented through the efficiencies of co-location. Follow-up "causal" information flow was typical in hallway conversations, desk visits, and outside meeting discussions. E-mail and voice mail were utilized as secondary communication tools for individuals who could not be located, information files that needed to be transferred, general communication, or documentation of a conversation.

3.5.1 Meetings

Information flow, shown in Figure 3.6, between the CIPT engineering disciplines, the program business office, customer support and systems integration was completed during regularly scheduled MIPT or systems integration Chief Engineers meetings. Program level direction, funding, scheduling, and priorities were established for the CIPT at the MIPT meetings, which took place three times per week for each program. Technical evaluation and systems integration communication with the CIPTs for major design challenges were resolved during daily systems integration Chief Engineer's meetings.

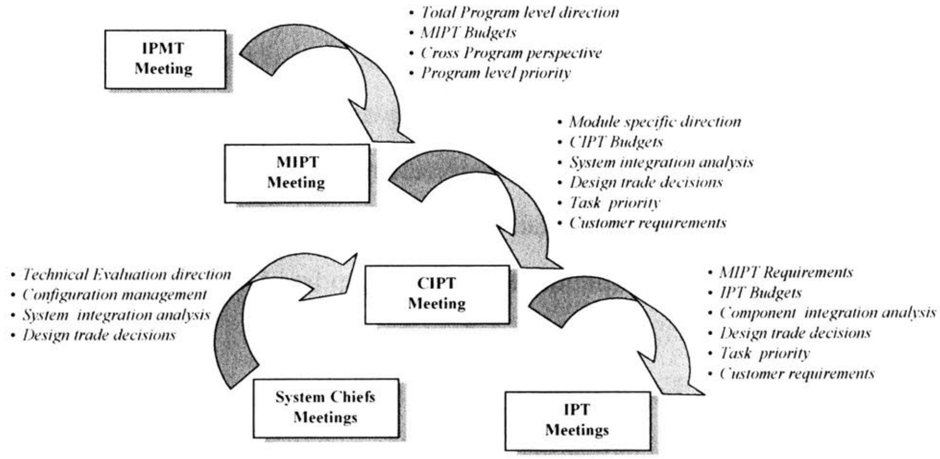


Figure 3.6
Meeting information flow

3.5.2 Co-location

The benefits of co-location in the information flow and knowledge capture of the IPD environment at Pratt & Whitney was not fully understood until it change with the Module Center implementation, specifically, in the systems integration function. The daily Chief Engineers meeting is a valuable tool for information flow and technical decision making for large issues. But, due to the complex nature and coupled design of a jet engine, thousands of system integration issues are resolved or communicated during informal face-to-face discussions between IPTs, systems integration engineers, and the program business office. The efficiencies of co-location made all of this information flow and knowledge transfer possible. Very often, 'casual' interactions communicated subtle but clear messages, small changes in direction, and system interaction management.

3.5.3 Experience Base Knowledge

The experience based knowledge possessed by the members of the IPT and CIPT was a significant contributor to the communication and information flow paths in the Component Center/Product Center environment. Typically, the IPT leaders and CIPT leaders were experienced individuals that had good overall knowledge of how their specific part or components effect the overall engine system. If a change was made to a specific part or component, the IPT leader or CIPT leader knew how it affected the interfacing systems, at a high level, and who to flow the information to ensure proper system integration of the change. This tacit knowledge transfer greatly facilitated the systems integration management of the efforts of the IPTs and CIPTs. As long as the knowledge base resided in the CIPT, a formalized systems integration communication methodology was not critical. Standard Work was utilized to capture detail part design knowledge, best practices, and validation requirements, but was not implemented at a system level.

3.5.4 Information Technology

The combination of IPT meetings and co-location limited the direct need for complex information technology tools. The CIPT leaders, IPT leaders, and Discipline Chief Engineers, and Chief Systems Engineers were the primary knowledge repositories and the IPD methodology and co-location facilitate effective information flow of the knowledge captured in these individuals.

E-mail or voice mail was typically used as the primary information technology tools for communication to support the decisions or action items generated during the various integrated product team meetings.

Lotus Notes was utilized is several specific areas, including field issue communication, test job requirement documentation, and Product Development &Validation reports. This tool was not universally used throughout all the engineering or Product Center organizations.

The internal Pratt & Whitney Intranet was utilized for general communication, such as job postings, Standard Work documents, policies and procedures, and ISO9001 documentation. Each Product Center and many of the engineering organizations developed their own web sites for high level organizational communication. The Intranet was not used as an active information flow device.

3.6 Organizational Analysis/Summary

This chapter reviewed, in detail, the organizational architecture that existed at Pratt & Whitney prior to the implementation of the Module Centers, which is covered in Chapter 4. The existing architecture, prior to the Module Centers, had many benefits in Product development and Systems integration, but was weak in the integration of manufacturing and engineering. This section provides a brief summary of the benefits and weaknesses, from knowledge capture and information flow perspectives, of the existing organizational architecture.

3.6.1 Benefits of CIPT/Product Center organization

One of the primary benefits of the organizational structure as it existed prior to the Module Centers, was the co-location of the Engineering, Systems Engineering for each program, Program Management, and Customer Support. The benefits of co-location greatly facilitated the communication and information flow within each CIPT at the component level and between components at the system level. Outside of the scheduled meetings, systems engineers often communicated face-to-face with the IPT and CIPT engineers to manage system level integration issues. Program management decision were easily communicated at the MIPT meetings and getting the proper attendance was not an issue, as all the required resources were located in the same building.

The benefits of co-location were particularly important when dealing with critical field issues, or Post Certification Engineering (PCE) work. Timely response and resolution of customer related field issues are critical for achieving customer satisfaction and reducing unnecessary financial exposure. Often, daily meetings are required to provide timely response and to determine the best possible solution to critical customer issues and Pratt & Whitney stakeholders.

The authors find it interesting that in the Module Center organization during the conceptual and preliminary design phases of new product development, the process methodologies will co-locate all necessary design and systems engineering resources with Program management. This is intended to manage the iterative nature of new product development, facilitate the large number of system level interfaces required during design iterations and trade-off, and reduce the product development cycle time. This process is supported through the analysis of the DSM constructed by Greg Mascoli and his conclusions[20]. He states that:

"The Conceptual and Preliminary Design phase of the engine program are extremely iterative in nature. It makes sense to co-locate the System engineers with Component Team members during this phase to facilitate design trades and iterations."

We agree with this conclusion, but wish to address the fact that redesign efforts are typically required during field issue resolution and have the same iterative nature requiring many design trade evaluations.

Finally, one the other critical benefits of the exiting CIPT/Product Center organizations was that the IPT design, aerodynamics, systems, and project engineering resources reported directly to their respective CIPT leaders. This is extremely important and allowed the CIPT leader to effectively manage their resources to meet program level requirements and provided flexibility in dealing with the unanticipated workload resulting from field issue resolution activity.

3.6.2 Weaknesses of CIPT/Product Center Organization

The primary weakness of the CIPT/Product Center organization was the poor integration of manufacturing and engineering. Initiatives such as existing product cost reductions, design for manufacturing, design for cost, or design for assembly were very difficult to achieve. The individual IPTs had manufacturing representation, but that's what it primarily was, just representation. It was very difficult to truly integrate manufacturing and engineering for several reasons including:

- Manufacturing not co-located with engineering reducing the amount of information flow between the groups
- Large number of IPTs required for the complex design of a jet engine prohibited the true integration of manufacturing and engineering, simply not enough manufacturing resources or time to properly support all IPTs

[20] Mascoli, G.J. "A systems Engineering Approach to Aero Engine Development in a Highly Distributed Engineering and Manufacturing Environment", Systems Design and Management Thesis, Massachusetts Institute of Technology, January 1999, pp 88

- Cultural design engineering mentality of technical requirements optimization resulted in secondary importance of design for manufacturing, cost or assembly

The Module Center organizations have addressed the manufacturing integration issue and the lack of information flow across programs. At each Module Center all required engineering resources are co-located with the manufacturing engineers. This should facilitate the information flow between these groups and result in an atmosphere for successful design for cost, manufacturing, and assembly products. The issue of cross program communication is also addressed with the new Module Center organizations, which have aligned the engineering resources along part families across all programs and not components specific to one program, as will be described in the following chapter. "Lessons learned" and design methodologies across all programs will be easily communicated in the new organization.

The Module Centers provide solutions to the issues of the previous CIPT/Product Center organizations, but there are trades. Systems Integration, program management communication, and field issue resolution has become more difficult in the dispersed engineering Module Center organization. The information flow processes and knowledge capture tools need to evolve with the new organization to ensure effective management of system level issues and continued timely support of field issues. It the objective of this thesis to identify the knowledge capture and information flow issues created with the transition of Module Centers and recommend potential solutions.

Chapter 4

CIPT/Module Center Organization

4.1 Overview

The transition to the Module Center organizational structure is an extension of the Integrated Program Deployment (IPD) methodology to more fully encapsulate manufacturing and to leverage the benefits of an extended value stream within the organization. The Module Centers have full product ownership of their respective components with co-located disciplines required to support the product from raw material procurement to customer delivery and beyond in terms of support of product in the field.

The first thing to recognize in the Module Center structure is that the detailed part design IPTs and manufacturing are together physically and organizationally. In simple terms, the transition to Module Centers co-located the detailed part IPTs at the manufacturing facilities. This change, which was initiated in late 1998, became operational in early 1999. Pratt & Whitney organized into five Module Centers, which correspond to engine sections. The Engine Center is an exception because they are responsible for engine assembly, but contain engine level activities, such as development engine test and production engine delivery.

1. Engine Center	EC	Middletown, CT
2. Electronic & Mechanical Systems Module Center	EMSMC	East Hartford, CT
3. Compression System Module Center	CSMC	Middletown, CT
4. Combustor, Augmentor & Nozzle Module Center	CANMC	East Hartford, CT
5. Turbine Module Center	TMC	North Haven, CT

Each Module Center contains all the required organizations/disciplines to support the personnel, products, and services: Human Resources, Environment Health and Safety, Facilities, Machine Services, Information Systems, Finance, Quality, Continuous Improvement, Mechanical Design, Manufacturing Engineering, Procurement, Commodity Management, Project, Secondary Flow, Heat Transfer, Aerodynamics, and Structures.

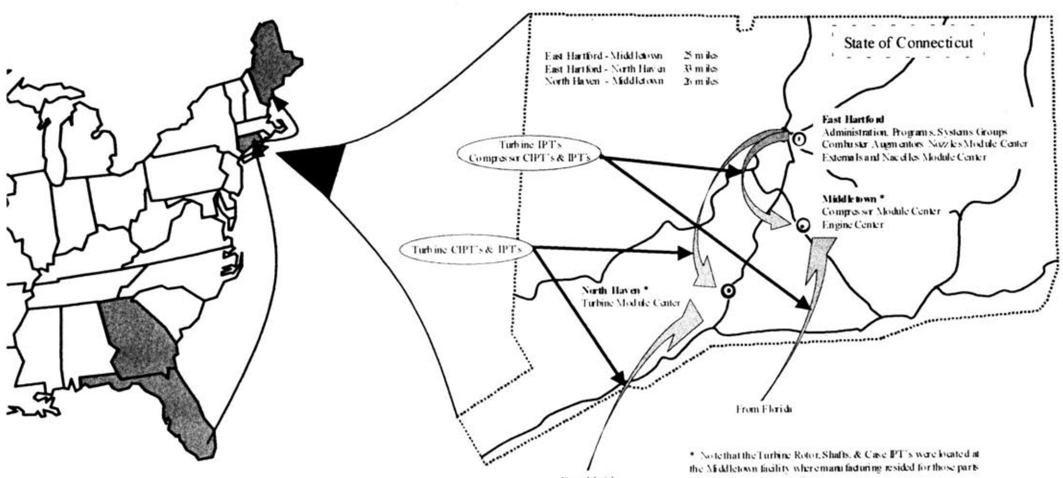
The prior organizational structure at Pratt & Whitney with the manufacturing Product Centers and the engineering Component Centers made it difficult to see the full value stream to eliminate the *muda*[21]. This new structure provides a tremendous opportunity for value stream optimization, but it comes with an increase in organizational interaction costs.

4.2 Module Center Deployment - Physical Site Changes

One of the cornerstones of the Module Center concept was to have all the resources for designing and manufacturing that module reporting together and co-located. While this transition entailed significant changes to organizational reporting structure, the impact of significant relocation of personnel from one facility to another can not be overstated (see Figure 4.1). The primary thrust of this relocation effort was in dispersing the engineering talent from the two primary plants in West Palm Beach, Florida, and East Hartford, Connecticut, to the Module Centers.

While the movement of personnel from our engineering plants in Florida to manufacturing centers in Connecticut may have accounted for the largest distance change, the movement from site to site within Connecticut was more numerous and more challenging.

Figure 4.1: Personnel Relocation



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[21] *Muda*, Japanese word for "waste". In general, it is any activity that consumes resources, but does not create value.

The cornerstone of the Module Center concept was co-location of all the activities for that center. This meant that in addition to the relocation of engineering personnel, the co-location extended to all of the manufacturing activities. The prior Product Centers were formed around part families across the engine and, as a result, contained parts belonging to multiple engine modules. To arrive at the true Module Center vision, the manufacturing personnel and equipment would have to be segregated according to Module needs. While this type of a structure may be relatively easy to set up with a green field site, it is a different challenge to extract from facilities that have been established and operating for decades. While this full manufacturing co-location with the Module Center home was always the vision, in some cases, it will not occur with the initial Module Center formation due to cost and schedule constraints.

4.3 IPT Co-location with Manufacturing

The Product centers had been formed across part families. This alignment was put in place to achieve the benefits of manufacturing process commonality across a wide range of parts within part families. This manufacturing based co-location was employed strategically to identify the best of the manufacturing practices and apply them consistently across all the parts in the family. The manufacturing centers were able to modify processes that were consistent with our Engineering Source Approval (ESA), but if changes impacted the detail part fit, form or function, that needed to be engineering IPT approval. Once the IPT evaluated and approved the change, it was routed through the CIPT and Pratt & Whitney's Configuration Control Board (CCB) for production incorporation.

This type of activity caused roadblocks for the Product Centers due to priority conflicts. The manufacturing sites were unable to complete IPT review and change authority in a timely manner. The CIPT/IPT organization metrics did not drive behavior to fully support Product Center cost reduction efforts. Thus cost reduction opportunities were not being realized. The Module Center cornerstone of integrating engineering and manufacturing addressed this Product Center weakness.

Movement of the IPTs to the Module Centers was a significant change to the way the company had operated for the preceding eight years. The transition to Module Centers removed the detailed part IPTs away from the CIPTs, both physically and reporting structure, and placed the IPTs at the manufacturing facilities, reporting with manufacturing, to the Business Center Managers. Each of these Business Centers within the Module Centers is focused on a part family. These changes while dramatic to the direct *control* of the CIPTs over their IPTs, was done to fully realize the cycle time and cost benefits of integrating part design and manufacturing.

4.4 Reporting Structure and Co-location

In the Component Center organization, the IPTs were co-located with and reported to the CIPTs. In the Module Center structure, the IPTs continue to support the CIPTs and respond to their priorities for engine program issues, but they report to the Business Center. Figure 4.2 illustrates the change going from the Component Center/Product Center structure to the Module Center structure.

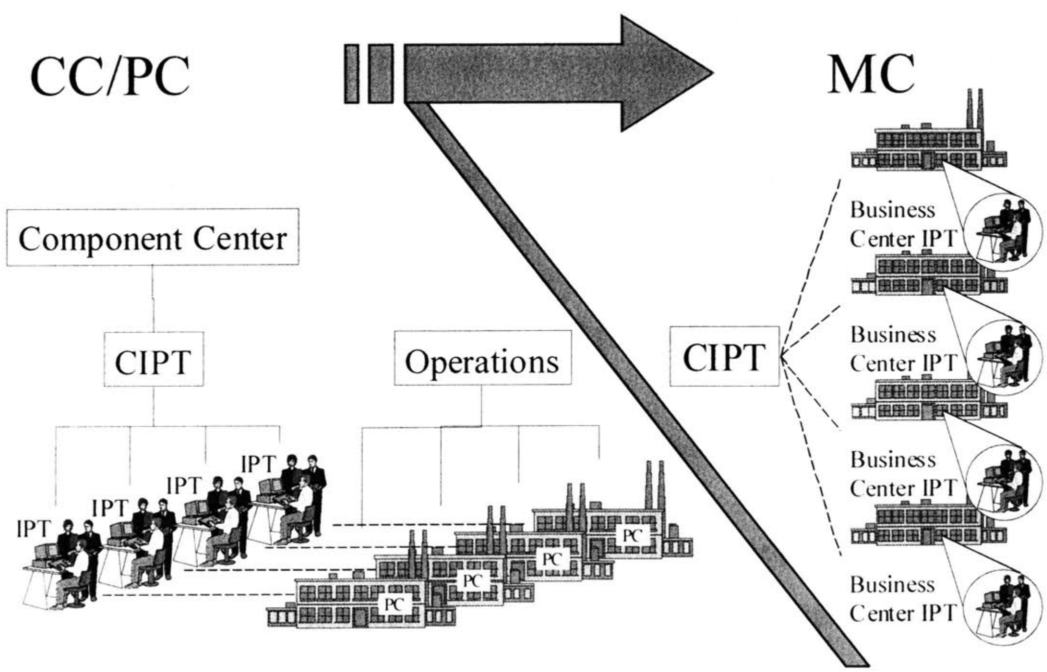

Figure 4.2: IPT Structure - Product Center vs. Module Center

In the Component Center/Product Center organization, the IPTs were co-located by engine program in order to achieve program focus that had been lacking in the preceding functional organization. This program alignment, while a benefit for engine program in terms of priority issues, came at the expense of the technical discipline learning communities. Commonality of process and sharing of best practices were difficult to deploy across programs. Pratt & Whitney recognized this need and created discipline chiefs[22] and implemented Standard Work.[23] These initiatives provided significant improvement and maintained the technical disciplines, but they were missing the critical mass needed to advance the disciplines adequately. Business Center co-location of all the IPTs responsible for a given part attempts to provide this critical mass to facilitate engineering learning.

4.4.1 Roles and Responsibilities of the Module Centers / Business Centers

The Module Center Directors have complete responsibilities from conceptual design through engine retirement for all the parts that comprise their engine module. Each Business Center within the Module Centers is then responsible for their respective detailed parts. The Business Centers execute the design, manufacture/procure the hardware, and provide all necessary field support of the hardware. This structure is intended to drive to the lean vision of full integration of the manufacturing and engineering organizations.

The Module Centers now control most of their fate, since they control nearly all the resources required to execute product design and manufacture for their component parts. While this control is the goal, significant aspects of component design still rely on information from outside the Module Centers. The hierarchy of activity for product design starts at the system level and then works it way to engine section requirements and ultimately to detail part requirements. This part level distribution of the design task occurs after the system level issues have been fully characterized. While system level issues flow down to the Module Centers, detailed part and module configurations have to flow back and to the system level for iterative evaluation. Thus, the Systems Engineering organizations are fully retained and have not been organizationally altered.

[22] Disciplines: Design, Structures, Manufacturing, Project, Drafting, Aero, Heat Transfer.

4.4.2 Roles and Responsibilities of the CIPT

The strong success of the IPD structure, including the CIPTs interface role to the engine program office and component level integration, is fully retained as described in detail in Chapter 3. The CIPTs continue to serve as the primary technical interface with the customer and the MIPT focal point for dealing with all Post Certification Engineering (PCE) efforts. The CIPT leader is still responsible coordinating all necessary IPTs during field issue investigation and resolutions. The CIPT model mangers are responsible, through the work of the IPTs, for determining root cause and corrective action of all field issues involving their component.

Recognize that the execution of this role has been significantly complicated with the reporting structure change, part family focus and the dispersed IPT environment of the Module Centers. This is discussed in the subsequent knowledge capture and information flow section of this chapter.

4.4.3 Roles and Responsibilities of the IPT

The IPT responsibilities have not changed, since they are still responsible for all aspects of design, development, and validation of detailed parts (or groups of parts). The engineering to manufacturing interface has been strengthened through the parallel reporting of manufacturing engineers and design engineers to the same technical leader. Similar to the CIPTs, the execution of this role that has been impacted greatly and is discussed in a subsequent knowledge capture and information flow section of this chapter.

4.4.4 Roles and Responsibilities of the System Engineering Organizations

The roles and responsibilities of the Systems Engineering organizations has been unchanged in the transition to the Module Centers. The communication and information flow with the CIPTs and IPTs has been impacted with the reporting structure change, part family focus and the dispersed IPT environment of the Module Centers.

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[23] Standard Work is a set of documents that describe the requirements, tools/procedures used and the results associated with Product Development tasks.

