ORGANIZATIONAL STRUCTURES FOR TECHNOLOGY TRANSITION: RETHINKING INFORMATION FLOW IN THE INTEGRATED PRODUCT TEAM

by RENATA ALMA POMPONI

S.B., Physics with Electrical Engineering (1990); S.B., Humanities and Science (1990);
S.M., Aeronautics and Astronautics (1995); S.M., Technology and Policy (1995)
Massachusetts Institute of Technology

Submitted to the Department of Aeronautics and Astronautics
in Partial Fulfillment of the Requirements for the Degree of

DOCTOR OF PHILOSOPHY
in TECHNOLOGY, MANAGEMENT AND POLICY
at the
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

JUNE 1998

Signature of Author ....
Technology, Management and Policy Program
Department of Aeronautics and Astronautics
April 15, 1998

Certified by ....
John S. Carroll, Professor of Behavioral and Policy Sciences
Thesis Supervisor, Doctoral Committee

Certified by ....
John J. Deyst, Jr., Professor of Aeronautics and Astronautics
Chairman, Doctoral Committee

Certified by ....
Earll M. Murman, Professor of Aeronautics and Astronautics
Doctoral Committee

Accepted by ....
Richard L. de Neufville, Professor of Civil and Environmental Engineering
Chairman, Technology, Management and Policy Program

Accepted by ....
Jaime Peraire, Associate Professor of Aeronautics and Astronautics
Chairman, Department Graduate Committee

ORGANIZATIONAL STRUCTURES FOR TECHNOLOGY TRANSITION: RETHINKING INFORMATION FLOW IN THE INTEGRATED PRODUCT TEAM

by RENATA ALMA POMPONI

Submitted to the Department of Aeronautics and Astronautics on April 15, 1998
in Partial Fulfillment of the Requirements for the Degree of
Doctor of Philosophy in Technology, Management and Policy

ABSTRACT

Integrated product and process development (IPPD) is an organizational approach designed to facilitate the creation of new products by making a single team responsible for all development activities from concept design through production. While the introduction of IPPD in the manufacturing sector has generated considerable improvements in product performance, cost, and cycle time, the focused nature of its team-based approach may also lead to greater isolation between programs. One area where this fragmentation is of greatest concern for the achievement of company-wide strategic goals is in the introduction of new manufacturing technology. Since manufacturing processes are often applicable to multiple product lines, organizational mechanisms are needed to coordinate the strategic implementation of technology across the organization.

The dissertation examines how organizational structure affects the implementation of new technology within an IPPD environment, focusing on information flow among integrated product teams (IPTs). The research consists of a telephone survey of eighteen aerospace companies and a set of four detailed case studies of technology transition initiatives. Analytical tools were developed to capture information flow paths within different organizations and to assess how those structures impact technology transition effectiveness. Four unique information structures were identified in the first phase of the research, termed the management chain, focal point linkage, focal point inclusion, and network structures. The results of the telephone survey were used to select case study sites.

The results of the case studies indicate that organizational structures which promote the flow of information to and from the IPT level contribute to a more effective technology transition process, as evidenced by the ability to deal effectively with organizational conflict, to coordinate across functional groups, and to plan for the future use of the technology in the firm. These structures were also shown to increase the ability of the manufacturing technology to positively influence the product design. Focal inclusion links between IPTs and a centralized technology transition function are recommended as a means to accomplish company-wide strategic goals within the focused development activity of the IPPD environment. The dissertation supports the importance of information structure analysis in product development theory and calls for further research into the measurement of strategic information dissemination.