4.4.5 Roles and Responsibilities of the Engine Program Management (IPMT & MIPT)

The roles and responsibilities of these management teams is unchanged in the transition to the Module Center structure, although the communication and information flow with the CIPT's has changed dramatically for the same reasons as noted with the CIPTs and System Engineering.

4.5 Knowledge Capture and Information Flow in the Module Center Structure

While some engineering groups were not organizationally altered during this transition to the Module Center structure, all groups were impacted due to the change in communication and information flow that resulted from the physical location movement and reporting structure change of the CIPTs and IPTs.

The changes to the CIPTs and IPTs were along several dimensions. Obvious and visible changes were physical location, composition of the teams, and team reporting structure. To obtain the desired integration and alignment between design and manufacturing along part families, the IPTs were removed from the CIPTs, physically dispersed to the appropriate part family-manufacturing site and organizationally aligned within the respective Business Center. More significant, but less visible changes effected communication strategies and product integration issues.

Two areas that need a change in communication practices are the (IPMT/MIPT) Program Office to CIPT interaction and the CIPT to IPT interaction. As discussed in Chapter 3, these teams had been co-located[24] and significant information flow was completed with formal and informal meetings. The Module Center structure physically relocated the CIPTs to the Module Centers, away from the IPMT/MIPT Program teams. Figure 4.3 provides the Module Center locations in Connecticut. The Turbine and Compression System Module Centers

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[24] The IPT's were fully co-located with the CIPT, the CIPT's were in close proximity (same building complex) to the Program teams

team physically moved 33 and 25 miles, respectively. The CAN Module Center is located at the same site, but the CIPTs were to buildings located across the complex (1-2 miles).

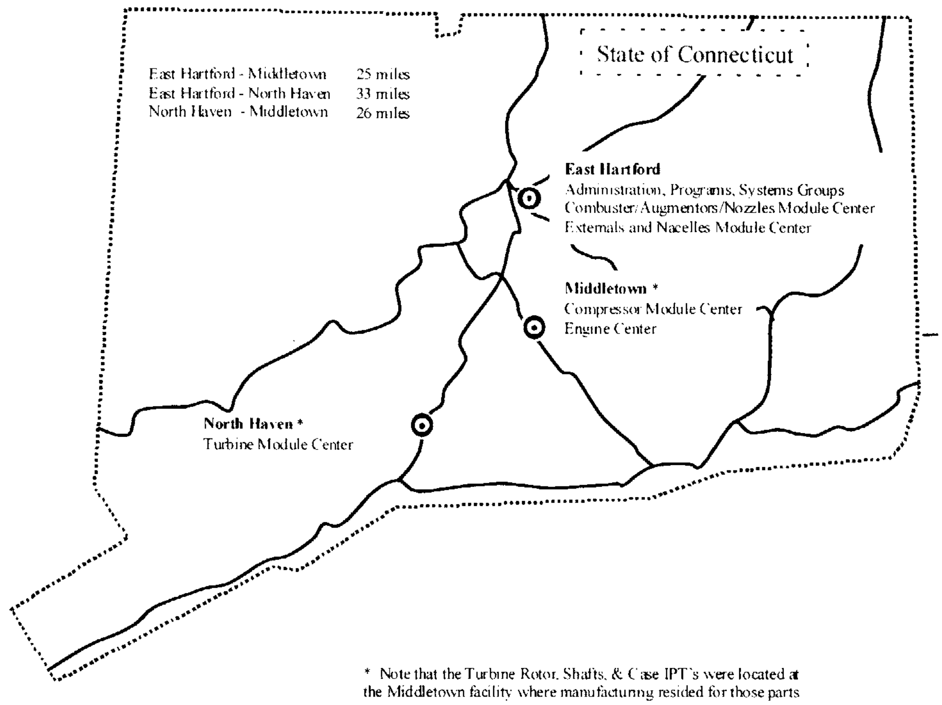

Figure 4.3: Module Center Homes

The significant impact on the Program Office IPMT/MIPT to CIPT value stream stems from the information flow that had been primarily face-to-face with minimal use of information technology. Program office meeting rooms were not equipped with the necessary information technology tools for remote presentations or interactive video capabilities. Because of the relative short distances between the sites within Connecticut, midday site to site travel for face to face meetings was still possible, and unfortunately remained the expectation. While there is a need for face to face meetings, no effective process was defined to deal with this significant change in information flow. The non-productive time on the road traveling to and from meetings is a burden some of the CIPT and IPT personnel and a significant source of wasted time.

Similarly, the significant impact to the CIPT to IPT value stream stems from the old information flow that was also face-to-face due to both the co-location and the IPTs reporting organizationally to the CIPTs. With the Module Center structure four significant differences arose in this area.

1. The IPT's do not organizationally report to the CIPT
2. The IPT's are not co-located with the CIPT
3. The IPT's are not co-located with the other IPT's within the CIPT
4. In some cases, the IPT's are not located at the same site as the CIPT (because of constraints in movement of manufacturing equipment)

4.6 Product Integration Impact From Module Center Structure

A result from the change to the Module Center structure was the need for increased attention and focus on the product integration across IPTs within the Module Centers. The System Design and Component Integration organization was put in place partially in response to the need for cross-CIPT integration of hardware requirements; the Module Center structure also adds *cost* to the System Design and Component Integration function.

It would be easy to assume that each IPT must worry about integration, but the reality of how the IPT functions is that information flow to other IPTs is not a high priority. "It's someone else's job" mentality prevails that may lead to technical escapes.

It is these communication and integration issues that have led us to continue to explore the use of the Design Structure Matrix (DSM) as a facilitating tool. Exploration of the DSM continues in the chapter 6.

4.7 Summary of MC Transition Issues

1. Movement of IPT's to the Module Center Business Centers strengthens cost focus & part family technical learning community
2. Movement of IPT's to Business Centers increases the communication & information interaction costs and weakens component/system integration
3. Movement of IPT's away from CIPT's increases need for CIPT and system integration functions and drives a need for standard knowledge capture and information flow processes
4. Part family focus of Module Centers also contributes to the system and component integration issues

Chapter 5

Research Methodology

5.1 Overview

The focus of this thesis is to explore the issues in initial product development and in post-certification product support as they pertain to information flow and knowledge transfer across design teams, system integration, and program management. We intend to codify issues and opportunities identified as Pratt & Whitney transitioned to the Module Center organizational structure. In this specific case, an additional complexity was the physical site changes that accompanied the organizational changes, as detailed in Chapter 4. During our research, we were investigating issues that had already presented themselves as well as issues that would be expected to arise as the transition progressed.

Our overall research process compiled information and data collected from five distinct sources, each of which is subsequently discussed in detail in the following sections of this chapter.

5.1 Personal experiences of the authors who lived through this transition
5.2 Data collection from individuals regarding information flow issues
5.3 Building on related prior thesis work of our colleagues from Pratt & Whitney
5.4 Literary search on information flow, knowledge capture, and organization
5.5 Extraction and application of relevant course work from the SDM program

5.2 Authors' Personal Experience

The origins of this joint thesis were a direct result of the authors' personal exposure to the issues that arose during the transition from Product/Component Centers to Modules Centers. From this direct involvement, we observed the issues from our unique vantage job roles.

Steve Glynn's background at Pratt & Whitney began in the functional group organizations that existed prior to the early 1990s. Steve joined Pratt & Whitney in 1985, specifically in the area of structural analysis of detailed parts at the East Hartford Connecticut site. The isolation within functional discipline focused groups of course gave way to distributed Integrated Product Teams (IPTs) during the engineering re-organization that occurred in 1993.

Steve's role in the evolving Product Center / Component Center organization continued to focus on structural analysis, but also included supporting the Mid-Thrust IPMT/MIPT Engine programs in the Turbine Module Center. Initial structural support was for a single IPT, but eventually expanding to cover multiple IPTs.

As demands and opportunities of the Turbine Module Center CIPT organizations evolved, Steve transitioned to support the PW4000 engine programs for structural analysis across multiple IPTs. This exposure to multiple engine program CIPTs and the reporting IPTs, provided him an opportunity to observe differences along several dimensions.

- Physical Architecture
  - the building worked in
  - the floor they were on
  - the physical dispersion of the IPT members (office layout)
- Engine Program
  - the maturity level of the engine programs[25]
  - the nature of program office that they reported to
- People
  - the specific work habits and personalities of the individuals

These dimensions may glance appear innocuous. Further research[26] and personal experience has demonstrated that they can play significant roles in information flow.

As discussed in Chapter 4, the transition to Module Centers in 1999 moved the individual part IPTs from reporting to the CIPTs Business Centers focused on part families. Steve was

[25] Maturity level in terms of ratio of new engine development activity vs. support for existing product out in the field. This issue of maturity level (or age in some cases) also impacted the expertise required for working with historical part analysis.

involved in this transition as some Turbine Module Center IPTs moved to the Middletown and North Haven Connecticut sites[27].

Tom Pelland's background at Pratt & Whitney has focused primarily on Project Engineering. He spent eight years in the Product Development and Validation (PDV) organization in positions of increasing responsibility, including several years as a senior Development Test Engineer. The experience gained in the PDV organization provided broad exposure to all levels of the engineering, program office and system integration organizations. Additionally, it provided a good perspective of the knowledge capture processes and information flow requirements and issues that existed in both the Product Center/Component Center and Module Center organizational structures.

Tom most recently spent two years in the PW4000 program business office as the Cost Reduction Manager and PW4098 Model Manager. These positions also afforded a broad spectrum of the information flow and knowledge capture issues by demanding constant communication and information between all organizations at Pratt & Whitney.

The authors' background and most recent positions at Pratt & Whitney provide a unique and balanced perspective of the communication, information flow, and knowledge capture issues present prior to the transition and created by the transition to Module Centers. The authors' are positioned on opposite ends of the information flow, Engineering to Programs, and have very different information and knowledge capture requirements.

5.3 Data Collection Philosophy and Process

To insure a broad perspective on the issues, implications, and recommendations of this thesis, extensive data was collected from cross-section of people within Pratt & Whitney. The cross-section chosen spanned the company in terms of organization, level, function, plant

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[26] For a classic reference on study of physical architecture on communication see: Allen, T.J. (1977), *Managing the Flow of Technology*, Cambridge: MIT Press. Chapter 5 will discuss in more detail
[27] Reference Figure 4.3 in Chapter 4

site, and exposure to other organizational forms. To explore potential generic issues, we also obtained perspectives of several other companies.

Our data collection process consisted primarily of face-to-face interviews with our selected cross-section. This methodology allowed us to account for non-verbal / non-written responses, and probe with follow-up question to identify the root case of issues raised. To facilitate the face-to-face interviews, we created a structured questionnaire. This baseline set of question/responses enabled us to perform quantitative comparisons.

5.3.1 Questionnaire Development

The questionnaire developed took four steps.

STEP #1: Establish the questionnaire purpose
The authors had a general idea of the issues affecting people, so the questions defined should confirm / deny known issues and be broad in scope, so as to find additional issues defined. The authors brainstormed questions for the starting questionnaire.

STEP #2: Test the questionnaire
The authors conducted face-to-face interview with a limited number of our peers to ensure the scope and depth of the questions met the needs of our research. Specifically, feedback addressed clarity of our questions, appropriateness of the questions in gaining quantitative data, and ability to extract information flow issues from responses.

STEP #3: Review and incorporate findings from Step 2
Initial testing strongly confirmed that known issues were important to our peers. Further, the tests confirmed that the form of the survey was unwieldy for the user. The initial spreadsheet format requested too much information in an unstructured manner. The questionnaire was transferred to a simplified document with reworded questions grouped into four sections.

STEP #4: Perform a confirmation test to establish data collection methodology
This step focused on capturing and recording the questionnaire results. The confirmation test indicated the new questionnaire was clear and manageable. Data were compiled into a spreadsheet, which captured both the questionnaire answers and the additional issues/concerns generated.

5.3.2 Questionnaire Deployment through Interviews

Face-to-face interviews conducted with sixteen individuals provided not only their responses to the questionnaire, but also a starting point for capturing their broad-based personal experiences. An additional 37 questionnaire responses filled in the issues across the organization. Detailed response statistics are summarized in Table 5.1.

Total face to face interviews:	16
Electronically mailed questionnaires	60
Total returned questionnaires	37 (62%)
Total (interview or questionnaire)	53
Range of 'years with company'	3-37 (mode=12, median=14)
Number of Companies	5
Number of organizations	16
Number of functional areas	8
Number of captured comments	562

Table 5.1: Questionnaire Statistics

The overall feedback process as outlined initially by the authors, captured the issues and questions clearly. Follow up questions arose after detailed data were collected. A small sub-set of the sixteen interviewees was polled for these additional questions. The face-to-face interviews was the most valuable, since sensitivity level of a given was more easily captured by free flowing thought process. The burden of having to write (or type) the information will shorten the response. Face-to-face, interviewees can also be probed more deeply to understand the tangential and / or root cause details not evident in a simple response.

5.3.3 Questionnaire sections and Statistics

The final questionnaire in Appendix A breaks down into a cover sheet and three main sections. The cover sheet contains the highest level information, such as the participant name, title, company/organization, and years at the company. Section A contains five general questions to address product of the enterprise, position within the organization, functional description of the organization, and primary and secondary source/method for information flow. Section B contains 24 questions to address organizational issues, both in terms of the structure of the organization and the operational norms of the organization with a focus on communication. Section C contains eighteen question sto address the method, volume, and effectiveness of the communication.

5.4 Building on Related Thesis

Over the course of 1997 and 1998 there were two separate theses written by Greg Mascoli and Craig Rowles which dealt with the topics of systems engineering in aero engine development and systems integration of IPTs. These works which explore use of the Design Structure Matrix for aero engine design tasks form one corner of the foundation for this effort. While we certainly recommend that the reader take the time to fully read their work, we will provide a brief synopsis of their work.

Mascoli, Gregory J., "A Systems Engineering Approach to Aero Engine Development in a Highly Distributed Engineering and Manufacturing Environment", MIT MS Thesis, 1999

In this thesis, Mascoli looks at the issue of how well a parameter based Design Structure Matrix facilitates the component integration issues for product development in distributed engineering and manufacturing environments, specifically for use in the aero engine design process.

Mascoli's thesis recommends the need for component-based systems engineers for integration issues across the distinct engine components. Beyond the need for these systems engineers serving a "Glue Role", Mascoli also recommends further strengthening of the systems level organizations by bringing them under an overall umbrella chief Systems Engineer. Finally, Mascoli recommends product team co-location during the very early conceptual and preliminary design phases when the iterative information exchanges are at the peak and the interaction costs for anything but co-location cannot be justified.

Rowles, Craig M., "System Integration Analysis of a Large Commercial Aircraft Engine", MIT MS Thesis, 1999

In this thesis, Rowles looks at system integration issues for product development which is similar to the work by Mascoli, but coming at the issue through review of team based decompositions for a complex product[28]. This work looks at creation of a Design Structure Matrix for a recently launched product to perform a post-mortem to review possible organizational changes or modified integration strategies for subsequent similar product development efforts.

One of the focuses of this thesis was a review of the existing clustering of individual part (or part systems) IPT's into their CIPT's to review their

[28] The product reviewed was a high bypass-ratio turbofan engine, the Pratt & Whitney PW4098

"efficiency" in terms of the design relationships and resulting cross team interactions. A comforting finding was that for the most part, the existing distribution of the IPT's to the CIPT's were in fact efficient but with the notable recommendation for need to strengthen cross-CIPT integration. Additional recommendations include strengthened functional discipline management and more clearly defined roles and responsibilities for key players.

5.5 *Literary Search*

In order to gain additional perspectives on topics of this thesis and for incorporation and building from existing research, we explored related articles, journals, and publications. Clearly some of the topics or 'key-words' for this thesis are rich in published materials and we had an interesting time in paring down the material to incorporate into our work. Topic areas that we explored included:

Product Design	Knowledge Management	Networking
Product Development	Knowledge Capture	Information Flow
Product Integration	Interorganization communication	Virtual Workgroups
Product Decomposition	Organizational Change	

The reference materials from this literary search that were utilized as part of the research into the topics of this thesis are listed in the bibliography.

5.6 *Application of Relevant SDM Course Work*

A significant portion of this search process originated with much of the material that we were exposed to in our two year endeavor spanning the wide spectrum of course material that comprised the System Design and Management (SDM) program. Perhaps the greatest exposure to alternate perspectives on both product development as well as organizational structure came from the core courses of System Engineering, System Architecture, and the Fundamental Courses of Organizational Processes and Systems Optimization. These courses provided us with a foundation through the direct class materials as well the multitude of side reference material discussed in our studies. An additional elective course that the authors had the fortunate opportunity to participate in during our last semester (Integrating the Lean Enterprise) also provided rich food for thought in our thesis.

Beyond the material that came directly through the institute, we were able to also build upon the combined knowledge that we were exposed to from our SDM classmates. In fact, it is from this community and the resulting exposure to practices and techniques employed in other companies and industries that have been drawn upon not in any specific way, but through our own enriched knowledge base.

Chapter 6

6.1 Product Development Information Flow & Knowledge Capture Tools

The product development process can be defined as a sequence of steps that transforms a set of inputs into a set of outputs[29]. The high level steps of a Product Development process include concept development, system level design, detailed design, system integration, testing, production, and finally product launch. Within and across each of these process steps, a tremendous amount of information flows as the effort proceeds from individual task to task. The ability to recognize and manage the multiple tasks and their dependencies is critical to creating a successful lean process. Many tools are employed to facilitate the reconciliation of task sequencing, but not all of them accurately capture the distinct nature of product development.

6.2 Types of Task Dependencies

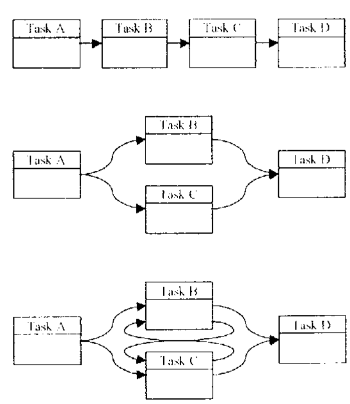
In general tasks can be one of three types of dependencies. Tasks can be sequential: task B follows completion of task A, task C follows completion of task B.... Tasks can be parallel: task B and task C both follow the completion of task A, A & B independent of each other. Tasks can be coupled: task B and C requires information from each other in order to be completed. Perhaps a brief figure will help to convey these task dependencies.

Figure 6.1: Task Dependencies

4 task project with tasks B & C in series

4 task project with tasks B & C in parallel

4 task project with tasks B & C coupled



[29] Eppinger, Steven D. and Ulrich, Karl T., Product Design and Development, McGraw-Hill, Inc., New York, 1995, page 14

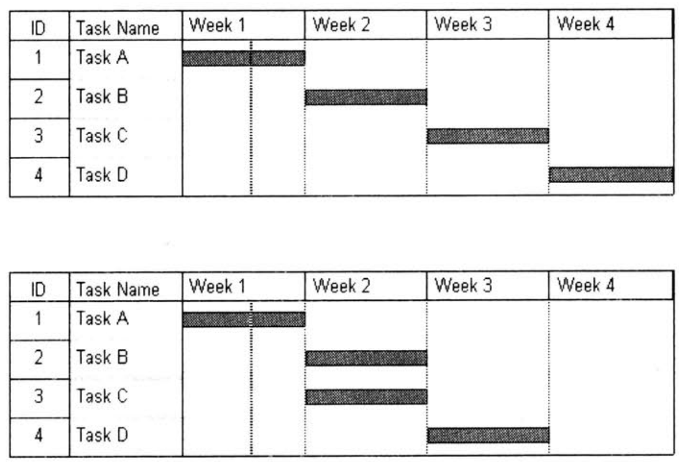
6.3 *Project Task Representation with Gantt and PERT charts*

Gantt charts[30] are a common tool used to display project tasks. A Gantt chart representation of our four-task project is shown in Figure 6.2. A Gantt chart captures the explicit start and finish of tasks and conveys the overall schedule, but it does not capture task precedence especially when it contains significant aggregation of the true subtasks.

Figure 6.2: Gantt chart representation of 4-task Project

4 task project with tasks B & C in series

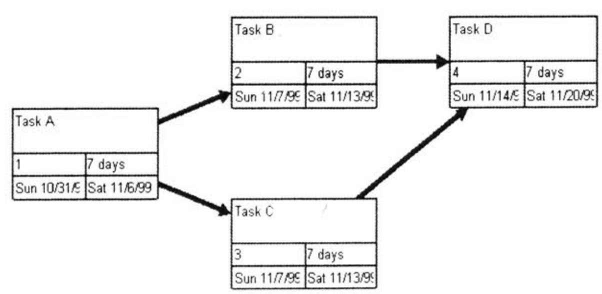
4 task project with tasks B & C in parallel



PERT charts (Project Evaluation and Review Technique) are another tool for representing projects as illustrated in Figure 6.3. This form has its origins in the 1950's as part of the department of the Navy Polaris weapons system[31].

Figure 6.3: PERT chart representation of 4-task Project

4 task project with tasks B & C in parallel



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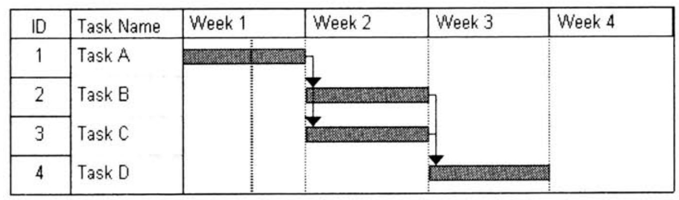
[30] Gantt charts are derived from Henry Gantt who in the late 1800's arrived at this general form of project representation

[31] Nahmais, Steven.(1997), *Production and Operations Analysis*, Third Edition. Boston, MA: Irwin

The PERT format was created to capture task dependency, task uncertainty, and the critical path. However, PERT charts do not adequately capture or convey coupled dependencies. Recent software packages have enhanced Gantt charts with the addition of task links (Figure 6.4). While this is an improvement over the original form of Gantt charts but still does not handle coupled tasks adequately.

Figure 6.4: Gantt w/links Representation of 4-task Project

4 task project with tasks B & C in parallel



These scheduling tools are prevalent in the market and are somewhat adequate for overall program scheduling of higher level tasks. However, as mentioned, they do not capture dependencies of coupled tasks. Accurate capture of task dependencies for a design process is essential for understanding the interactions and improving the product and process.

6.4 Design Structure Matrix (DSM)[32]

The DSM is a useful tool for representing and analyzing task dependencies. Task dependency shows how information must flow from one task to another task or to multiple tasks. It is in this study of the information flow across tasks where the DSM becomes so valuable. Our four-task project example illustrates the ability of a DSM representation to clearly capture task dependencies.

[32] Eppinger, S. D., Whitney, D. E, Smith, R. P., Gebala, D. A., "A Model-Based Method for Organizing Tasks in Product Development", Research in Engineering Design, Vol. 6 1994, pp. 1-13

4 task project with tasks B & C in series

B & C Series	Task A	Task B	Task C	Task D	
Task A					
Task B	X				
Task C		X			
Task D			X		

4 task project with tasks B & C in parallel

B & C Parallel	Task A	Task B	Task C	Task D	
Task A					
Task B	X				
Task C	X				
Task D			X		

4-task project with tasks B & C coupled

B & C Coupled	Task A	Task B	Task C	Task D	
Task A					
Task B	X		X		
Task C	X	X			
Task D		X	X		

Figure 6.5: Design Structure Matrix (DSM)

6.5 Design Structure Matrix - explanation

A DSM can be constructed for a multitude of design elements. The DSM represented in Figure 6.5 captures task based dependencies. A DSM could also capture design team dependencies, or design parameter dependencies. When reading across a specific row (task), an "X" indicates that the task under review is receiving information from the task in that column. Similarly, when reading down a specific column (task), an "X" in the row indicates that the task under review is conveying information to.

Specifically, in the coupled case of Task B (Figure 6.6), reading across the row indicates information comes from Tasks A and C. Reading down the row indicates information flows to Tasks C and D. A helpful way to remember the information flow is:

** **R**ows = **R**eceiving, **C**olumns = **C**onveying **

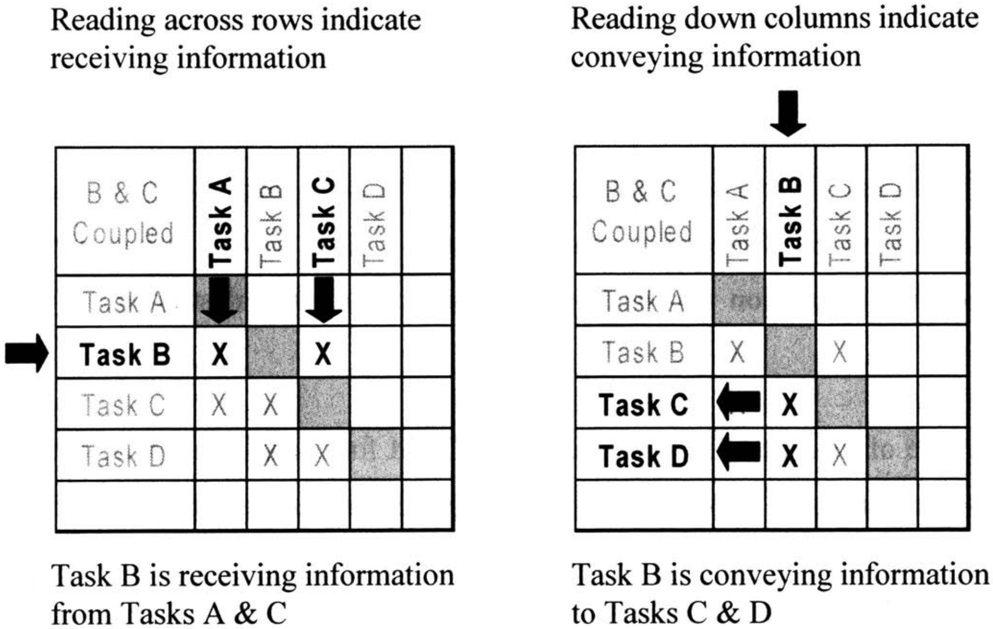


Figure 6.6: Reading A Design Structure Matrix

This DSM form can be altered slightly to visually capture the *strength* of the coupling. For example, numbers or symbols can be used in place of an "X" to signify the strength, as shown in Figure 6.7. For most coupled systems, some dependencies are stronger than others and without this strength-capturing measure, the relative importance of one dependency versus another would not be evident.

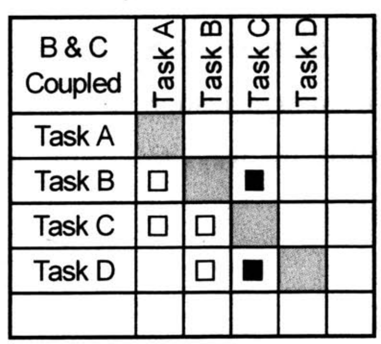


Figure 6.7: DSM indicating task dependency strength

The benefits to capturing design information in a matrix of this type are two fold. First, the interactions are captured in a convenient compact form including dependency interactions. Second, it enables a rapid review of the interaction impact for altered decompositions. In the four-task example that has been presented, it would be advantageous to the design effort if Task B and Task C were accomplished either by the same design team or within the same design organization. The matrix simply provides a clear way to convey for a given task decomposition interaction will be high with one organizational structure versus low with another.

The purpose of this thesis is not to develop a DSM for use within P&W, but to assess the benefits of extending a DSM to additionally capture the specifics of information flow across IPT's. To accomplish this we will draw upon the work of two of our fellow employees and SDM associates[33].

6.5 IPT Interaction DSM

An IPT-based DSM construct is valuable because it easily conveys the parallel and coupled nature of dependencies. However, we believe that it can easily be extended to become a valuable extension the existing Pratt & Whitney Standard Work methodology. To illustrate this extension, we will build off of the IPT interaction DSM work of Craig Rowles. Craig Rowles worked through the creation and documentation of a DSM for a modern Pratt & Whitney high bypass-ratio turbofan engine, the PW4098. Specifically, he mapped out a DSM based on IPT interactions looking for and finding opportunities for organizational and IPT deployment. His work illustrated the value in recognizing team interactions and reviewing them in terms of team/organization structure. The value of that effort should be extended to explore and identify the ways to identify and capture the specific information that comprises these interactions.

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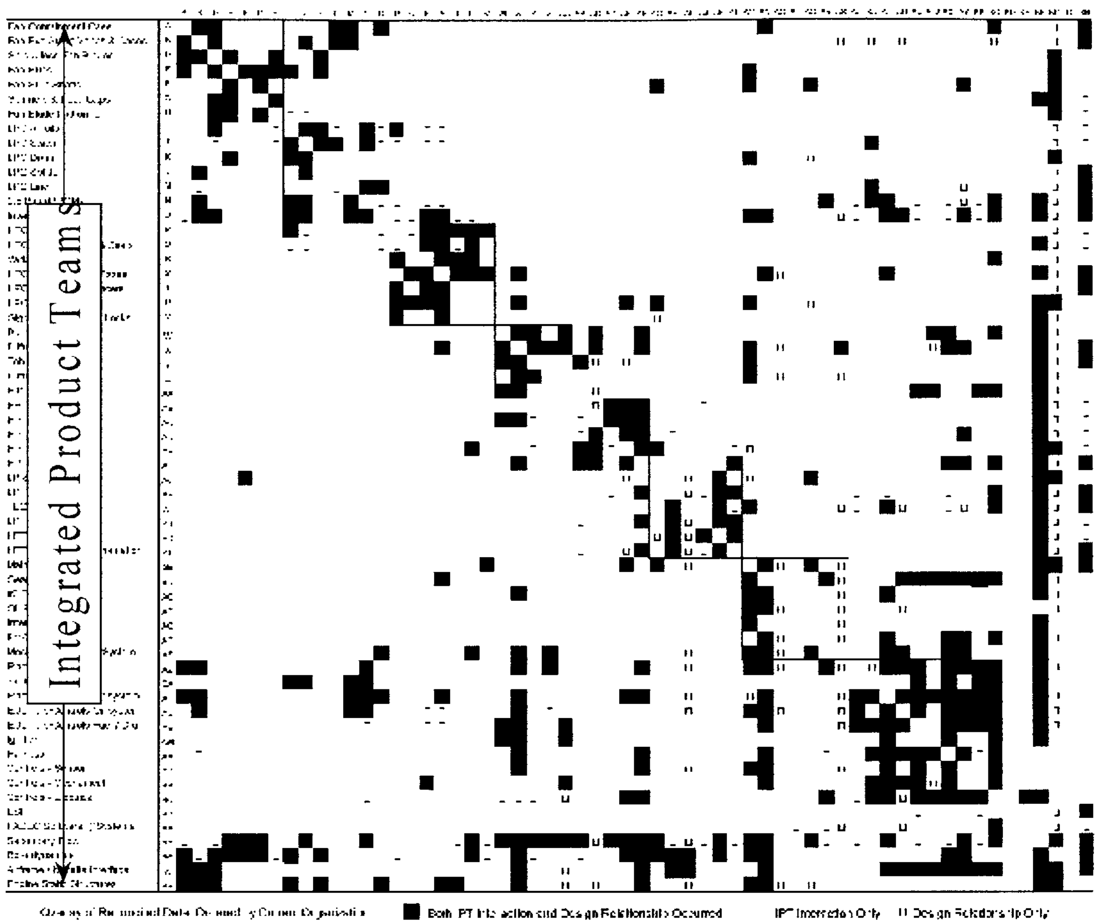
[33] Mascoli, Gregory J., "A Systems Engineering Approach to Aero Engine Development in a Highly Distributed Engineering and Manufacturing Environment," Massachusetts Institute of Technology, System Design and Management Program, Unpublished Master of Science Thesis, 1999 & Rowles, Craig M., "System Integration Analysis of a Large Commercial Aircraft Engine," Massachusetts

Figure 6.8: DSM indicating interactions of IPT's across



The power of a DSM is that it graphically shows IPT to IPT interaction. With this detailed information flow some of the information issues that arose during the transition to Module Centers would have been predicted. A section of the DSM that contains the IPTs for one CIPT is shown in Figure 6.9.

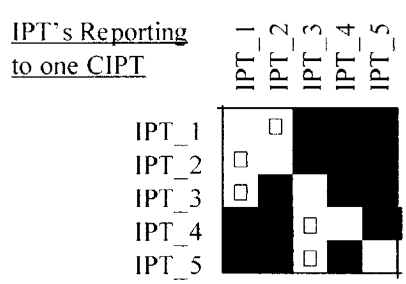


Figure 6.9: DSM indicating interactions of IPT's within a CIPT

Institute of Technology, System Design and Management Program, Unpublished Master of Science Thesis, 1999

This clustering of five IPTs represents the teams that in the prior Component Center / Product Center (CC/PC) structure had reported to a single CIPT. One of the findings that Craig Rowles developed in his Thesis was that for the majority of the CIPTs at Pratt & Whitney, the clustering of tasks within the IPTs was verified as efficient. Efficient clustering means that the interactions are contained within specific CIPT groups. Recognizing this, it should be no surprise that as the IPTs are removed from the CIPTs and dispersed to separate Business Centers, within each Module Center, increases the interaction complexity.

6.6 Pratt & Whitney Standard Work

Pratt & Whitney has Standard Work documents, which describe the requirements, design tools/procedures, and the results associated with the product development task. Standard Work assures consistent, best practices are applied. These documents are intended to achieve a uniform approach to meeting design criteria. Standard Work documents evolve new to approaches are developed and new hardware behaviors are identified. Safety paramount to our requirements and Standard Work documents are on the 'conservative' side until hardware and processes are better developed and mature. Standard work documents are a central set of documents for all engineers across all module centers and our systems engineering groups to utilize.

Standard Work documents extensively detail component or piece part design, but they do not yet fully explore and capture the cross-component team information exchanges required to insure that nothing is missed. Use of an extended team-based DSM with capture of the cross team exchanges can be accomplished with an electronic based DSM.

6.7 Electronic IPT Interaction DSM – extended with information needs

The power of the DSM described in detail in the preceding sections is in its ability to concisely capture and convey information flow relationships required for product design execution. Not only does it capture the complete set of exchanges, but it clearly defines precedence information. As a new design progresses, the DSM will detail what information channels need to exist and what order to complete the design task.

For complex products with coupled systems, parallel designs tasks often start with 'placeholder' inputs to perform initial subsystem design space exploration. In reference to the DSM, these are the relationships that lie above the diagonal. Once the values are more precise, the updated precedence information can be integrated into the analysis process for that subsystem. Depending on the magnitude (and direction[34]) the updated information has to the output subsystem, there may or may not be the need for domino-ing this down through the rest of the matrix. A team-based DSM, which is enhanced with full documentation of the specific information exchanges required at each matrix intersection, is required to insure that design issues are not missed. More details on this recommendation are discussed in Chapters 7 and 8.

6.8 E-mail for Information Exchange and Capture – A Lost Cause?

E-mail in the workplace at Pratt & Whitney, as well as the other companies is used for such a wide range of items beyond exchange of information for product development that is negatively impacts development efforts. A question asked during our research was whether a condition of information overload[35] existed. The response was overwhelming, with 94% of the respondents indicating yes and 81% of these respondents expanding with comments. Some of the direct comments from the respondents are listed below.

"Yes, TOO much information about peripheral issues. Too much side issue details. Ratio of useful e-mail 10%"

"Yes. I'm living it. Missing meeting notices and high priority e-mails since they are buried among the other e-mails."

"Absolutely. Far too many spamming of e-mail. The important get mixed in with the junk. Too easy to send out little missiles hoping that something comes back."

"Definitely. Receiving the same or similar information for multiple sources is annoying. Also receiving information in such a rapid fire manner that you don't have time to digest it can also greatly reduce its effectiveness."

"Yes, HUGE portion of day is sifting through e-mail. Takes TOO much time"

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[34] By direction we are referring to whether the change is in the direction of improving or degrading

[35] Reference question C.16 of questionnaire in appendix A.

A majority of the comments are along these lines (some even more pointed) and the authors' opinion is similar to theirs. Beyond the issue of e-mail overload there is several other issues with e-mail are driving us to recommend another vehicle for information exchange and capture for product development tasks.

E-mail exchanges information with the specific players known at that time of correspondence. E-mail does not facilitate a historical capture of the exchanged information nor does it lend itself to bringing new players up to speed on a project. As key players move from one task to another, the information they received necessary to previous tasks is often 'lost', i.e., it is not accessible in a reasonable amount of time. E-mail messages are never gone, but in context for the work of the remaining IPT, the information is lost.

Another E-mail issue on direct transfer of IPT communication is that information can be exchanged easily with unintended audiences. This misdirection could have a malicious nature or just as easily be an inadvertent step in addressing. One of the things that Pratt & Whitney and many other companies have done in order to facilitate communication with supplier, customers, and even partners is inclusion of the contact personal within the company's drop-down e-mail address books. This data facilitates the ease in which desired communication can occur, but it also increases the risk that unintended communications land in the wrong hands. This risk increases when partners in specific programs are also competitors on other programs.

To retain the desirable access to information and to address some of the concerns, we recommend alternate existing communication technologies. Specifically, the use of a centralized web based system with password protection. This recommendation will be fully explored in Chapter 8.

Chapter 7

Findings

7.1 Overview

This chapter provides the overall findings of our research and survey results. The nine findings discussed in this chapter are a result of comparative analysis of the new Module Center organization relative to the Product Center architecture, analysis of the in-depth interviews, literary search data, and the quantitative data obtained through our survey. Additionally, we also utilized the previous relevant thesis work completed by our fellow SDM and Pratt & Whitney cohorts.[36]

The nine findings are defined as issues that resulted either from the transition to Module Centers and the resultant dispersed IPT environment or were identified through our research and found relevant to the knowledge capture/information flow processes currently utilized at Pratt & Whitney.

A list detailing the areas of our primary knowledge capture and information findings is provided below. Each finding will be discussed in detail in subsequent sections of this chapter. Our conclusions and recommendations addressing each of these issues is provided in Chapter 8.

Knowledge Capture/Information Flow Findings

Finding #1: Internal Module Center IPT to IPT integration
Finding #2: System level integration
Finding #3: Standard Work limitations

[36] Mascoli, G.J., "A systems Engineering Approach to Aero Engine Development in a Highly Distributed Engineering and Manufacturing Environment", System Design and Management Thesis, Massachusetts Institute of Technology, January 1999

Rowles, C.R., "System Integration Analysis of a Large Commercial Aircraft Engine", System Design and Management Thesis, Massachusetts Institute of Technology, January 1999

Finding #4: Standard Module Center organizational architecture

Finding #5: Organizational roles and responsibilities

Finding #6: Information flow and knowledge capture methods

Finding #7: Knowledge Management philosophies: Codification versus Personalization

Finding #8: Information Technology utilization in knowledge management

Finding #9: Post Certification versus Clean Sheet information flow requirements

7.2 Finding #1: Internal Module Center IPT to IPT Integration Issues

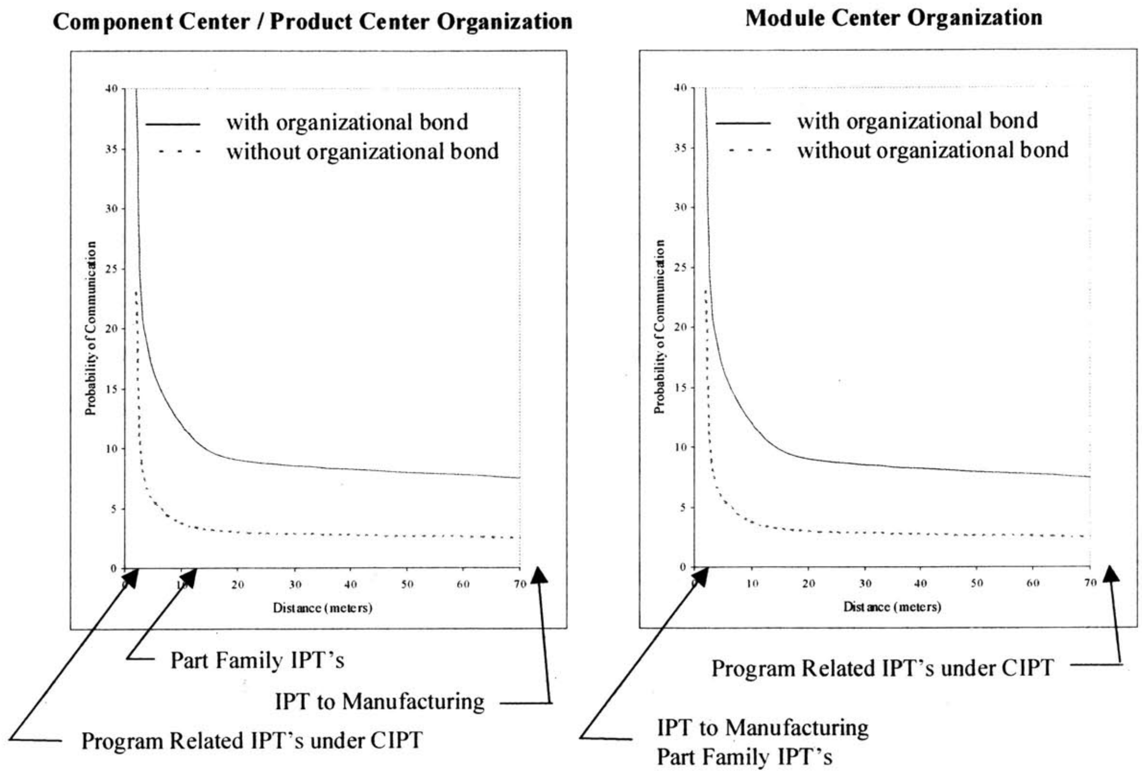
Organizational analysis, interview results, and the authors' recent experience show that Integrated Product Team (IPT) integration *within* each Module Center has become more difficult. In the past Product Center/Component Center organization, all the engineering resources required for each module of the engine were co-located and reported to one CIPT leader. The IPT leaders of each sub-component or part in a module were physically located in the same area and informal information flow was a critical component of knowledge management and transfer. This co-location and program specific module organizational alignment greatly facilitated the internal module IPT to IPT communication and integration, both through formal structured CIPT and IPT meetings and the informal communication paths created by co-location.