Thesis Supervisor:	John S. Carroll
Title:	Professor of Behavioral and Policy Sciences

BIOGRAPHICAL NOTE

Renata A. Pomponi has been a graduate student at the Massachusetts Institute of Technology since 1992, during which time she has pursued an interdisciplinary doctoral degree through the Technology Management and Policy Program and the Department of Aeronautics and Astronautics. Her academic work spans the fields of system engineering, innovation management, and organizational studies. Her doctoral appointment involved serving as a research assistant with the Lean Aerospace Initiative, a government and industry sponsored research project to investigate the potential application of more effective design, manufacturing, and managerial techniques in the aerospace sector. In additional to her research into the management of new technology introduction, she has held several teaching positions. As a teaching assistant to the Technology and Policy Proseminar, she developed and taught a set of case studies on technology policy issues that continue to serve as the core academic course work for entering graduate students. She has also served as a teaching assistant for the Department of Aeronautics and Astronautics' *Introduction to Aerospace Design* freshman elective, where she participated in technical design reviews and interactive educational media development.

Ms. Pomponi received Master of Science degrees at M.I.T. in 1995 from the Department of Aeronautics and Astronautics and from the Technology Policy Program, with a thesis involving a survey of manufacturing inventory control practices in 30 aerospace firms. In 1990, she received Bachelor of Science degrees from M.I.T. in physics with electrical engineering and in music. Her undergraduate thesis involved the construction and calibration of diagnostic experiments for the Institute's tokamak plasma fusion reactor.

Prior to graduate study, Ms. Pomponi was employed with the Systems Analysis and Cost Department of The MITRE Corporation in Bedford, MA. As a member of the technical staff, she provided systems support and cost estimation for a variety of governmental sponsors including NASA, FAA, FCC, and DoD. Her interest in aerospace product development began when she joined the MITRE Orbital Mechanics Specialty Group, where her activities included satellite constellation design, spacecraft mission planning, and parametric modeling.

A lifelong Boston-area resident, Ms. Pomponi enjoys spending her free time rowing on the Charles River as a member of the Cambridge Boat Club and playing the oboe with the Lexington Bicentennial Band.

ACKNOWLEDGMENTS

> *Be patient toward all that is unsolved in your heart and try to love the questions themselves like locked rooms or books that are written in a foreign tongue. The point is to live everything. Live the questions now. Perhaps you will then gradually, without noticing it, live your way some distant day into the answers.*
>
> – Ranier Maria Rilke

These past six years have not at all been what I thought they would. Certainly, the hard work and intellectual challenge have been there, but accompanied by some unexpected exercises in other areas – interdisciplinary integration, organizational skills, human resource management, and, unfortunately, negotiation, strategy, and politics. Out of these diverse lessons has come the most valuable personal legacy of my M.I.T. experience, that of inner strength. I am pleased to have this forum, which represents far more in the way of a testimony to the fruits of persistence than to that of academic achievement, to acknowledge those individuals whose help and support has been invaluable in leading me to this realization.

To my professors: John Carroll, who led me through the initial theoretical foundations for my research and willingly took on the responsibilities of thesis advisor; John Deyst, who provided inertial guidance during the crucial first flights of my dissertation proposal and contributed a great deal to my understanding of strategic technology insertion in the aerospace industry; and Earll Murman, whose understanding of my vision for a new kind of product development research was evidenced not only through his thoughtful advice, but by his willingness to lend financial support through the Lean Aerospace Initiative for two years of doctoral research.

To the companies and personnel who participated in Phases I and II of the research: Their willingness to open their facilities to my questions resulted in new insights, I hope, for all of us. Special thanks to those industry members of the Lean Aerospace Initiative who provided feedback on my thesis drafts, including John Carraway, Jerry Halley, Geary Long, Fred Stahl, John Stankoven, John Walvoord, and Mario Vitale.

To my colleagues in the Technology and Policy Program, with special thanks to Jennifer Howard, Charlette Geffen, and Christina Houlahan, whose friendships were the best combination of intellectual exchange, camaraderie, and empathy.

To my family, whose encouragement has meant so much over the past three decades: my Mom, who led by example (M.I.T. Ph.D., Chemistry, 1961); my Dad, who provides daily confirmation that "measure twice, cut once" is the way to get through life; my brother Marco, who reminds me to get out of the office and ride my bike now and then; and my sister Annie, who made the first four years of my return trip to M.I.T. so much more special.

And, finally, to Karl, whose support and strength are boundless. The only way I would do this over again is if I could still end up with you.

> *To strive, to seek, to find, and not to yield.*
>
> – Alfred, Lord Tennyson

The author acknowledges the financial support for this research made available by the Lean Aerospace Initiative at M.I.T., sponsored jointly by a group of aerospace companies, the U.S. Air Force, and other federal government agencies. All facts, statements, opinions, and conclusions expressed herein are solely those of the author and do not in any way reflect those of the Lean Aerospace Initiative, the sponsoring companies (individually or as a group), the U.S. Air Force, other federal government agencies, or M.I.T. The latter are absolved from any remaining errors or shortcomings, for which the author takes full responsibility.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

Al	Aluminum
AMT	Advanced Manufacturing Technology (department in Company B and in Company C)
CRAD	Contract Research and Development
DFMA	Design for Manufacture and Assembly
DoD	Department of Defense
EMD	Engineering and Manufacturing Development
FSD	Full Scale Development
FY	Fiscal Year
HSM	High Speed Machining
HST	High Speed Technique
IPD	Integrated Product Development
IPPD	Integrated Product and Process Development
IPT	Integrated Product Team
IRAD	Internal Research and Development
LAI	Lean Aerospace Initiative
LRIP	Low-Rate Initial Production
M.I.T.	Massachusetts Institute of Technology
MR&D	Manufacturing Research and Development (department in Company A)
NC	Numerically Controlled
PIP	Product Improvement Process
POC	Point of Contact
PPO	Polyphenylene Oxide
PVD	Physical Vapor Deposition
R&D	Research and Development
R&T	Research and Technology (department in Company C)
RF	Radio Frequency
RPM	Revolutions per Minute
RTM	Resin Transfer Molding

CHAPTER 1 INTRODUCTION

Integrated product and process development (IPPD) is an organizational approach designed to facilitate the creation of new products by making a single, cross-functional team responsible for all development activities from the initial concept design through the production phase. The introduction of these integrated product teams (IPTs) in the manufacturing sector has been enormously successful in bringing together previously isolated functions and in allowing efficient tradeoffs between competing elements. However, while the performance, cost, and cycle time for individual products may have significantly improved, the focused nature of the team-based approach may also lead to greater isolation between product lines. One area where this organizational fragmentation is of greatest concern for the achievement of company-wide strategic goals is in the introduction of new manufacturing technology.

In today's technology-intensive manufacturing sector, new product development often includes technology development, rendering technology an integral part of the firm's strategic outlook. While a great deal of planning and decision making goes on among senior managers concerning the products and markets the firm will invest in to maintain its competitive advantage, many additional decisions reside at the product development level regarding the manufacture of those products. Manufacturing process technologies can represent a critical investment of development resources, a challenge to existing process capabilities, and/or a significant reduction in production costs. Decisions about adopting new technologies can therefore have strong competitive consequences, especially if they involve the choice between techniques that trade off cost, schedule, and performance. With market share and company profits at stake, these decisions require input as to the organization's strategic goals. And yet, since the senior executives who typically formulate strategy are organizationally removed from the engineers and low-level managers who grapple with the day-to-day details of product development, effective communication between these two groups may be a challenge.

Since manufacturing processes are often applicable to multiple product lines within a single firm, new organizational mechanisms are needed to coordinate the strategic implementation of technology across the organization. Given their position in the technology lifecycle between R&D and production, IPTs could play a pivotal role in the transition of new technology. As firms begin to rely even more strongly on the IPT approach, attention must be paid to getting information about the company's technology strategy down to the team level, so that IPTs can become effective decision makers in the technology transition process. This will require an analysis of how the organizational structure of the firm, which determines the paths by which different individuals and groups communicate, impacts technology transition initiatives.