Studies on physical proximity impact to communication confirm the communication benefits of co-location[37]. As the IPTs moved from being co-located under the CIPTs, within a program, to being co-located with other part family IPTs at the Module Centers the strengthing and weaking of communication is shown by the distance vs. probability of communication chart from the work of T. Allen (Figure 7.1).

[37] Allen, T.J., *Managing the Flow of Technology: Technology Transfer and the Dissemination of Technology Information Within the Research and Development Organization*, Cambridge: MIT Press, 1977, pp. 234-247

Figure 7.1: Probability of Communication as a Function of Distance

Figure from Managing the Flow of Technology[38]



The module center organization has structured the IPTs along part families, and not program modules. This structure provides a better communication path for lessons learned across programs and better manufacturing integration for the specific part families. However, these benefits are at the expense of inter-module IPT integration and the informal information flow facilitated by co-location in the previous Product Center/Component Center organization. For example, in the Product Center/Component Center organization the high-pressure turbine (HPT) stage 1 blade IPT resources were co-located next to the HPT stage 1 disk resources in the HPT CIPT for a specific program. Component level IPT to IPT integration was formally conducted during structured CIPT meetings and through informal communication facilitated by co-location. In the Module Center organizations, the HPT stage 1 blade engineering and manufacturing resources for all programs are co-located in the HPT stage 1 blade Business Center located in North Haven, Connecticut, while the HPT stage 1 disk engineering and manufacturing resources are co-located in the cases and rotors Business Center, located in Middletown Connecticut, approximately 25 miles away. Again, this part family focus has created a technically stronger organization able share "lessons learned" across programs with better manufacturing integration, but it has weakened the component and system level IPT integration.

Based on our survey, 56% of respondents either disagreed or strongly disagreed that their organization communicated effectively (reference Appendix A, question B.16). Further, when asked what type of organizational structure they felt communicated the most effectively the responses were heavily weighted towards co-located architectures (45% cross-functional teams, 25% matrix co-located).

Finally, our interviews also indicated the internal Module Center IPT to IPT integration issue. Comments, such as those listed below, exemplify a common theme expressed by the respondents during our interviews and in questionnaire responses. The comments listed are from various Module Center interviewees.

> " IPT interfaces have now been transferred across knowledge centers, in the prior organization they were all in the CIPT. The program technical leaders are now responsible to know all IPT to IPT interface issues, but no communication path exists between IPT's at the program technical leader level."
>
> "Pratt & Whitney is better now with lessons learned, etc., but poor on a program basis."
>
> "One hallway conversation equals one *week's* worth of e-mails"

Recent literature on the Toyota Production System (TPS) by Spear & Bowen[39] points out that one of the four rules that encapsulates the tacit knowledge for the TPS is that "Every customer-supplier connection must be direct, and there must be an unambiguous yes-or-no

[38] Allen, T.J., *Managing the Flow of Technology: Technology Transfer and the Dissemination of Technology Information Within the Research and Development Organization*, Cambridge: MIT Press, 1977, pp. 241, Figure 8.4

[39] Spear, Steven and Bowen, H. Kent, "Decoding the DNA of the Toyota Production System", Harvard Business Review, September-October 1999, pp. 97-106

way to send requests and receive responses"[40]. This type of interface document does not exist currently at Pratt & Whitney, although the more one looks at it, it is clear that there is the need. In a lecture with Professor Spear[41], he expands on this connection design rule which includes the specific "goods and services 'customer' can request from 'supplier'" and that there is an explicit need to "define defect free for each item (form, quantity, and timing)"

Chapter 8 will discuss recommendations on how to improve the IPT to IPT integration within the Module Centers. These recommendations will include potential organizational changes and integration of existing Standard Work documentation with a Design Structures Matrices tool.

7.3 Finding #2: System level integration issues

Similar to the internal Module Center IPT to IPT integration, total system (engine) level integration has become more difficult in the new organizations. In the Product Center/Component Center organization, the System Engineering organizations were co-located with the CIPT organizations. As with the IPTs, the informal systems integration communication paths that were facilitated through co-location have been eliminated with the dispersed nature of the IPTs and the systems engineering groups in the new Module Center organization. Module to Module systems integration was managed through face-to-face discussions during formal chief engineers meetings and MIPT meetings, which continue in the new organization. However, it's the informal tacit knowledge and information transfer that is severely limited in the dispersed engineering environment created by the Module Centers.

The organizational analysis and questionnaire data confirm that engine level systems integration in the dispersed IPT environment of the Module Centers is more difficult. Ten members of the Systems Engineering organization were contacted and responded to our questionnaire. The comments below are representative of many of the responses received.

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[40] ibid., Spear, page 98

"Most of the daily contacts have now been re-located to their respective module centers and no formal communication tools are in place to use (I.e. face-to-face contact) that replaces that need."

"Co-location has definitely shown an advantage to me probably due to the amount of informal communication that is achieved."

"The co-located organization gives best access to people in other organizations who are working on the same tasks."

Previous thesis work completed by Mascoli[42] recognized the systems integration issues created by the dispersed IPT environment of the Module Centers, the author concluded:

"We conclude that once target values for the system level parameters are defined and documented, the geographically distributed teams will be able to work on their designs with relatively little interaction with the other component teams, except through the *significant* efforts of the System Engineers. P&W must have a strong Systems Engineering Organization and Process, managed by the Systems Engineers, that ensures that the components can be reintegrated in a system optimizing manner at the completion of the component design process."[43]

This conclusion was valid for new system design tasks past the preliminary design phase. However, based on the highly iterative nature of conceptual and preliminary design indicated on their design structures matrix the author also concluded:

"The DSMs show that all the component designs are coupled through system level design parameters. Conceptual and Preliminary Design is a highly iterative process in which performance, weight, cost trades are continuously made between components. The DSM indicates that this phase should not be completed by distributed teams. Even in the Module Center structure, representatives from the component teams should be co-located with the Systems Engineers and the Advanced Engine Program analysts to define the target values for the system level parameters, and to derive the System Requirements and Component Requirements."[44]

Our research concurs with these conclusions reached above. Primarily, if the system level requirements are clearly defined and documented, then the system engineers will be able to

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[41] Spear, Steven, "Toyota's 'Rules-In-Use' for Designing and Improving Organizations" MIT Class Presentation, Integrating the Lean Enterprise, December 8, 1999.

[42] Mascoli, G.J., "A systems Engineering Approach to Aero Engine Development in a Highly Distributed Engineering and Manufacturing Environment", System Design and Management Thesis, Massachusetts Institute of Technology, January 1999

[43] ibid, Mascoli, G.J., page 57-58

[44] ibid, Mascoli, G.J. page 56

manage the integration of the dispersed component teams effectively with standard processes and methodology.

However, our research also indicates that no communication process has been defined to manage the efforts of the distributed component teams and to effectively capture the informal information flow critical to systems integration that was facilitated by co-location. The standard systems integration processes, detailed in Chapters 3 and 4, were primarily through the use of Chief Engineer's meetings, MIPT meetings, and the Configuration Control Board (CCB) meetings, which are increasingly difficult to attend by the dispersed engineering staff.

Additionally, we have also found that the prior analyses completed by Mascoli and Rowles completed did not investigate the down stream Post Certification Engineering (PCE) efforts that typically absorb up to 60%[45] of engineering resources after a product has been launched into production. PCE efforts are also highly iterative in nature and, our research indicates, for the same reasons as conceptual and preliminary design phases, would require co-located systems and design engineering. This issue will be covered in more detail in section 7.10.

7.4 Finding #3: Standard Work Limitations

The implementation of Standard Work methodology is currently complete throughout the design engineering disciplines at Pratt & Whitney and is a valuable tool used codify design knowledge and lessons learned. The definition of Standard Work used at Pratt & Whitney is:

> "A disciplined approach to achieve business process effectiveness, efficiency, and agility. Standard Work is a method for capturing both process and product knowledge. It relates the best process approach developed to date and accesses historic levels of performance (capability) to frame the expected results."[46]

An issue our research has identified, and one that also is recognized by Pratt & Whitney, is that Standard Work has only captured and codified design knowledge at the part or sub-component level. Standard Work documentation does not exist for component or system

[45] This data was estimated through several discussions with Module Center project engineers and the authors personal experience

[46] "Standard Work – Overview for IPD", Copyright © 1999 by United Technologies Corporation

level integration. At the part level, Standard Work is a valuable tool in understanding and capturing best practices for part design, development, data requirements, and lessons learned. It has been particularly valuable for inexperienced designers who can access Standard Work documentation for process definition and design methodology for their respective parts.

The Module Center environment has increased the need to extend Standard Work application to the component and system level. A standard methodology for capturing the component and system integration issues needs to be developed, documented, and implemented. During several of our interviews with Module Center employees it was stated that the inexperience of the part level designers, coupled with the dispersed engineering environment, has made integration of IPT efforts more difficult. New designers do not understand the complete process for systems integration and do not have the experience to know who should get and give them necessary data. It is our assertion that a standard approach to systems integration would minimize this issue.

In Chapter 8 we conclude that a part attribute level Design Structures Matrix should be utilized as an extension of the Standard Work methodology for system level integration.

7.5 Finding #4: Standard Module Center organizational architecture

The Module Center General Managers and their staff developed each Module Center organization individually and separately. Thus, the organizational architecture for each module center is different. This variability has contributed significantly to the component and systems integration issue detailed in Finding #3. Systems integration engineers and the Program Office personnel are not clear whom to contact in the Module Center organizations for information and interaction.

A standard Module Center organizational architecture would lead to better defined information flow paths and a better understanding of roles and responsibilities. This common organizational structure is particularly important in the "virtual" communication environment of the dispersed IPT's. Knowing who to contact and whom needs specific information will facilitate required communication while reducing unnecessary wasted communication. A more detailed analysis of this issue is provided in the next Finding.

7.6 Finding #5: Organizational Roles and Responsibilities

Our research has shown that a fundamental understanding of the roles and responsibilities of each organization and the positions that make up these organizations is critical to efficient communication and information flow. Our data shows that 89% of the people responding to our survey feel that a condition of "communication overload exists". Overwhelmingly, the comments supplied were directed to the amount of unnecessary E-mails they received. Some of the more interesting comments included:

> "These days, e-mail is so convenient that there are days when in excess of 100 messages are received. The task is to filter out the ones that provide no useful information from the ones that are "nice-to-know" from the ones that are essential information from the ones that need my immediate attention. There is nothing more frustrating than being away from your desk at a 2-hour meeting and returning to your desk to find 25 more e-mail messages…"

> "Yes! It is very easy to forward masses of information to people who do not need it. Sometimes there is remarkably little wheat mixed in with all the chaff."

> "E-mail is an example of this. It is not unheard of for me to return from a one-day absence to find 60+ messages in my in-box with less than 20 that are important to me and less than 10 that require my action. Yet, correspondents expect that I have read and digested their communication, which is not a reasonable assumption, given the number of daily correspondents."

Because of the ease of electronic mail forwarding and the lack of understanding who needs information, notes are being sent to more people that necessary. Based on our interviews and survey responses this "CC list" mentality is partially a result of individuals not understanding the roles and responsibilities of other organizations and who needs specific information. If organizational roles and responsibilities were fully understood across the enterprise, then people would know who needs specific information and when. This clarification would reduce the amount of non-pertinent information flow, reduce information "filtering" time, and facilitate more timely critical information flow.

7.7 Finding #6: Information Flow and Knowledge Capture Methods

The Information flow and knowledge capture methods utilized at Pratt &Whitney were outlined in detail in Chapters 3 and 4. Based on our research, 48% of the respondents utilized face-to-face communication (both individual and meetings) as their primary source of information flow, with an additional 40% stating that E-mail was their primary source of communication. In the past, the face-to-face communication and information flow typically took place in the hallways, at individuals' desks, or in scheduled meetings. As stated, co-location was a significant influence on the information flow and knowledge capture methods of the organization. The need for follow-up communication, usually E-mail, to face-to-face information transfer was minimized since people communicated directly with one another. As the organization transfers into the Module Center format and the IPT's become dispersed, this informal communication network facilitated by co-location will need to be replaced to ensure proper information flow.

In the new dispersed IPT environment of the Module Center organization, face-to-face meetings will be replaced with "virtual meetings" via teleconferencing, Picture-tel, and other types of "GroupWare" software. However, our research indicates that for these types of media to be successful, visual presentation materials must be provided to all parties prior to the meeting, typically through E-mail. Follow-up information flow from the meeting that was typically conducted via face-to-face conversation will now also take place through E-mail or voice mail. As the organization fully transition to the Module Centers, the probability of a significant increase in E-mail traffic is great. Yet, the vast majority of the individuals we interviewed, in addition to the survey responses, stated that a condition of "communication overload" exists and is primarily a result of the amount of E-mail communication and the time it takes to filter through to find relevant information

E-mail is a powerful tool when utilized properly and is a critical enabler of effective communication in dispersed teams. However, it is not the complete answer and needs to be managed properly. Understanding organizational roles and responsibilities, knowing who needs information and when, and standard information flow processes are needed.

Additionally, in this "virtual" meeting environment our research found that the perception of the discussion and decisions made during the meeting might differ greatly among the participants. The informal or disconnected nature of teleconferencing, and even picture tell, will increase these differences in perceptions. Our survey found that 79% of the individuals agreed or strongly agreed that meetings were a primary source of information flow in their organization, but only 10% said that meeting minutes were regularly published. As the organizations begin to utilize teleconferencing and other forms of virtual meetings, meeting minutes will become critical. Meeting minutes should be published to ensure all participants involved in the discussion have a unified perspective of the outcome and the decisions made. These same meeting minutes can be a form a knowledge capture and placed in a centralized database that can be accessed for future reference and by those not attending the meeting, but interested in the outcome.

Finally, when asked specifically if information flow/communication processes or policies existed in the various organizations at Pratt & Whitney, we have found that they are either not defined, not followed, or are unclear. This data is shown in Figure 7.2.

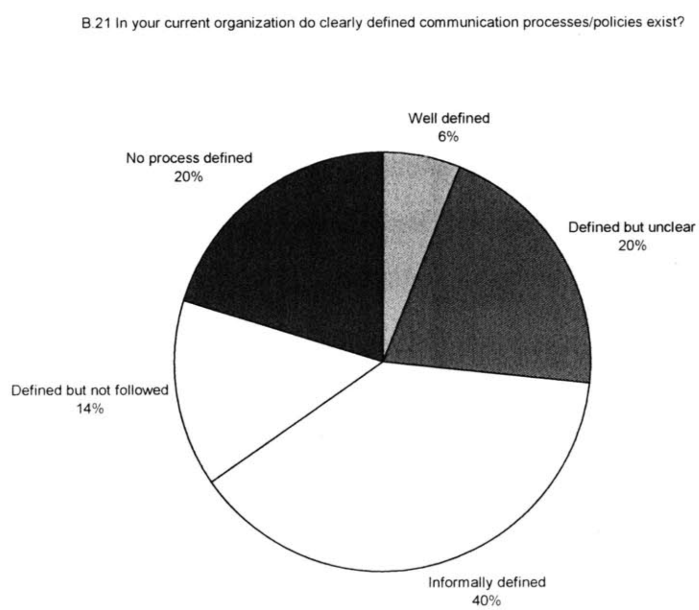

Figure 7.2 Information Flow Policy Definition

It is our recommendation that formal standardized information flow and knowledge capture processes must be developed, documented, and understood to ensure efficient information flow. This standardization will reduce that amount of unnecessary communication through a better understanding of who needs what information when and systems and component integration will be facilitated as everyone in the value stream will know where to get the latest most relevant information. Finally, the codification of explicit knowledge will be driven to become part of the daily routine through a formalized process.

7.8 Finding #7: Knowledge Management: Codification versus Personalization

Knowledge management is becoming an important strategic initiative for many organizations today as companies begin to realize that it is the people and the knowledge these people posses that are the critical enablers of business success. But what is a knowledge management strategy? Recent research completed by Morten T. Hansen, Nitin Nohria, and Thomas Tierney[47] concluded that there are two basic knowledge management strategies: Codification and Personalization. In this article Hansen, Nohria, and Tierney concluded, "emphasizing the wrong strategy or trying to pursue both at the same time can, as some consulting firms have found, quickly undermine a business." As the Pratt & Whitney transitions to the Module Centers, attention must be focused on the alignment of the new organizational architecture and the knowledge management strategy. In particular, the apparent conflict between the personalization IPD philosophy and codification knowledge management strategies.

Before we detail the issue of knowledge management further, we need to provide a few basic definitions of the types of knowledge that exist in organizations today and the definitions of codification and personalization knowledge management strategies discussed above. First, there are two types of knowledge, explicit and tacit that are defined as follows[48]:

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[47] M.T. Hansen, N. Nohria, and T. Tierney, "What's Your Strategy for Managing Knowledge?", Harvard Business Review, March-April 1999

[48] Prof. Debbie Nightingale, "Knowledge Management" presentation November 3, 1999, Integrating the Lean Enterprise, course 16.852

- <u>Explicit Knowledge</u>:
- Can be expressed in words and numbers
- Easily communicated and shared in hard form
- Examples: scientific formulas, market data, codified procedures

- <u>Tacit Knowledge</u>:
- Difficult to formalize
- Examples: scientific expertise, operational know-how, industry insights

The two types of knowledge management strategies can be best summarized as follows:

- <u>Codification Strategy</u>
  - Computer Centric
  - Knowledge codified & stored in database
  - Accessible to anyone in company

- <u>Personalization Strategy</u>
  - Knowledge closely tied to person who developed it
  - Share mainly through direct person-to-person contact
  - Computers help communication, not storage

Source: Hansen, Nohria, and Tierney, Harvard Business Review, March-April 1999

The successful IPD philosophy adopted by Pratt & Whitney for product development and support is fundamentally based in the personalization knowledge management strategy. The objective of the formation of the integrated product teams is to facilitate tacit knowledge transfer between experts by placing these experts together on a team. This is the core philosophy of IPD. Tacit and explicit knowledge is primarily managed through face-to-face contact during scheduled meetings or informally between individuals. Explicit knowledge is also communicated via electronic media such as E-mail and voice mail, but only to augment person to person information flow not store it.

Yet, as the company disperses the engineering resources to the Module Centers and with the implementation of Standard Work, ISO 9000, and the utilization of central databases such as Lotus Notes and the Intranet, Pratt & Whitney has given focus to the codification knowledge management strategy. This inherent conflict between the IPD methodology, dispersed engineering resources in the Module Centers, and the use of a codification knowledge management strategy needs to be addressed in the overall knowledge management strategy at Pratt & Whitney. A comparison of the two knowledge management strategies provides a good perspective on this issue[49]:

Codification	versus	Personalization
PEOPLE-TO-DOCUMENTS		PERSON-TO-PERSON
• Develop an electronic document system that codifies, stores, disseminates, and allows reuse of knowledge • Invest heavily in IT; the goal is to connect people with reusable codified knowledge		• Develop networks for linking people so that tacit knowledge can be shared • Invest moderately in IT; the goal is to facilitate conversations and the exchange of tacit knowledge

Source: Hansen, Noria, Tireney, Harvard Business Review, March - April 1999

Hansen, Norhia, and Tierney conclude that "companies should pursue one dominate strategy and use a the second strategy to support the first."[50] The article goes on to state that " When people use tacit knowledge most often to solve problems, the person to person approach works best."[51] We will conclude in Chapter 8 that although the engineering resources have been distributed in the new Module Center format, the personalization knowledge management strategy should still be utilized. This recommendation is primarily due to complex and coupled nature of jet engine design, the seemingly impossible task of codifying the vast amount of tacit knowledge capture required, and the demonstrated success of the

[49] ibid., Nightingale, D.
[50] M.T. Hansen, N. Nohria, and T. Tierney, "What's Your Strategy for Managing Knowledge?", Harvard Business Review, March-April 1999, pg 112
[51] ibid., M.T. Hansen, N. Nohria, and T. Tierney, pg 115

IPD process. We also introduce the Design Structures Matrix as a codification tool to map the required information flow and facilitate communication between IPT's and Systems Integration.

Please note that while we are recommending the utilization of a personalization knowledge management strategy at Pratt & Whitney, we are not advocating the reduction of the use of Standard Work. Standard Work is an excellent use of the codification strategy for capturing part level design process knowledge. It is the next level systems and component integration knowledge capture that we conclude is too diverse and rich to be codified and placed in a centralized repository for reuse.

7.9 Finding #8: Information Technology utilization in knowledge management

Knowledge management strategies, particularly the codification strategy, involve information technologies that focus on database repositories such as Lotus Notes and the internal web based Intranets. Our research and supporting existing research has shown that human interface with these IT tools and human interaction is a very important element in effective information flow and knowledge transfer. Information technologies can only make dispersed team information flow *more* efficiently. Note only 13% of our survey responses stated that the communication media was a critical enabler to effective information flow.

7.9.1 Human Interface issues

Issues such as search time required finding relevant information, time criticality of information, and ease of use were all critical issues identified through our research. One person interviewed working in the automobile industry stated that their company has extensively used its internal Intranet as the primary information flow and knowledge capture tool. But, when asked if they utilized this vast repository of information in their day to day work culture the answer was no. They stated that there was so much information available on the web that it was very difficult to find the specific information you were looking for. It was just to cumbersome searching for the data that they often just began the trial and error process of finding the correct person to contact for the relevant information. This sentiment was echoed throughout our survey responses when asked what issues existed with a centralized database. Our survey results showed that 70% of the people polled stated that a centralized, "pull" type system could be an effective information flow and knowledge capture tool. Yet, only 5% said they often used a centralized system for these purposes. Many of the positive responses were qualified assuming the following issues were addressed:

- Time critical information: People did not like to use a centralized database for time critical information that needed an immediate response. If this type of system is used, they wanted a secondary notification that the information was available (E-mail, phone call)
- Upper Management Support: As with all initiatives upper management support and backing is critical in the implementation of a centralized database to be used in knowledge capture and information flow.
- Incentives: Incentives must be developed to motivate people to capture knowledge and place value on knowledge management initiatives
- Cross-organizational participation: Basically, one common centralized system should be used. Multiple "pull" type centralized databases would lead to sub-optimal performances of each.
- Organizational discipline: People who own the information must be disciplined in updating it. Once someone gets misinformation from a centralized database, they will loose trust in the system quickly. Conversely, people receiving information must be disciplined in not requesting it via other methods (E-mail, paper) and retrieve the information from the database
- Training: Employees must be trained in the usage, both for inputting and retrieving data, of a centralized "pull" type system. Also, in the case of an Intranet database, training should be provided on setting up an effective standardized web page.
- Ease of Use: The centralized database must be easy to use and easily accessible for both a workstation and PC. As in the case described above, if people cannot access the information quickly and easily, they will not use the system.

7.9.2 Human Interactions

"Although Technology creates business openings by enabling us to communicate with colleagues and business partners in far-flung places, we cannot rely on technology alone to capture them. Human relationships are still paramount."[52]

[52] Benson-Armer, R. and Hsieh, T.,"Teamwork across time and space", The McKinsey Quarterly, 1997, No. 4, pp 19

Our research supports this assertion with 100% of the people surveyed for this thesis felt that trust was a critical enabler of effective information flow. Furthermore, 49% felt that weekly face-to-face communication was required to develop trust and an additional 28% felt that daily face-to-face communication was required. While we cannot conclude from our data what the optimum amount of face-to-face contact required to develop trust is, we do want to point out that it is an important enabler in effective communication in a dispersed IPT environment.

Additional insight to another human interaction of priorities and focus was provided in the Benson-Armer and Hsieh article:

> "Technology increases the potential for conflict as it cuts across corporate fiefdoms, with each team member trying to balance the demands and priorities of power bases at home with those of the team. Team leaders are likely to find it more difficult to marshal support from colleagues dotted around the globe, who are understandably caught up in their own local problems."[53]

While the transition to Module Centers has not resulted in globally dispersed teams, it has created the issue noted in the reference above. One of the primary objectives of the transition to Module Centers was the integration of engineering and manufacturing resources and the organization change has accomplished this. But, one of the new issues is obtaining engineering resources to focus on Post Certification Engineering (PCE) field issues. Team leaders dealing with field issues are finding it more difficult to obtain the engineering resources required because these same resources are focusing on other Module Center objectives, such as manufacturing cost reduction. All critical field issues are being addressed on a priority basis by the Module Center engineering staff, it is these secondary issues that there are not enough resources to adequately cover that could lead to increasing customer dissatisfaction.

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[53] ibid., pp 21

7.10 Finding #9: Post Certification versus Clean Sheet information flow

Much research and organizational change has been dedicated to understanding and optimizing the processes and structures required completing the design and development of new product *systems*. But, our research indicates that Post Certification Engineering needs to be addressed also. In particular, in this thesis we have referenced several times the previous work of fellow SDM and Pratt & Whitney cohorts, Greg Mascoli and Craig Rowles. Their thesis focused on systems integration issues during new product design and development, but did not address the PCE phase of the product life cycle.

This previous work concluded that, with clearly defined systems integration requirements and through the dedicated efforts of the systems engineers, design engineering could complete part and component level designs practically autonomously in the dispersed Module Centers after the conceptual and preliminary design phases.[54] This was based on the highly iterative nature and large number of trade studies required during these phases of the design process. In fact, to date all new engine design programs have been conducted according to these conclusions. Design engineers have been co-located with the systems engineering and the program organizations during these phases and then subsequently dispersed to the module centers for final design. The issue we are highlighting is that PCE efforts require the same amount of preliminary design iterations and trade studies. Additionally, PCE accounts for a significant amount of the total engineering resources allocated to many programs.

Currently, if a field issue requires a redesign of a part or component, the preliminary design phase is completed by the individual dispersed IPT's located in the Module Centers. But, analysis of the information flow required shows that this same highly iterative process exists involving significant trade study analysis prior to selecting a final design path. The conclusions reached in the prior reference thesis work that was based on DSM analysis should also be applied during PCE efforts. For example, if a redesign of the 2nd stage High

[54] Mascoli, G.J., "A systems Engineering Approach to Aero Engine Development in a Highly Distributed Engineering and Manufacturing Environment", System Design and Management Thesis, Massachusetts Institute of Technology, January 1999, pp 56

Turbine Blade is required to address a field issue and it involves changing several internal cooling passages, this change could have system level effects in the:

- Secondary flow system
- Engine bearing thrust balance system
- Engine level performance
- Operability characteristics of the engine.

Multiple preliminary designs and trade studies are required by the CIPT, MIPT and Systems Integration organizations to converge on the final design path. Yet, PCE efforts are currently completed by dispersed IPT's. In Chapter 8 we propose the utilization of a part attribute DSM to facilitate the system level integration issues created by the dispersed PCE IPT's.

Chapter 8

Recommendations

8.1 Overview

The preceding chapters have reviewed the impact of structural and operational changes that occurred within Pratt & Whitney as the company evolved from the Product Center/Component Centers to the Module Centers. Specifically, the review focused on the transition from engine program aligned, co-located IPTs, to manufacturing part family aligned, co-located IPTs. Data gathered through interviews, surveys, and personal experience and built off the work of Craig Rowles and Greg Mascoli[55] in order to understand the emerging information flow issues.

Data and development of this thesis continually pointed to a central theme.

> *Enhancing the flow of information within and across Integrated Product Teams alone will not achieve desired engine system results if it is not integrated properly. A rapidly designed, flawlessly executed, and cost effectively manufactured sub-system component that is not integrated efficiently with other sub-system components in the overall system is valueless.*

The opportunities identified to enhance and add value to our information flow and knowledge capture practices are necessary; however these changes do not sufficiently address the integration roles within and across the Module Centers. The issue of integration across the engine module was raised through the work of Craig Rowles and Greg Mascoli; however their work was generated while the CIPTs were co-located at one site with the program management teams (IPMT/MIPT). As described in Chapter 4, the IPTs have been dispersed from the CIPTs and the CIPTs from the IPMT/MIPT. This significant change has placed an even greater need to focus on information flow and system integration.

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[55] Independent MIT-SDM thesis work of Craig Rowles and of Greg Mascoli

From the information flow and knowledge capture practices analyzed at Pratt & Whitney, we formulated a holistic set of recommendations that are required to counter some of the undesirable side effects of the initial Module Center structure. The six recommendation areas are:

1. Design Structure Matrix - A Management Tool For IPT Information Exchange
2. Information Exchange Strategy For The Evolving IPT Environment
3. Design Structure Matrix – A Tool for Insights Into Organization Architecture
4. Clear Roles and Responsibilities Definition and Module Center Organizational Change
5. Knowledge Management Strategy
6. Lessons for Virtual Teams

The dilemma of the situation is that the Module Center structure integrates manufacturing fully with product design and promotes discipline learning across engine programs, but this same structure also results in the system level engine program issues detailed in Chapter 7. Derived from analysis of our thesis research, we believe that these six recommendation areas will provide real benefits and counter the program/system integration deficiencies.

8.2 Design Structure Matrix - A Management Tool for IPT Information Exchange

From the information flow specifics raised in our research, we explored the Design Structure Matrix (DSM) as a tool to understand greater details of the information exchanges that take place across IPTs. The result of this exploration is a *smart* DSM, which captures the specific exchanges needed between IPTs and visually displays which of these exchanges have or have not taken place. This initial implementation utilizes an electronic spreadsheet with hyperlinks to second-tier information exchanges and supporting documents and files. Key to successful deployment of this tool will be the ease of user understanding and user interface.

8.2.1 IPT Based DSM Shows High Level Information Interactions

The IPT interaction DSM that Craig Rowles created was the starting point for our efforts in exploring use of a DSM as a tool to capture the specific information exchanges and to help manage those exchanges. Rowles' IPT DSM was structured around the design effort of the PW4098 turbofan engine. Through the course of his research, Rowles identified sixty unique IPTs that combined to have 630 interactions.[56] The following DSM (Figure 8.1) is from Rowles' thesis.

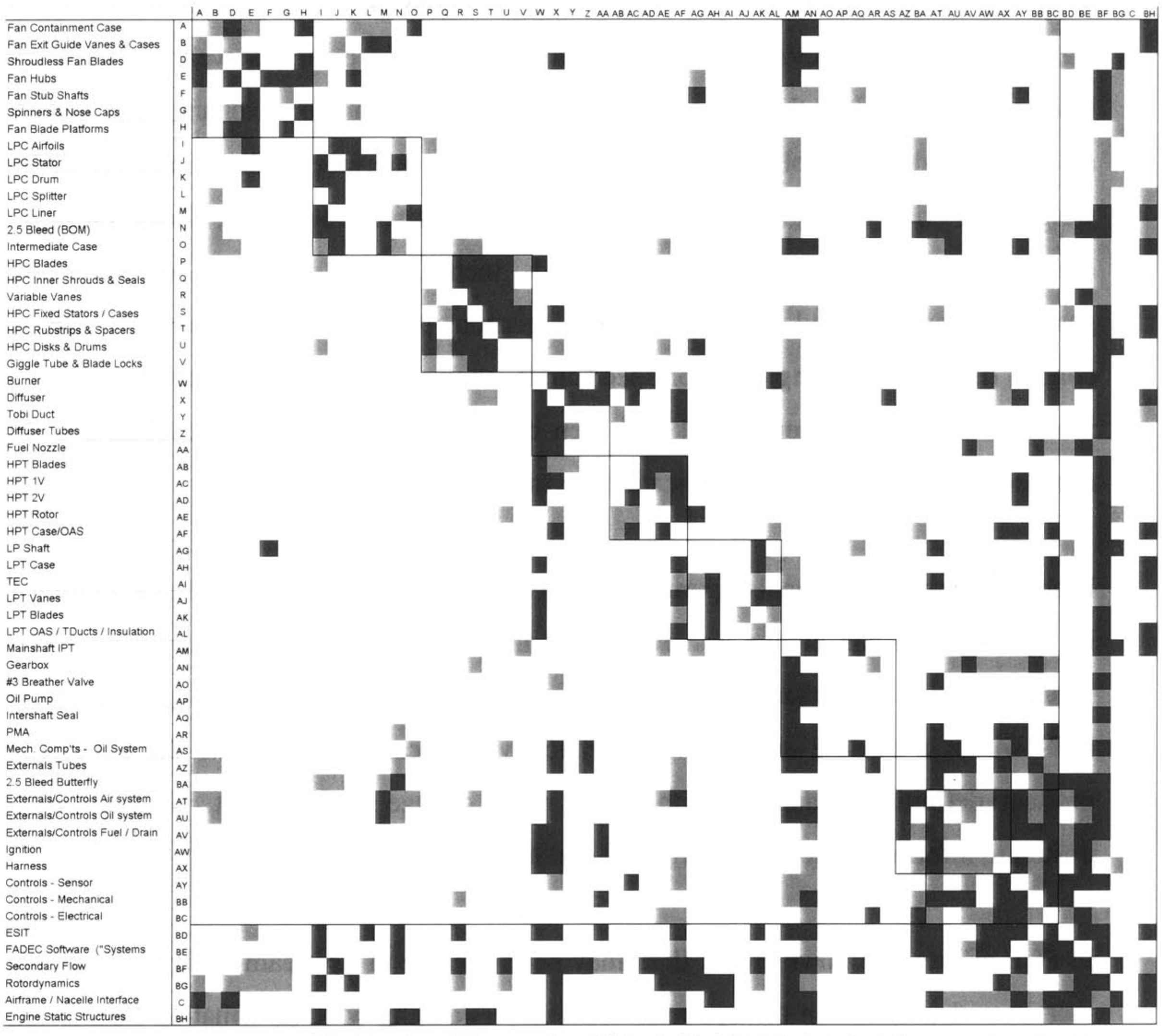

Figure 8.1
IPT Interaction DSM[57]

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[56] Total of strong and weak design relationship & information interactions.

[57] Rowles, C.R., "System Integration Analysis of a Large Commercial Aircraft Engine", System Design and Management Thesis, Massachusetts Institute of Technology, January 1999, Figure 22

8.2.2 *Smart DSM to Capture the Specific Information Flow Across IPT Interactions*

We recommend that the IPTs codify the specific detailed information in-flow that they require and designate the IPT that is responsible for the out-flow of that information for all exchanges. This IPT-to-IPT required information exchange could then be incorporated into an electronic spreadsheet DSM, or smart DSM. Linking the detailed information exchange to the overall IPT interaction DSM, provided in Figure 8.1, will provide a concise 'home' and 'road map' for reviewing the IPT interactions that exist, as well as, what specific information comprises the interaction. The types of information exchange can include, but are not limited, to the following: geometric envelope, interface loading, interface deflection, weight, material, temperature limits, load limits, required flow areas, flows, pressure, part coating, efficiency, part lives, part limit loads, inertia, center of gravity, center of pressure, gas path profiles, bleed schedule, aircraft mission, performance deterioration rate, engine control default logic, engine rotor speed limit, engine exhaust gas temperature limit. This information-rich, or smart, DSM will then be used from conceptual development through detailed design and all post-certification engineering (PCE) efforts.

From the authors' personal experiences with several PCE efforts, we believe a living DSM, i.e. a DSM that can evolve as new system interactions are defined, would be even more valuable during PCE than during initial development. During initial engine development, IPTs within a module are typically physically co-located to facilitate the expected rapid product definition change. Within this rapid change environment, IPTs actively seek upstream information to ensure efficient and timely information flow.

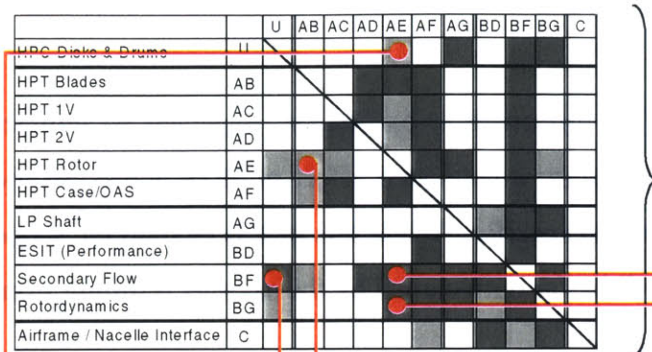
In PCE efforts, the downstream IPTs may not be aware of upstream design activity and are, therefore, dependent on the upstream IPTs understanding what information flow is required to the other IPTs. With the dispersion of IPTs from the CIPTs and from the systems engineering organizations, the IPTs have less access to the systems knowledge. If not thoroughly trained, IPTs may not know the information to pass downstream. The authors' believe that the recommended smart DSM can be a valuable tool to begin to address this issue.

Capturing the specifics of the required IPT information exchanges, expected to number several hundred to several thousand, will require a dedicated effort of IPTs across all the engine modules and some will be engine model specific. While this task is beyond the scope of this thesis, the effort required per IPT will be far outweighed by the savings resulting from streamlining of the information flow process.

The concept is to establish a placeholder for each required IPT information exchange. The process would clearly identify the "From-IPT" and the "To-IPT" along with the specific form that the downstream IPT requires the information, as well as, the downstream use. One source of waste in the existing information flow process is that upstream information producers do not always know how their deliverable is being used downstream. Establishing the link from upstream to downstream user will begin to define a seamless information flow.

Figure 8.2 expands on several of the envisioned IPT-to-IPT interactions to illustrate the detailed information content transferred in these interactions. For illustration purposes, the DSM focuses on an 11x11 matrix, which is a subset of the full 60x60 matrix from the previous Figure 8.1. The required second-tier IPT information exchange specifics are hyperlinks from the appropriate 'cell' in the top level DSM.

The authors wish to clarify that the 60x60 IPT interaction DSM of Rowles was based on post-certification interviews with IPT members for the PW4098. This product was a derivative of the PW4000 – 112" fan series of engines and may not have all the IPT interactions that a clean sheet product might have.



11X11 subset of Full 60x60

Hyperlink'd second-tier IPT exchanges
(one per populated DSM 'cell')

Back to DSM	From: hpt_blade To: hpt_rotor				
From-IPT	**To-IPT**	**Info-type**	**Info-specific**	**Info-form**	**Downstream Use**
hpt_blade	hpt_rotor	geometry	attachment form	3d geometry	attachment sizing
hpt_blade	hpt_rotor	weight	blade	lbs-force	rotor sizing
hpt_blade	hpt_rotor	location	blade cg	in from zplane	rotor rim moment
hpt_blade	hpt_rotor	weight	blade damper	lbs-force	rotor sizing
hpt_blade	hpt_rotor	location	damper cg	in from zplane	rotor rim moment
hpt_blade	hpt_rotor	location	cp	in from zplane	rotor rim moment
hpt_blade	hpt_rotor	area	flow area to blade	in^2	attachment sizing

Back to DSM	From: hpc_rotor To: sdci_sec_flow				
From-IPT	**To-IPT**	**Info-type**	**Info-specific**	**Info-form**	**Downstream Use**
hpc_rotor	sdci_sec_flow	deflection	stg 1seal dx_dy	value_vs_time	flows
hpc_rotor	sdci_sec_flow	deflection	stg 3 seal dx_dy	value_vs_time	flows
hpc_rotor	sdci_sec_flow	deflection	stg 5 seal dx_dy	value_vs_time	flows
hpc_rotor	sdci_sec_flow	deflection	stg 7 seal dx_dy	value_vs_time	flows

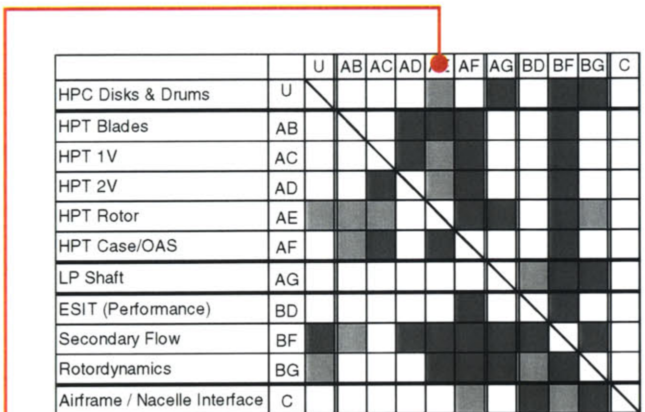
Back to DSM	From: hpt_rotor To: hpc_rotor				
From-IPT	**To-IPT**	**Info-type**	**Info-specific**	**Info-form**	**Downstream Use**
hpt_rotor	hpc_rotor	load	shaft axial - lbs	value_vs_time	hpc rotor flight cycle
hpt_rotor	hpc_rotor	load	stack axial - lbs	value_vs_time	hpc rotor flight cycle
hpt_rotor	hpc_rotor	load	nut axial - lbs	value_vs_time	hpc rotor flight cycle

Back to DSM	From: hpt_rotor To: sdci_sec_flow				
From-IPT	**To-IPT**	**Info-type**	**Info-specific**	**Info-form**	**Downstream Use**
hpt_rotor	sdci_sec_flow	deflection	1st od seal dx_dy	value_vs_time	flows
hpt_rotor	sdci_sec_flow	deflection	1st id seal dx_dy	value_vs_time	flows
hpt_rotor	sdci_sec_flow	deflection	mid seal dx_dy	value_vs_time	flows
hpt_rotor	sdci_sec_flow	deflection	rear seal dx_dy	value_vs_time	flows

Back to DSM	From: hpt_rotor To: sdci_dynamics				
From-IPT	**To-IPT**	**Info-type**	**Info-specific**	**Info-form**	**Downstream Use**
hpt_rotor	sdci_dynamics	weight	rotor system	lbs	rotor dynamics
hpt_rotor	sdci_dynamics	inertia	rotor system	in-lb-sec^2	rotor dynamics
hpt_rotor	sdci_dynamics	load	shaft snap -lbs	value_vs_time	rotor dynamics

Figure 8.2
IPT Interaction DSM Hyperlinks To Required Information Exchange

Utilizing this format to capture the required specific exchange greatly facilitates a systems view of the product since it forces a systems view of the information process. Utilizing capabilities within electronic spreadsheets, the information exchanges going "To" a specific IPT, or information exchanges coming "From" a specific IPT can be summarized to provide awareness of what deliverables are part of the task (Figure 8.3).