This research represents a first attempt to identify the variety of structures in use in industry for the distribution of strategic information through the organization, in particular to the IPT level. The process of technology transition is used as a lens through which to view the information flow paths in the organization that govern the distribution of information about the firm's technology strategy. The relationships between organizational structure, technology transition, and decision making are examined through a combination of survey and case study methods. The goal is to identify the characteristics of information structures that better incorporate strategic considerations into the technology transition process, taking into account the organizational and cognitive limits encountered when dealing with multidisciplinary teams.

1.1 Overview of Research Questions

The main premise of the research is that differences in organizational structure influence the participation and effectiveness of IPTs in the technology transition process. Specifically, the research examines how IPTs are positioned within the information flow paths for the firm's technology strategy and how that affects their contribution to technology transition initiatives. This role for the IPT has not yet been addressed in the literature.

In reviewing the literature and observing firms' experiences with strategic decision making, four research questions have been identified to focus on the ways in which firms deal with this problem and how different information distribution structures impact the product development process. The overarching question of this research can be phrased as:

> How does organizational structure affect the transition of new technologies from development into production within an IPPD environment?

In approaching this topic, a set of supplementary questions emerge:

Q1. What is the current role of IPTs in regards to...
  - the distribution of information about the firm's technology strategy?
  - the decision making process for technology transition?

Q2. How does the use of IPTs help or hinder...
  - the distribution of strategic information?
  - the technology transition process?

Q3. How are the activities and performance of an IPT affected by organizational structure, in terms of...

- what information the team is given?
- how this information gets to the team?
- how the team participates in the series of decision stages for technology transition?

These questions serve to approach the issue of organizational structures for technology transition in three ways. Answers to the first set of questions are highly descriptive, focusing on the identification of the different information structures currently being used in industry. The second set adds an analytical component by evaluating how these different structures affect IPT performance. The final set of questions focuses on a normative assessment of which organizational structures are most conducive to effective technology transition.

The analysis of these questions will focus on observations from the aerospace industry.

1.2 Scope and Assumptions

The subject of this work is the large manufacturing firm in which the development of new products requires decisions about which manufacturing process technologies should be used to produce them. The unit of analysis is the integrated product team, assuming its format to be today's accepted and effective means of incorporating design, manufacturing, and cost considerations into product development [Wheelwright and Clark, 1992]. The core assumption of the research is that technology transition decisions should consider information from multiple perspectives, since the complex nature of technological development requires tradeoffs between competing advantages and disadvantages along various dimensions. The IPT must consider, therefore, not just the engineering, manufacturing, financial, and marketing issues typically represented in the team membership, but also the strategic goals of the organization [Schoen, 1969; Kantrow, 1980; Pappas, 1988; Cooper and Kleinschmidt, 1996]. Since strategic planning typically takes place at the corporate level, some communication of strategic information has to occur across the levels of the organization in order for the strategy to be operationalized in project decisions [Kaplan and Norton, 1996]. The purpose of this research is to identify methods for the communication of strategic information and to analyze their impact on decision making at the team level. The firm's organizational structure is therefore examined in the context of technology transition.

1.3 Motivation

Making decisions at the lowest possible organizational level is one of the central principles of lean manufacturing management. In fact, previous research has identified a strong positive correlation between the effectiveness of IPTs and the extent to which team members are involved in decision making [Klein, 1995; Klein and Sussman, 1995]. Accordingly, post hoc rejection of team decisions by senior management has significant negative effects on the product development process. Revisiting decisions slows the pace of development, introduces redundancy of effort, and frustrates team personnel. Not incorporating strategic information into team decision making from the start therefore results in longer schedules and increased costs – the opposite of what is desired for effective and efficient product development. In addition, the philosophy of the IPT format is undermined when power is taken away from the team level, leading to lower team effectiveness and decreased team member satisfaction. At the same time, if a team analysis results in a deviation from corporate strategy that is *not* caught by senior management and instead proceeds with a costly development project, the firm may lose valuable resources by investing in technologies that are not in its best competitive interests, leading to long-run strategic weakness. These negative consequences point to the need for attention to strategic information flow to be included as an important aspect of successful technology transition and product development.