From-IPT	To-IPT	Info-type	Info-specific	Info-form	Downstream Use
hpt_rotor	sdci_sec_flow	deflection	1st od seal dx_dy	value_vs_time	flows
hpt_rotor	sdci_sec_flow	deflection	1st id seal dx_dy	value_vs_time	flows
hpt_rotor	sdci_sec_flow	deflection	mid seal dx_dy	value_vs_time	flows
hpt_rotor	sdci_sec_flow	deflection	rear seal dx_dy	value_vs_time	flows
hpt_rotor	sdci_dynamics	weight	rotor system	lbs	rotor dynamics
hpt_rotor	sdci_dynamics	inertia	rotor system	in-lb-sec^2	rotor dynamics
hpt_rotor	sdci_dynamics	load	shaft snap -lbs	value_vs_time	rotor dynamics
hpt_rotor	hpc_rotor	load	shaft axial - lbs	value_vs_time	hpc rotor flight cycle
hpt_rotor	hpc_rotor	load	stack axial - lbs	value_vs_time	hpc rotor flight cycle
hpt_rotor	hpc_rotor	load	nut axial - lbs	value_vs_time	hpc rotor flight cycle

Figure 8.3
Second-Tier Information sorted by "From-IPT"

This smart DSM provides an awareness of the required information exchange, but it does not capture the actual information exchange. Through our exploration of the DSM format, we propose a further expansion of this DSM to capture the actual information that is exchanged. Since a significant portion of IPT-to-IPT design related information exchange is accomplished in electronic means[58], these files can also be hyperlinks to the second-tier, detailed information spreadsheet. Figure 8.4 illustrates the usefulness of the DSM as a roadmap to show both the required information exchanges, as well as, the actual information exchanged.

[58] Electronic means such as analysis processor output, memos, presentations, spreadsheets, e-mail, etc.

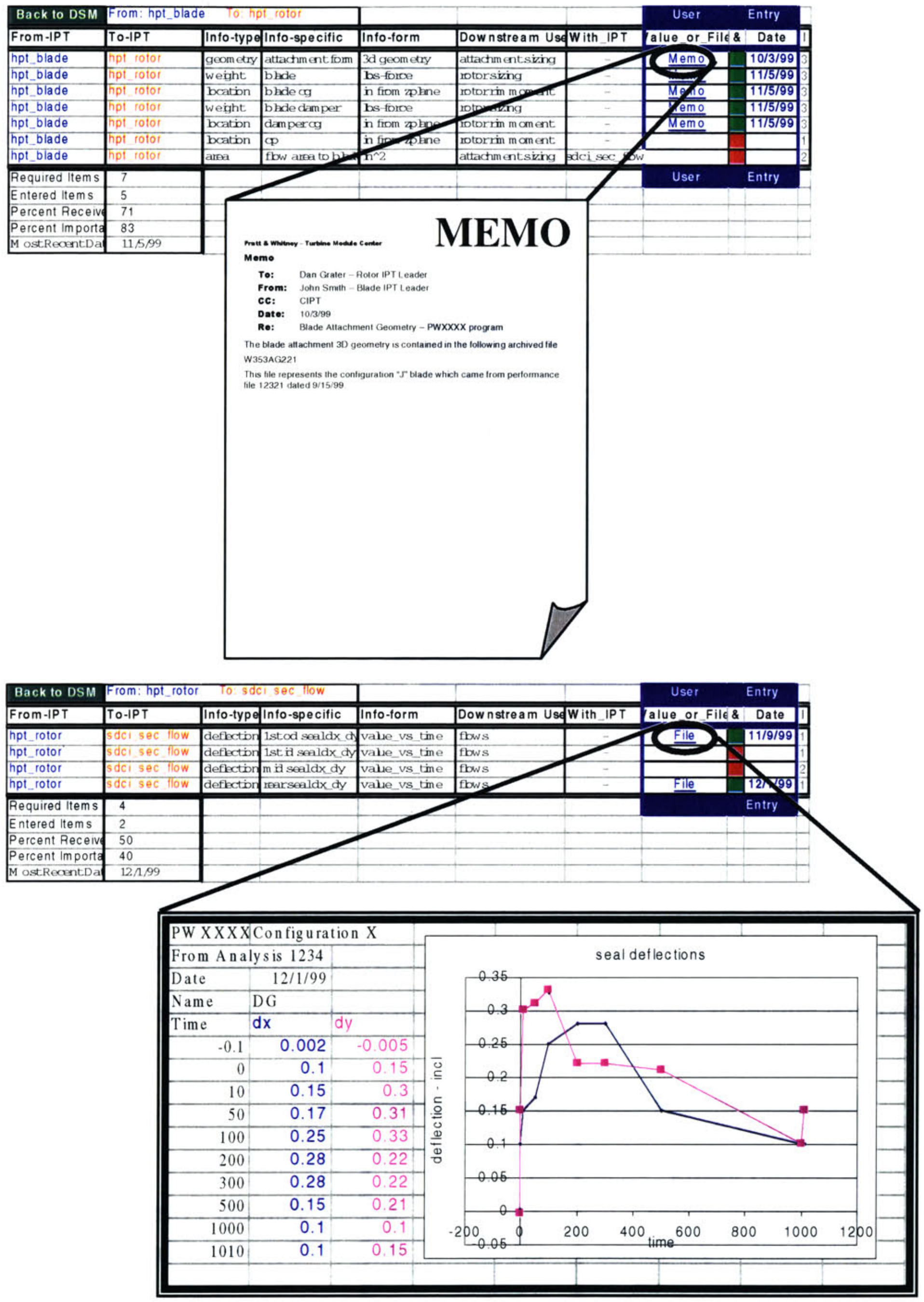


Figure 8.4
IPT Interaction DSM Second-Tier Hyperlinks To <u>Actual</u> Information Exchanged

8.2.3 Information Exchange Tracking DSM to Inform and Manage.

Figure 8.4 illustrated how the actual information that was exchanged between IPTs can readily be linked to the DSM. Again, the DSM format for information flow visualization can be expanded by using a binary indicator to the second-tier information exchange entries. Figure 8.5 shown below highlights this indicator.

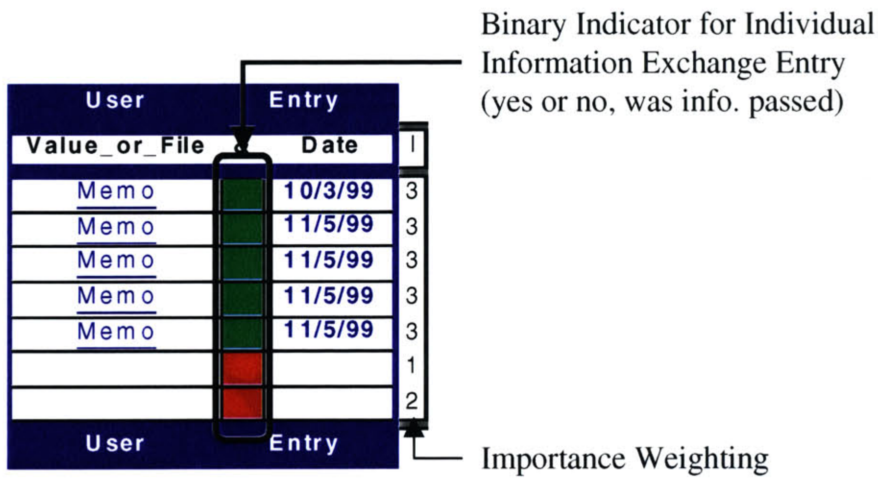


Figure 8.5 Binary Indicator of Information Posted

With this visual indicator, the percentage of the required information available, as defined by the "From" IPT, to the downstream IPT is readily calculated (Figure 8.6). Weighting of the individual entries is possible to more accurately reflect the relative importance.

Required Items	7	
Entered Items	5	
Percent Posted	71	← Percent Posted
Percent Importance	83	← Percent w/Importance Weighting
MostRecentDate	11/5/99	

Figure 8.6 Summary of the Percentage of the Required Information Posted.

Once the percent posted (or percent importance) is identified for each of second tier information exchange sheets, status of all system integration can be rolled up to the top level to provide rapid visualization of where efforts are needed to insure that all required information is exchanged. The methodology chosen in this example is to color code the cells in the DSM matrix indicating the percentage of information posted (Figure 8.7).

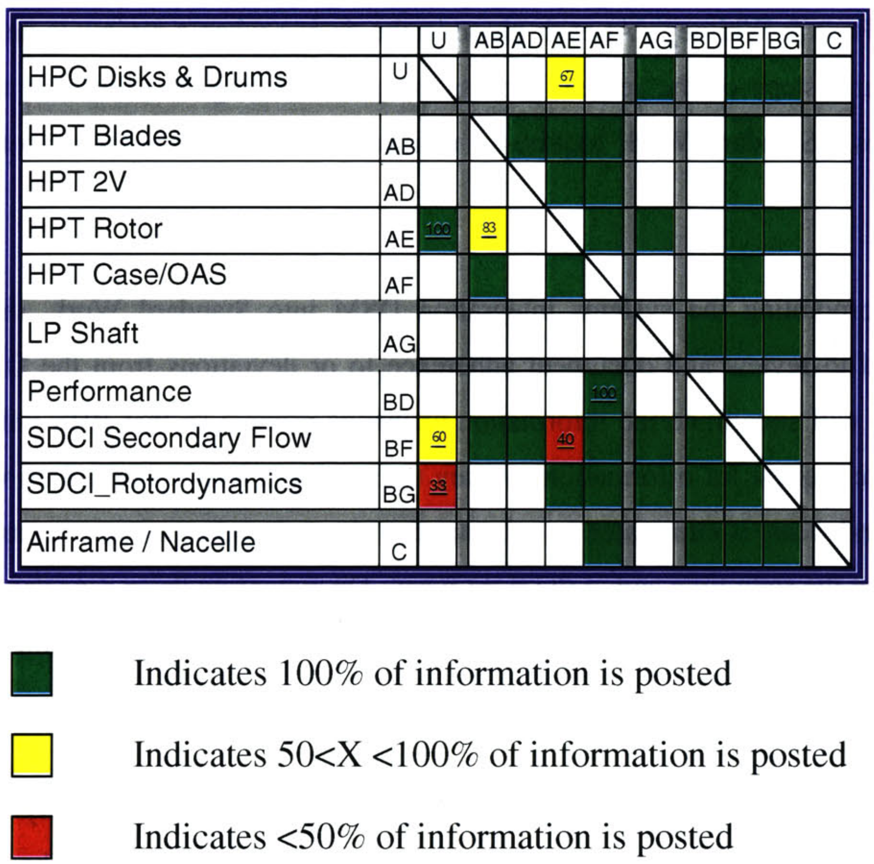


Figure 8.7 Top Level DSM Showing Percentage Of Posted Information

Now from one tool, with all aspects incorporated in the DSM, the following is available:

- The codification of the required information exchange between IPTs
- Ready access to the specific information that was delivered from the upstream IPT
- Capture of the date that the information was posted
- A management tool showing where focus is needed for information passing.

8.2.4 Capture of Required IPT to IPT Information Exchange into Standard Work

As discussed in Section 8.2.2, we believe IPTs need to codify the IPT interaction information exchanges in a DSM and add them to Standard Work documentation. Pratt & Whitney's existing part focused Standard Work lays out all the design and analysis considerations needed to insure that a part, or part change, has been fully evaluated to the current standards within Pratt & Whitney. At each phase in the design when a review is held, one of the first procedural steps of the review process is an accounting of adherence to Standard Work practices. Standard Work requires a review of each consideration, so that it can not be missed.

By incorporating the systems integration DSM into Standard Work, the IPTs would be required to review and document adherence to or deviations from the DSM. This review process will streamline the information exchange process so that IPTs will not be surprised by a late request for information. A key to creating a lean value stream where information flows and waste is eliminated is to insure that the right information is transferred to the right person at the right time and in the right form. Documenting these aspects: the what, the who, the when and the how, is required so that information transfer is succinct and confirmed at each step in the process.

The baseline codification of these exchanges should be relatively easy to create, but will require dedicated, experienced, resources to identify all interactions. The Component Chiefs and IPTs across an engine program need to define the information that they need and from which IPT they believe it should come. After consolidating this information from all IPTs and reviewing for correct ownership, information from the DSM could then be included into the Standard Work for the appropriate IPT. In this manner, at a design review, each IPT would be asked if they passed on the appropriate information and had concurrence that this was acceptable to downstream/upstream IPTs. This process would be far less burdensome than the part focused Standard Work.

8.3 Information Exchange Strategy for the Evolving IPT Environment

As alluded to in the previous sections of this chapter, a tremendous amount of information is exchanged between IPTs, as well as, from IPTs up through the CIPT and the MIPT during a design effort. The current process is one where several means are utilized to exchange this information. Our research found the following breakdown of primary means of communicating (Figure 8.8).

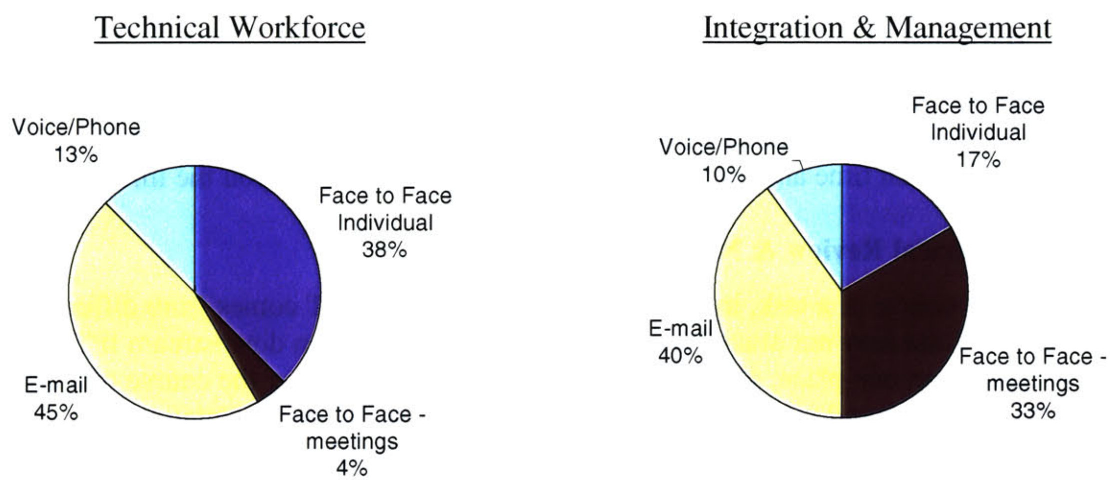


Figure 8.8 Primary Means Of Communication

These data begin to tell the story of the information flow challenge that is faced as Pratt & Whitney transitioned from program co-located IPTs to dispersed IPTs under the Module Center structure. Prior to the Module Center IPT dispersal, the close proximity of the IPTs, the CIPTs, and the program management teams (IPMT/MIPT) fostered and relied on face to face communication. The dispersal of the CIPTs from the program teams and the IPTs from the CIPTs essentially eliminated 42% of the face-to-face communication of the part-focused teams and 50% of the face-to-face communication of the integration and management teams (see Figure 8.8).

One possible course of action might be to *convert* all the face-to-face communication over to E-mail. However our research has identified several concern areas related to relying solely on E-mail. As defined in Chapters 6 and 7, the deficiencies with shifting all the communication to E-mail include:

1. Overload

Our data uncovered that the majority (94%) of those surveyed were already under an E-mail overload condition as discussed in Section 6.8. One issue that is beyond the scope of this thesis, but was brought to our attention during several of our interviews, was the issue of the correct use of E-mail and establishment of norms. We recommend that a team be established to review what of the general information currently being sent with E-mail could be shifted to take advantage of the extensive Intranet.

2. Retrieval

E-mail is a push system sent to specific downstream users. It relies on the upstream senders being knowledgeable about whom to send it to. If not on the original distribution list it can take significant time and effort to track down someone to send you the information

3. Historical Review & New Players

Over the course of a task, information flowing out of an IPT comes from different IPT members and may not always be sent to the same member on downstream IPTs. The ability to capture, in one place, all the information flow of an IPT over the course of a task can be difficult at best and impossible at worst. The need for this documentation is to track consistent development versions of the product and to make it possible to rapidly bring new players up to speed on an issue and the specifics of 'what information was exchanged, who it was exchanged with, and when it was exchanged'.

4. Secure Communication

The current "E-mail push" system is prone to mis-direction of the information when the wrong addressee is selected. When sending the actual technical information in an E-mail, there is risk beyond just going to a wrong Pratt & Whitney recipient, it could go outside the company since a high percentage of employees have external E-mail for interacting with suppliers, vendors, partners. The concern for this type of mis-direction even within Pratt & Whitney is more of an issue with our recent integration of the military with the commercial IPTs at the Business Centers.

8.3.1 Information Exchange via a Web based centralized 'IPT communicator'

Derived from the research concerns related to "E-mail" overload, and to address some of the aforementioned deficiencies with e-mail, a central electronic repository for facilitating IPT information exchange is recommended. As shown in Figure 8.9, a clear majority of respondents felt that a central pull based system would be effective for communication and information flow.

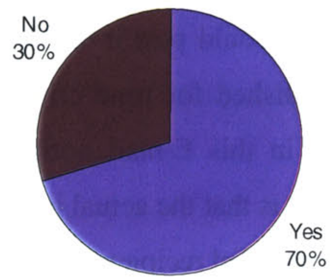


Figure 8.9 Respondents Believing That A Pull Based System Would Be Effective

However, at the same time, many of the same people who responded with a 'yes', did so only when it was followed with some concerns and caveats. The primary issues that were raised in the utilization of a central 'pull' type communication system were directed at the following six areas.

1. Acceptance for something 'new'
2. Training / Education about the proposed change in practices
3. Ease of use of the system for input/retrieval
4. Overall Implementation and maintenance of the system
5. Automated notification for newly posted material
6. Commonality across multiple organizations.

A central system developed for IPT information exchange must address these concerns. While these concerns were raised by 45% of the respondents, another 19% had very favorable experiences with web based exchanges on the existing Intranet tools. Our conclusion from this research is that a central system can be successfully implemented for many aspects of IPT information exchange. The benefits of this type of Intranet central information repository are described in the following sections.

Central & Secure

The 'IPT Communicator', as envisioned, would capture the design iteration information exchanges for each IPT in a central web based system specific to that IPT. Access to the information would require user specific permissions and the data could be searched by task number, engine model, information type[59], author, and date. Instead of directly E-mailing the information, the out-flowing IPT would post it to their IPT 'home page'. An automated E-mail notification could be established for time critical information and a hyperlink to the information could be included in this E-mail notification. A benefit of this process, as discussed in the previous section, is that the actual information is not being sent and therefore can not inadvertently go to un-intended recipients.

Historical Review & Access to Complete Set of Exchanges

Finding the trail of information is one of the first steps of any review process. The existing E-mail system does not facilitate this since any given individual may not have a complete set of the information exchanged. A centralized web system will provide the capability of capturing the complete set of information exchanges from the IPTs allowing review by anyone involved in the task, regardless of their entry point in time.

Reuse

Beyond design creativity and ability to execute and understand analysis, IPTs have to convey information to other groups. This information often takes the form of a presentation of the design status relative to requirements, to other historical configurations, downstream implications, etc. There is a potential to eliminate some non-value-added time in creating new presentations if past presentations can be updated such that the 'template' can be re-used. In order to be able to re-use a past presentation, you first have to find it. This centralized web storage will provide this capability.

8.4 Design Structure Matrix – A Tool for Insights into Organization Architecture

Our research and data review has found that in addition to capturing the specifics of information exchanges, as recommended in section 8.2, the DSM also provides a great way to obtain other insights into the organization architecture[60].

[59] Categories such as design data, trade studies, status to requirements, presentations, etc.
[60] Architecture in terms of physical layout/proximity of facilities, reporting structure, etc.

We extended the PW4098 IPT interaction DSM created by Craig Rowles[61] and added the dimension of physical location of the individual IPTs. The interaction cells in the DSM are color coded to indicate if the interacting IPTs were co-located on the same site (green for same site, red for different site). The resulting matrix under the Product Center/Component Center organization architecture and then under the Module Center Structure was reviewed. The result of this exercise is a visualization of the information flow issues raised during our research.

During the PW4098 development, completed in the previous Product Center/Component Center organization, 92% of the individual IPTs were co-located in one site (East Hartford Connecticut) and the remaining located in North Haven Connecticut. Applying the co-location color code to the IPT interactions in the DSM also shows that 92% of the interactions took place with IPTs co-located on the same site. Figure 8.10 illustrates this by the significant amount of green coded cells.

The same DSM analysis in the Module Center structure is visually quite different. Under the Module Center structure, 47% of the IPTs are located located in East Hartford, 42% in Middletown, 9% in North Haven and one IPT in North Berwick, Maine. Applying the co-location color code to the IPT interactions in the DSM, the result is 40% of the IPT interactions have to span different sites and 60% are co-located by site. This is shown in Figure 8.11.

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[61] The authors must point out that the DSM explored in this thesis has one IPT dropped relative to the original created by Rowles. This slight alteration was made since the IPT dropped was a 'one-time' IPT that has since disbanded and the part was never placed into production.

Figure 8.10 Development Program
IPT Interactions in Product Center/Component Center Structure

PW4098 effort involving 59 IPTs with a total of 605 IPT interactions (369 strong)

Under Product Center / Component Center Structure
- 559 of 605 (92%) interactions occur co-located on same site
- 46 of 605 (8%) interactions have to span sites

Vertical (and horizontal) strips of color indicate the IPT site
The matrix coloring indicates if the interacting IPTs are co-located by site
- (red) Indicates IPTs are NOT co-located on same site
- (green) Indicates IPT's ARE co-located on same site

Figure 8.11 Development Program
IPT Interactions in Module Center Structure

PW4098 effort involving 59 IPTs with a total of 605 IPT interactions (369 strong)

Under Current Module Center Structure

366 of 605 (60%) interactions occur co-located on same site

239 of 605 (40%) interactions have to span sites

Vertical (and horizontal) strips of color indicate the IPT site

The matrix coloring indicates if the interacting IPTs are co-located by site

- Indicates IPTs are NOT co-located on same site
- Indicates IPT's ARE co-located on same site

Chapter 7 detailed the issue of information flow during Post Certification Engineering (PCE efforts in a dispersed IPT environment. To analyze the PCE information flows, the DSM methodology was used to map out a recent PCE effort against the Product Center/Component Center and Module Center organizational structures. The previous DSMs, Figures 8.10 and 8.11, were used to overlay the IPTs involved in the PCE effort. These IPT interactions are represented in the DSM by "X"'s through the involved IPTs and at the involved IPT interactions (Figures 8.12 and 8.13).

The result of this exercise is that in the Product Center/Component Center organizational structure the percentage of co-located IPTs was 91%, compared to only 52% in the Module Center organizational structure. Furthermore, the interactions that have to span multiple sites increased from 9% in the Product Center/Component Center organization, to 48% in the Module Center organization. The DSM provided in Figures 8.12 and 8.13 provide a visual picture of these changes. Note the large increase in the 'red' cells in the Module Center PCE DSM (Figure 8.13), signifying non co-located IPTs, relative to small number noted in the Product Center/Component Center DSM (Figure 8.12). Based on our research, this lack of co-location of the IPTs involved in PCE efforts is a significant factor in the information flow issues noted in Chapter 7. This type of DSM analysis could have been utilized to predict these information flow issues.

During PCE efforts there are a significant amount of other organizations and IPTs that communicated on a regular basis[62] that are not part of development activity to the same degree. These organizations are currently located in East Hartford, Connecticut with the Systems Engineering, Program Office, and Customer Support organizations. These other groups include the following: Materials Analysis Group, Specimen Testing Group, Component Testing Group, Lifing Group, Reliability/Statistics Group, DERs[63], Customer Support, and MIPT.

[62] Pending the focus of the PCE effort this can vary from daily to weekly
[63] Designated Engineering Review – FAA designee

Inclusion of the IPT interaction with these groups under PCE tasks in the DSM will result in an greater impact from the current Module Center structure IPT dispersal than it had for new design development efforts.

Figure 8.12 PCE effort
IPT Interactions in Product Center/Component Center Structure

Actual PCE effort involving 14 IPTs with a total of 67 IPT interactions

Under Product Center / Component Center Structure
61 of 67 (91%) interactions occur co-located on same site
6 of 67 (9%) interactions have to span sites

Vertical (and horizontal) strips of color indicate the IPT site
The matrix coloring indicates if the interacting IPTs are co-located by site
- ■ Indicates IPTs are NOT co-located on same site
- ■ Indicates IPT's ARE co-located on same site

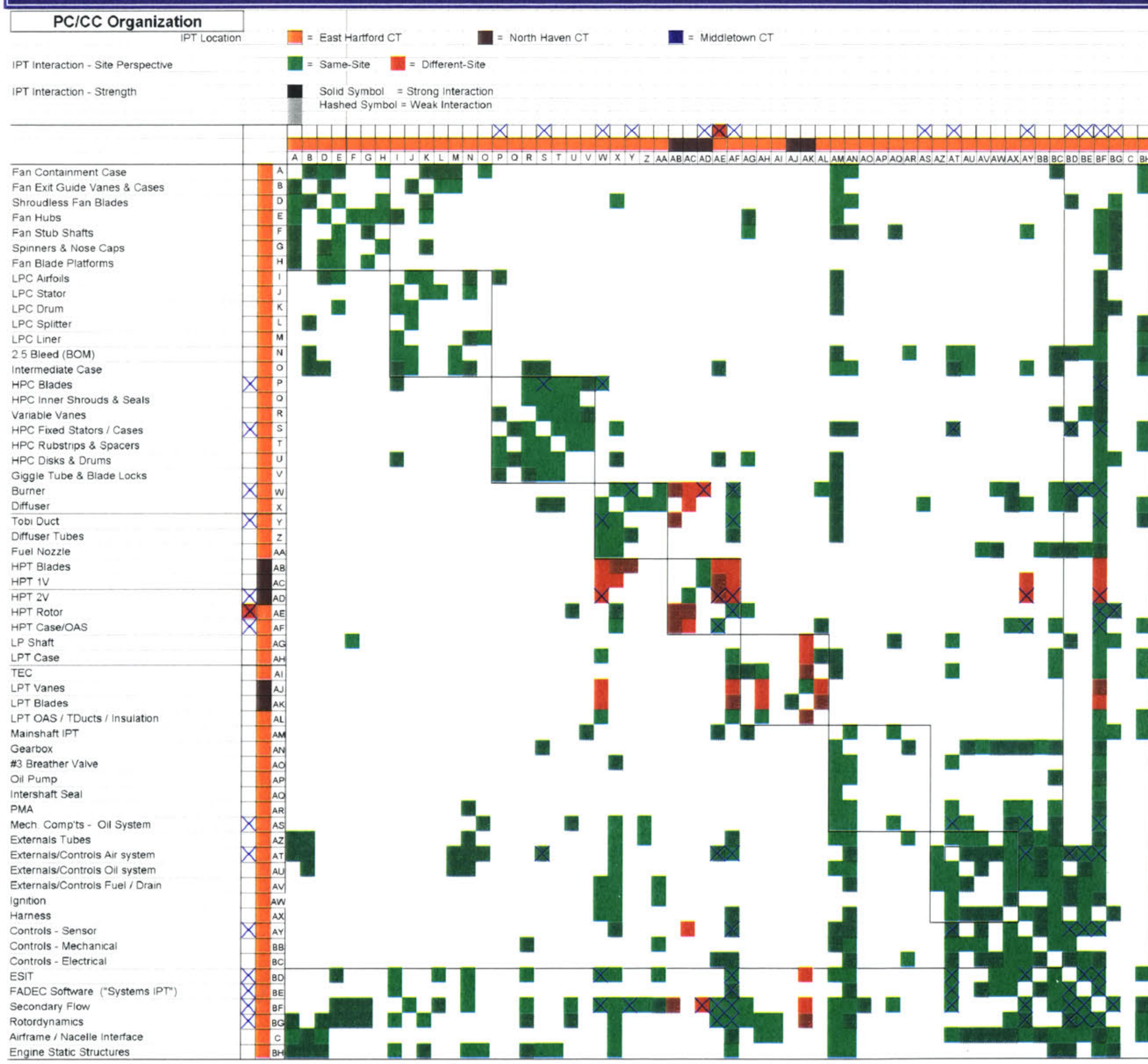

Figure 8.13 PCE effort
IPT Interactions in Module Center Structure

Actual PCE effort involving 14 IPTs with a total of 67 IPT interactions

Under Current Module Center Structure

35 of 67 (52%) interactions occur co-located on same site
32 of 67 (48%) interactions have to span sites

Vertical (and horizontal) strips of color indicate the IPT site
The matrix coloring indicates if the interacting IPTs are co-located by site

- ■ Indicates IPTs are NOT co-located on same site
- ■ Indicates IPT's ARE co-located on same site

8.5 Clear Roles and Responsibilities Definition and Module Center Organizational Change

The proposed development and utilization of the Intranet and DSM tools to identify, capture, and facilitate information flow across multiple IPTs and organizations provides a "road map" to address the system and component integration issues noted in Findings #1 and #2 of Chapter 7. However, our research and experience also indicate that a Module Center organizational change is also required to further address the information flow and integration issues. The establishment of the program focused CIPT organizations, as they existed in the Product Center/Component Center architecture, ***within*** the Module Centers is recommended. Additionally, a standard Module Center organizational architecture should be established to allow increased understanding of the roles and responsibilities of the Module Center resources to the interfacing organizations, such as Systems Engineering and the Program Office.

8.5.1 Module Center CIPT Re-establishment – Program Versus Part Family Focus

As discussed in earlier chapters, one of the significant issues in the previous Product Center/Component Center organization was the lack of manufacturing integration and focus on manufacturing cost. The Module Center transition has addressed these issues by not only co-locating design engineering disciplines with manufacturing, but also by realigning the new engineering organizations focus from program to part families.

From a manufacturing perspective, alignment along part families is logical because of the similar manufacturing processes that exist between similar parts, the ability to apply cost reductions across entire part families, and the facilitation of lessons learned across programs for a specific part. However, from a component or system engineering perspective, program focus provides better integration among the individual parts or subsystems that make up the entire system. As our organizational analysis and research findings have identified, system and component integration has been negatively impacted during the transition to part family focus and the Module Center architecture.

The concept of program versus part family focus is central to the issues noted in the Product Center/Component Center versus Module Center organizations. As shown in Figure 8.14, at some point in the product life cycle phase a transition must be made from program to part family or part focus. In the Product Center/Component Center organization this transition was not made organizationally or physically until the Product Centers, where the parts were manufactured, and production launch. In the Module Centers, the transition is made very early following preliminary design and the decomposition of system level requirements to component requirements. The CIPTs remain program focused, but the IPT resources have been completely aligned along the product families following the preliminary design phase.

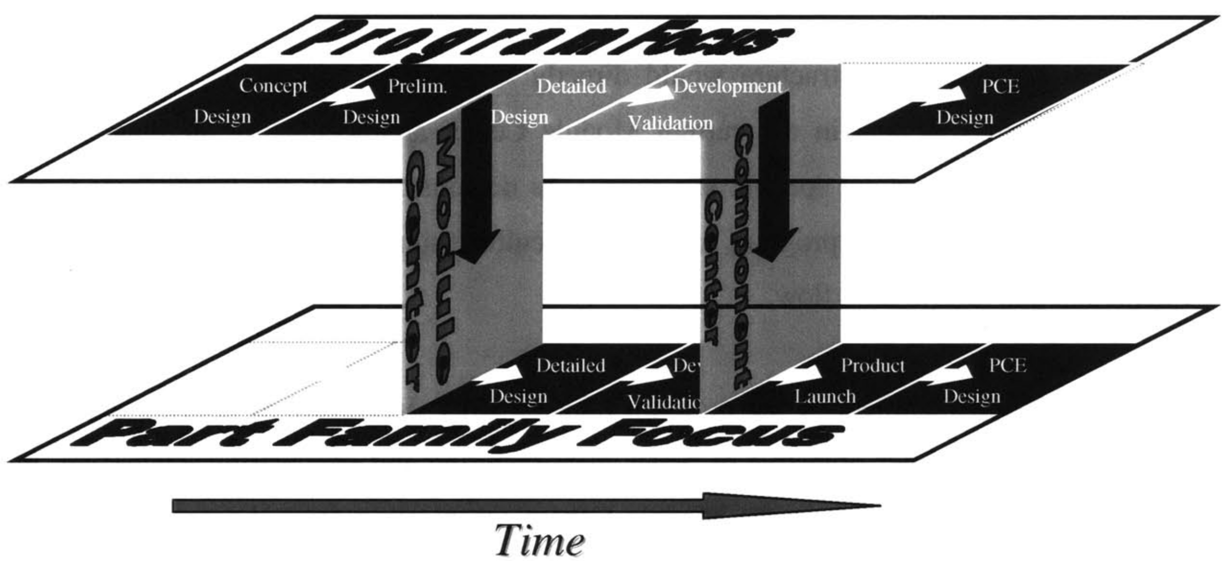

Figure 8.14
Program to Part Family Transition

We recommend that the CIPT to IPT reporting structure and program focus that existed in the Component Center organizational architecture be *re-established within* the Module Centers, as shown in Figure 8.15.

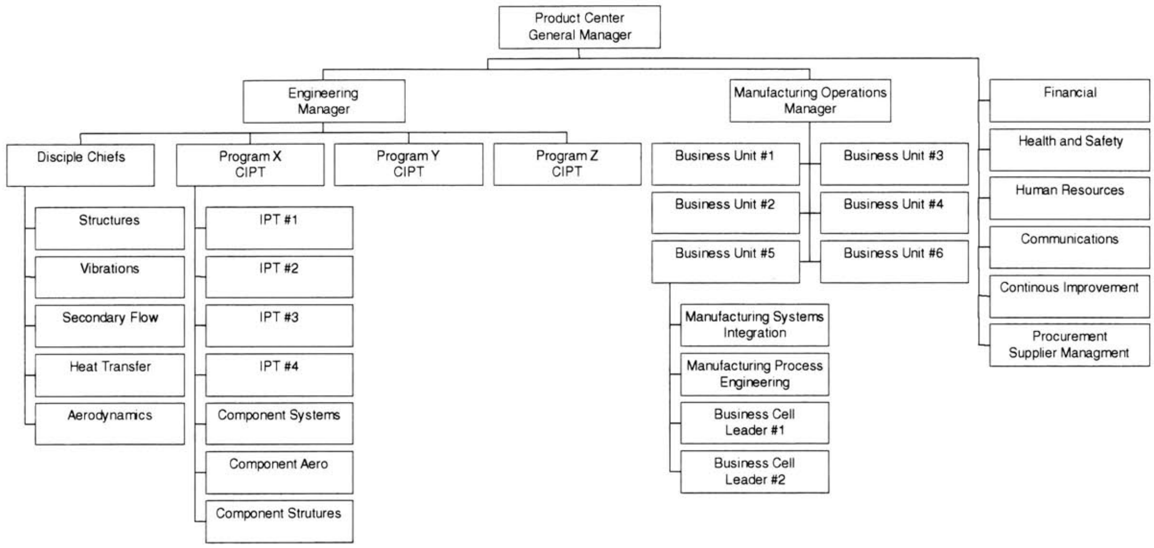

Figure 8.15
Recommended Module Center CIPT Organizational Structure

This new organizational structure would directly address the component, or IPT-to-IPT, integration issues present in the current Module Center architecture by aligning and co-locating these teams along specific programs. As demonstrated by the Component Center organization, a co-located program focused IPT culture significantly facilitates IPT-to-IPT interaction and information flow.

While the re-establishment of the program focused CIPT organizations appears to conflict with the Module Center objective of better manufacturing and engineering integration, two significant differences exist in the Module Center organization from the previous Product Center/Component Center CIPT organization. First, the CIPT/IPTs will still be co-located within the Module Centers and with the manufacturing operations and engineering staff. This co-location of the CIPTs with the manufacturing organizations will facilitate the necessary information flow and informal communication network required for efficient integration of these two groups. Second, the CIPTs will report through the Module Center General Managers, whose focus on manufacturing cost will result in the prioritization of cost reduction efforts within the CIPTs and provide the focus on manufacturing integration missing in the previous Product Center/Component Center organizations.

In this proposed CIPT/Module Center organization, the CIPTs will be immersed in a manufacturing culture, co-located with manufacturing operations and engineering, and report to a Module Center General Manager focused on integrating manufacturing and engineering for reduced product cost. These environmental and organizational attributes are significantly different that the engineering focused culture, dispersed manufacturing operations environment of the Product Center/Component Center organizations.

Additionally, we propose that the new CIPT/Module Center organization will include a Manufacturing System Integration job function. The primary responsibility of this position will be to ensure proper manufacturing integration within the IPTs and communication of best practices from a manufacturing perspective to the IPTs during design efforts. This position would report through the Business Unit managers and would facilitate the transition from program focus to part family focus discussed earlier. The Disciple Chiefs' responsibilities would remain unchanged from the existing Module Center structure and continue to focus on maintaining and developing the technical engineering discipline skills and implementing best practices across programs.

8.5.2 Clear Roles and Responsibilities Definition

Based on our interview data, a clear understanding of the roles and responsibilities of each position not only within the Module Center, but also across multiple organizations is a significant factor in efficient information flow and proper systems integration. Roles and responsibilities should be clearly defined and documented for each position and communicated throughout the Module Center and interfacing organizations. A clear understanding of who needs what information and who to contact for specific information will help to reduce the quantity of misdirected information flow (E-mail), better systems integration, and increased organizational efficiency, since organizations across the value stream will know where to get the most recent and relevant information.

A lack of understanding of who has or needs specific information significantly contributes to the vast quantity of E-mail traffic every day at Pratt & Whitney. If uncertain who has or needs specific information, the sender will often mass mail the information or question, typically via large "CC" lists. While this mass mailing could be perceived as an attempt to improve the information flow and communication throughout the organization, it usually results in non-value added processing time by the individuals receiving the information, filtering it for content, and determining if it is relevant to their responsibility. Conversely, our research has also found that a lack of understanding of organizational roles and responsibilities can also result in a reduction of information flow between interacting organizations. If the roles and responsibilities of a position or organization are not clearly defined or understood, information may not be transferred simply because the sender did not know the other person or organization needed it or what value they brought to the process.

8.5.3 Standard Module Center Architecture

Each of the current Module Center organizations has evolved autonomously, resulting in five distinct organizational architectures. This difference has made it difficult for external organizations, such as Customer Support, Systems Engineering, and the Program Office, to determine who to contact for specific information or where to direct work flow. The lack of a standard Module Center organizations, coupled with the dispersed IPTs, has made the systems integration task significantly more difficult due to a lack of understanding of the organizational responsibilities.

Our recommendation is to establish a standard Module Center organizational architecture that incorporates the best practices that have developed from each of the existing Module Center organizations and the CIPT structure described earlier in this section. A standard Module Center architecture would facilitate a better understanding of the organizational roles and responsibilities across the Module Centers resulting in more efficient information flow and improved systems integration. The standard organizational roles and responsibilities should be clearly communicated both internally and externally to better define the information flow requirements of each position and organization.

One additional aspect of organizational roles and responsibilities and information flow that our research has uncovered is the significance of where knowledge resides. Several of our survey questions were focused on whether or not information flow "work arounds" existed or did information flow through the expected path defined by the organizational architecture. The interview data from these questions indicated that one of the reasons information did not follow the expected path was because the technical knowledge did not reside with the responsible individual, as defined by their position in the organization. Basically, the information flow path was being defined by where the required knowledge resided and not by the roles and responsibilities defined by the position in the organization. Often, if a technical question arose about a specific issue or component, the information was directed to the technical expert with whom the knowledge resided, regardless of what their position was in the new organization. Based on this analysis, we recommend that attention be given to understanding where and with whom technical knowledge resides when establishing a new organizational structure and filling specific positions.

8.6 Knowledge Management Strategy

In Finding #7 of Chapter 7, the two primary knowledge management strategies, personalization and codification *(Hansen et al, 1999),* were discussed in detail along with the apparent conflict between the Pratt & Whitney IPD culture and the codification knowledge management strategy. Based on our research and personal experience, we recommend that Pratt & Whitney continue to utilize the Personalization Knowledge Management as the primary knowledge management strategy. This recommendation is based on the success of the IPD methodology at Pratt & Whitney and the complex nature of jet engine design and development.

The proposed recommendations made in this thesis are focused on improving the information flow in a dispersed IPT environment. The DSM tools developed attempt to not only codify the information flow paths between individual IPTs, but also the type and quantity of the information transferred. The DSM also provides a visual picture of the complexities of designing a jet engine through the mapping of the hundreds of information flow paths between the IPTs involved. However, these tools do not capture the tacit knowledge transfer and management that are required for proper systems integration of such a complex product. The DSM tool identifies the type and need of information flow, and potentially could capture basic explicit knowledge, but it does not capture the tacit knowledge content of the information that is transferred between technical experts.

Codification of the enormous amount of daily system integration issues and informal information flows is not realistic. The IPT DSM analyzed in this thesis was 60 X 60, with approximately 630 IPT to IPT information paths defined. Analyzing the information content DSM shows that for each of the 630 information paths defined by the high level IPT DSM there can exist over 10 discrete information transfers, which results in thousands of pieces of information being transferred between IPTs. Furthermore, the existing DSM analyses, including those contained in this thesis, do not capture the information flow of all the engine level System Engineering, Customer Support, and Program Office organizations.

Codification and identification of the information flow paths is a challenging task that is greatly facilitated by the DSM methodology and will be valuable in management tool for ensuring proper system and component integration. However, codifying the tacit knowledge that resides in the hundreds of technical experts is unrealistic. Thus, continued support of the IPD methodology and personalization knowledge management strategy is recommended. The Module Center organizational structure and processes need to support system and component integration by facilitating informal information flow between the IPTs, CIPTs, System Engineering, and the Program Office.

8.7 Virtual Teams

In Chapter 3, the information flow process of the IPD environment was defined primarily by the formal meeting structure described and the informal information flow facilitated by co-location. In the dispersed environment of the Module Centers, the face-to-face meeting can and is being replaced by virtual meetings through the utilization of information technologies, such as conference calls and Picture-tel systems. However, the information flow issues presented in this thesis focus not only on how meetings should be conducted, but also on how to we replace the informal "hallway" conversations that were such a large factor in the previous co-located engineering organizations. Replacing these informal information flows is the true issue. As shown in Figure 8.16, 26% of our respondents stated that informal face-to-face communications were their primary method of information flow with an additional 14% stating that it was the second most utilized method (Figure 8.17).

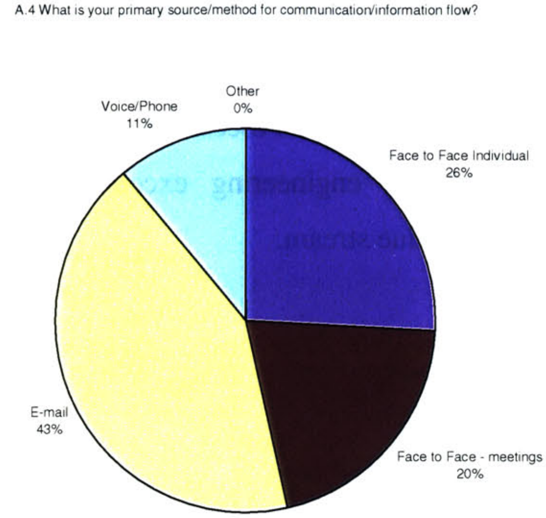

Figure 8.16
Primary Communication Tools

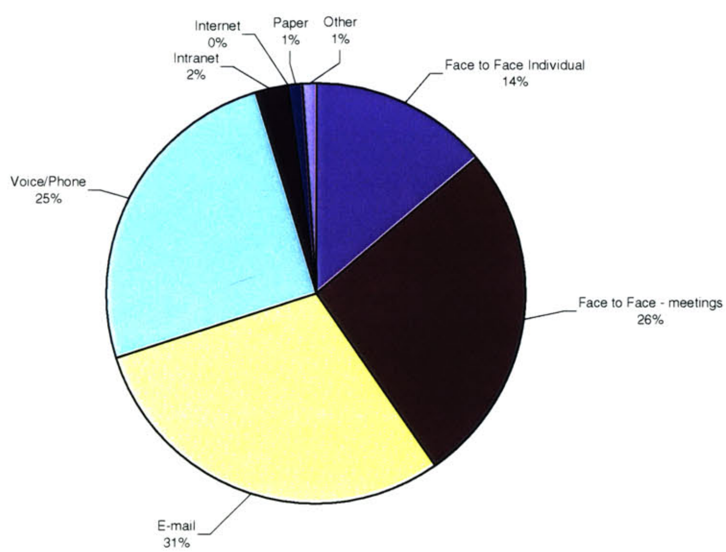

Figure 8.17
Secondary Communication Tools

Virtual teams must address the lack of these informal information flows through the utilization of tools such as the proposed DSM and the Intranet. Information technologies are only a small aspect of a sound knowledge management and information flow strategy. In a dispersed IPT environment knowledge management and information flow strategies must integrate organizational architecture, processes, and culture, along with the adaptation of tools such as Integrated Program and Process Development (IPPD) and the DSM into one cohesive plan that promotes engineering excellence and system and manufacturing integration throughout the value stream.

Chapter 9

Future Work

This thesis demonstrated the usefulness of detailing the information exchange process between integrated product teams for the purposes of enhanced information flow and integration management. Building on this topic, there are several areas that could benefit from additional exploration.

First, we recommend that full IPT interaction DSMs and smart DMSs, as developed in this thesis, be created which span Pratt & Whitney's product line. These DSMs should be 'owned' by the System Design and Component Integration (SD&CI) group and updated as additional new IPT interactions are identified. Codification of all IPT information exchange should be created by the individual IPTs, reviewed by the discipline chiefs within each of the Module Centers and then passed up to the SD&CI. We believe that the IPT interaction and smart DSM and the information contained in these DSMs can become the cornerstone of a system interaction-training module.

Parallel with creation of the IPT interaction and smart DSM for each model, the central IPT communicator should be created. We recommend a pilot application of this system be developed within a small group to allow rapid evolution to a desired level of functionality. This pilot deployment should be completed with multiple IPT member interactions to ensure the 'central pull communication system' issues, identified in Chapter 7, are addressed

The second area that could be expanded within the Smart DSM is to link the IPT in-flow to the IPT out-flow in terms of the primary effects. While there is not a clean one-to-one mapping, there will be some linkage. With this linkage created, a user could access the DSM second-tier information out-flow from a given IPT, highlight the new entry and the DSM would flow this change throughout the DSM in terms of highlighting which IPTs need to review their work based on the new information. Use of the DSM in this way for PCE and derivative engine work would enhance task planning and budgeting through better understanding of task scope.

A third area where significant benefits could be realized is the application of the DSM in the area of physical location of organizations and IPTs. Chapter 8 demonstrated how the DSM was able to visibly convey the site co-located & non-site co-located IPT interactions. The same approach could be employed within a site or Module Center to graphically display the interaction distance between groups required to communicate when laying out facilities. The focus would be to identify the communication frequency[64] based on separation distance and utilize this information to co-locate groups/IPTs with a high level of interactions and facilitate information flow.

The fourth area of potential study is in the area of information technology (IT). The benefits of the DSM as an entry point to specific data exchange is valuable, but could be extended to capture the whole history of evolving information as the design develops. Having the DSM as an umbrella application to capture not only the exchanges between IPTs, but also to capture the linkage to the analysis files employed within each IPT, would allow archival of all task information from one tool, the DSM. Capture of this information may allow one to instantaneously revisit a prior interim configuration to perform additional studies with the benefits of more refined knowledge.

A fifth area for future work is to map out the information flow channels, utilizing the DSM tool, between program management and IPTs for each Module Centers. As discussed in this thesis, the Module Centers do not have consistent organizational structures. Mapping each of these interactions in detail may provide insights into the relative strengths of the interactions and how these strengths apply to each of the phases in the product life cycle. The structure chosen must strike an appropriate balance across all phases.

[64] Allen, T.J., Managing the Flow of Technology: Technology Transfer and the Dissemination of Technology Information With the Research and Development Organization, Cambridge: MIT Press, 1977

Glossary

Unsorted

BC	Business Center
CC	Component Center
CCB	Configuration Control Board
CIPT	Component Integrated Product Team
CPC	Charter Parts Council
DSM	Design Structure Matrix
EC	Engineering Change
ESA	Engineering Source Approval
IPD	Integrated Product Deployment (Integrated Program Deployment)
IPMT	Integrated Program Management Team
IPT	Integrated Product Team
IT	Information Technology
MC	Module Center
MIPT	Module Integrated Product Team
PC	Product Center
P&W	Pratt & Whitney
SDM	System Design & Management – Program at MIT SW Standard Work
UTC	United Technologies Corporation – Parent Company of Pratt & Whitney

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Appendices

Appendix A:

Communication & Information Flow Questionnaire

Communication & Information Flow
Questionnaire

Your participation in this survey is very important to the success of this master's degree research thesis. Please be candid and honest in your responses, it is very important to get factual answers regarding your experience. Under no circumstances will the data be reproduced in any way that will damage and/or result in embarrassment to either you and or your represented organizations. All responses will be kept confidential. Only aggregate statistical results will be reported.

Stephen V. Glynn - glynnsv@pweh.com
Thomas G. Pelland - pellant@pweh.com

Name : ______________________________

Title (position): ______________________________

Organization: ______________________________

Years at company ______________________________

Telephone (Work): ______________ email: ______________

Do you wish to see a copy of the results? ❑ Yes ❑ No

Please provide the most appropriate response to each question based on the organization in which you currently work. If you do not know the answer to a question, if a term is unclear in a question, or if a question does not apply, simply leave the answer blank.

Section A- General

A.1 Which of these titles best describe your role in the organization? *(Select one)*

- ❑ Executive Management ❑ Senior Management ❑ Middle Management
- ❑ First Level Supervision ❑ Technical Team Leader ❑ System Integration
- ❑ Technical Workforce ❑ Other (Please explain) ___________

A.2 In which functional area of the organization do you currently work? *(Select one)*

- ❑ Engineering ❑ Product Validation ❑ Systems Integration
- ❑ Manufacturing/Operations ❑ Program Management ❑ Supply Management
- ❑ Finance/Accounting ❑ Marketing/Sales ❑ Human Resources
- ❑ Customer Support ❑ Business Center (combined Engineering & Manufacturing)
- ❑ Other (Please explain)________________

A.3 Which of the following categories best describes your company's product (s)? *(Select one)*

- ❑ Electronic systems ❑ Photo/Film processes
- ❑ Aircraft (engines) ❑ Automotive
- ❑ Aircraft (airframe) ❑ Hardware/Software systems
- ❑ Spacecraft or launch ❑ Digital copiers
- ❑ Elevator Systems ❑ Retail Products
- ❑ Other (Please explain)________________

A.4 What is your primary source/method for communication/information flow? *(Select one)*

- ❑ Face-to-face: individual ❑ Face-to-face; meetings ❑ E-mail
- ❑ Phone/voice mail ❑ Intranet ❑ Internet
- ❑ Paper/fax ❑ Other (Please explain) ___________

A.5 What are your secondary source/method for communication/information flow? *(Select two)*

- ❑ Face-to-face: individual ❑ Face-to-face: meetings ❑ E-mail
- ❑ Phone/voice mail ❑ Intranet ❑ Internet
- ❑ Paper/fax ❑ Other (Please explain) ___________

Section B- Organizational Context

B.1 Which type best describes the organizational structure of your company? *(Select all that apply)*

❑ Matrix organization: Co-located ❑ Matrix organization: Geographically dispersed
❑ High performance teams (temporary) ❑ Cross-functional integrated product teams
❑ "Flat" lean enterprise ❑ "Vertically" integrated hierarchy
❑ Other ______________________________

B.2 Which of the following best describes organizational alignment. *(Select one)*

❑ Functionally (technical disciplines) ❑ Product architecture/line ❑ Other ____________

B.3 Should there be different communication/information flow processes for communication inside and external to your organization? *(Select one)*

❑ Yes ❑ No Please briefly explain: ______________________________

B.4 Do you feel a "pull" type communication system such as the Intranet/Lotus Notes/etc. would be an effective media for communication/information flow in your organization?

____

____

____

B.5 What do you feel the "social" or organizational challenges of a "pull" or central communication tool would be?

____

____

____

B.6 Are you concerned about the "security" of your communication/information flow media? *(Select one)*

❑ Yes ❑ No

B.7 How many external organizations do you communicate with on a regular basis (more than once a week)? *(Select one)*

❑ 0-5 ❑ 5-10 ❑ 10-15 ❑ Greater than 15

Appendix A – continued

B.8 Which of the following organizations do you communicate with on a regular basis? *(Select all that apply)*

❑ Engineering ❑ Product Development ❑ Systems Integration
❑ Manufacturing/Operations ❑ Program Management ❑ Supply Management
❑ Finance/Accounting ❑ Marketing/Sales ❑ Human Resources
❑ Customer Support ❑ All of the above ❑ Other (Please explain) ______
❑ Business Center (combined Engineering & Manufacturing)

B.9 Are the organizations that you communicate with co-located with your organization or geographically dispersed? *(Select one)*

❑ Co-located ❑ Geographically ❑ Both

B.10 How many meetings are you typically requested to attend per day? *(Select one)*

❑ 0-1 ❑ 1-3 ❑ 3-5 ❑ greater than 5

B.11 How many people typically attend these meetings? *(Select one)*

❑ 5-10 ❑ 10-15 ❑ 15-20 ❑ greater than 20

B.12 Are meeting minutes published? *(Select one)*

❑ Always ❑ Most of the time ❑ Sometimes ❑ Infrequently ❑ Never

B.13 If meeting minutes are published, how are they distributed? *(Select all that apply)*

❑ E-mail ❑ Intranet ❑ Paper/fax
❑ Phone/voice mail ❑ Other (Please explain) ______________________________

B.14 Are meetings a primary source of information/communication flow in your organization? *(Select one)*

❑ Strongly agree ❑ Agree ❑ Disagree ❑ Strongly disagree

B.15 Is communication considered a management priority? *(Select one)*

❑ Strongly agree ❑ Agree ❑ Disagree ❑ Strongly disagree

B.16 Do you feel that your organization communicates effectively? *(Select one)*

❑ Strongly agree ❑ Agree ❑ Disagree ❑ Strongly disagree

B.17 Do you handle information exchange differently with various organizations? Briefly explain why:

Appendix A – continued

B.18 How many different organizational structures/types have you worked in? *(Select all applicable items)*

❑ Matrix organization: Co-located ❑ Matrix organization: Geographically dispersed
❑ High performance teams (temporary) ❑ Cross-functional integrated product teams
❑ "Flat" lean enterprise ❑ "Vertically" integrated hierarchy
❑ Other ______________________________

B.19 How long did each organizational structure/type typically remain in place?

❑ 0-2 years ❑ 2-4 years ❑ 4-6 years ❑ Greater than 6 years

B.20 Based on your experience, which organizational structure resulted in the most efficient communication/information flow? Briefly explain why.

❑ Matrix organization: Co-located ❑ Matrix organization: Geographically dispersed
❑ High performance teams (temporary) ❑ Cross-functional integrated product teams
❑ "Flat" lean enterprise ❑ "Vertically" integrated hierarchy
❑ Other ______________________________

Explanation: ____
____
____

B.21 In your current organization do clearly defined communication processes/policies exist? *(Select one)*

❑ Very well defined ❑ Defined, but unclear ❑ Informally defined
❑ Defined, but not followed ❑ No process defined

B.22 Do you feel the actual communication/information flow follows the defined or expected path? *(Select one)*

❑ Strongly agree ❑ Agree ❑ Disagree ❑ Strongly disagree

B.23 Which of the following most clearly define why communication/informational "work around" occurs outside of defined flow process. *(Select all applicable from 5 = most likely, 1 least likely)*

❑ No clearly defined communication flow process

❑ Organizational structure defining communication flow process not optimally designed

❑ Communication flow follows product architecture/requirements, not organizational structure

❑ Personal relationships/experiences define communication flow, not organizational structure position

B.24 Which of the following attributes/control mechanisms do you feel provide the most authority/power? *(5 = most influential, 1 least influential)*

❑ Budgetary control ❑ Resource (people) control ❑ Information control
❑ "Career" development ❑ Other: ______________________________

Section C- Communication method content

C.1 **How many E-mails do you receive per day?** *(Select one)*

❑ 5-15 ❑ 15-25 ❑ 25-35 ❑ Greater than 35

C.2 **How many E-mails do you regularly have in your "inbox"?** *(Select one)*

❑ 0-25 ❑ 25-50 ❑ 50-100 ❑ Greater than 100

C.3 **How many phone calls do you receive per day?** *(Select one)*

❑ 0-5 ❑ 5-10 ❑ 10-15 ❑ Greater than 15

C.4 **Which of the following communication/information needs are applicable to you?** *(Select all appropriate items)*

❑ General (day to day) ❑ Memo's/Reports ❑ Large technical data files

❑ Schedules ❑ Meeting minutes/notices ❑ UG or graphic data files

❑ Presentations ❑ Other ________________

C.5 **How often do you communicate via a "central" billboard system such as Lotus Notes or the Intranet?** *(Select one)*

❑ Always ❑ Most of the time ❑ Sometimes ❑ Infrequently ❑ Never

C.6 **Which information/communication media do you consider the most efficient?**
(5 = very efficient, 1 = not efficient)

❑ Face-to-face; individual ❑ Face-to-face; meetings ❑ E-mail

❑ Phone/voice mail ❑ Intranet ❑ Internet

❑ Paper/fax ❑ Other (Please explain) ___________

C.7 **What type of computer system do you primarily work on?** *(Select one)*

❑ PC ❑ Networked workstation ❑ Main frame system ❑ Other _____

C.8 **Is your phone capable of conference calling?** *(Select one)*

❑ Yes ❑ No

C.9 Do you feel conference calls are an efficient media of information flow?

❑ Strongly agree ❑ Agree ❑ Disagree ❑ Strongly disagree

Briefly explain your opinion:

C.10 How often do you feel face-to-face communication is required to allow effective information flow? ***(Select one)***

❑ Daily ❑ Weekly ❑ Bi-weekly ❑ Monthly ❑ Quarterly ❑ Never

C.11 Do you feel "trust" can be developed without face-to-face contact with the sender of information/communication flow? ***(Select one)***

❑ Yes ❑ No

C.12 Is "trust" of the sender important in evaluating information/communication content? ***(Select one, and please explain)***

❑ Strongly agree ❑ Agree ❑ Disagree ❑ Strongly disagree

C.13 In your opinion what are the key elements that enable effective communications? ***(5= very important, 1=least important)***

❑ Communication Media ❑ Content ❑ Trust/relationship with sender

❑ Communication frequency ❑ Training ❑ Organizational structure

C.14 Do you feel you have adequate training in all communication/information media available to you? ***(Select one)***

❑ Strongly agree ❑ Agree ❑ Disagree ❑ Strongly disagree

C.15 Would you be interested in being trained in all communication/information media available to you? ***(Select one)***

❑ Strongly agree ❑ Agree ❑ Disagree ❑ Strongly disagree

C.16 Is there such a condition as "Communication Overload? ***(Briefly explain)***

C.17 Do you feel your communication needs are satisfied? ***(Select one and please explain)***

❑ Strongly agree ❑ Agree ❑ Disagree ❑ Strongly disagree

Appendix A – continued

C.18 What issues do you have with each source/method for communication/information flow?

❑ Face-to-face: individual ____

❑ Face-to-face: meetings ____

❑ E-mail ____

❑ Phone/voice mail ____

❑ Intranet____

❑ Internet____

❑ Paper/fax____

❑ **Other (Please explain)**____

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Thank you very much for your time!