Additional urgency is introduced when considering the wide-spread acceptance the IPT format has gained in the manufacturing sector in recent years. The benefits of the cross-functional team approach are indeed significant and warrant its position as the primary manifestation of the concurrent engineering paradigm. However, when considering strategic information flow, the effect of the IPT arrangement is not at all clearly understood. Changes in organizational design by definition affect the way that information flows between different individuals and groups in the organization. In particular, the IPT format has dramatically increased communication between functions at the engineering level by creating teams with members drawn from different disciplines. The approach has also affected the timeline of product development, by calling for the simultaneous development of both the product and the process by which it will be manufactured. IPTs have had great success in improving cycle time, product quality, and the integration of design and manufacturing, in large part due to this increased communication at the engineering level. However, most measures of IPT success have been made at a team level of analysis and within a single product. Issues of how information flow to and from that product team fits into the broader perspective of the company's strategic goals have not yet been addressed. The adoption of the IPPD organizational design should therefore be accompanied by additional questions of whether there are any places in the firm where communication is now less than it was under the functional approach and how those changes might affect the team's ability to succeed. The basic question then becomes, "Is information getting where it needs to go?"

In fact, one might imagine that the traditional arrangement of separating product development functions according to disciplines might have facilitated the flow of strategic information more strongly than the IPT form. When design and manufacturing activities were organizationally separated, the two disciplines communicated primarily through upper management, with little interaction between lower level engineers. Results of analyses and suggestions for action by design engineers, for example, were communicated up the design functional hierarchy through layers of management until they reached a point where the design hierarchy intersected with the manufacturing hierarchy (see Figure 1-1). The information was then passed down the other chain to the corresponding manufacturing engineers at the bottom. While this organizational design contained significant inefficiencies and delays, one positive element with regards to strategy was that decisions were made at the intersection point, a level at which the managers had enough knowledge of corporate strategy, by virtue of their elevated hierarchical status, to understand how strategy should influence product development choices. Under the IPT format, the link between functions has shifted far down into the organizational hierarchy, with direct communication taking place at the engineering level between designers and manufacturing personnel (see Figure 1-2). While this enables concurrent engineering, it also eliminates some of the high-level communication that used to take place across programs, thus weakening the impact strategic information can have on decision making. This is not to suggest that the IPT format should be abandoned, as its benefits are indeed significant, and, as stated above, it is the current industry standard for product development. Unless some way is found to re-incorporate strategic information into technology transition decisions, IPTs will remain inferior to functional organizations when it comes to analyzing strategic dimensions of technology transition. The intent of this research is therefore to identify ways in which organizational structure can be used to recapture the benefits that communication at higher organizational levels provided.

1.4 Contextual Example

The research will focus on how the organizational structure of a firm influences the ability of IPTs to make decisions about the adoption of new technologies, focusing on the distribution of information through the organization. In order to contextualize the ensuing discussion of relevant theoretical background material, consider the following hypothetical example of strategic decision making.

> An automotive product development team is in charge of the body panel assembly for an annual update or "refresh" of one of the firm's established car designs. One of the technology decisions they face is whether or not to use a composite material in place of traditional steel.
>
> The design analysis performed by the engineers shows that the composite is stronger and lighter than the steel version, allowing an increase in gas mileage of one mile per gallon. Meanwhile, the manufacturing analysis shows that the factory's processes are not yet advanced enough to meet quality requirements with the composite, which would require twice the manufacturing time and material to make up for the poor yield. After the marketing personnel discover that consumers

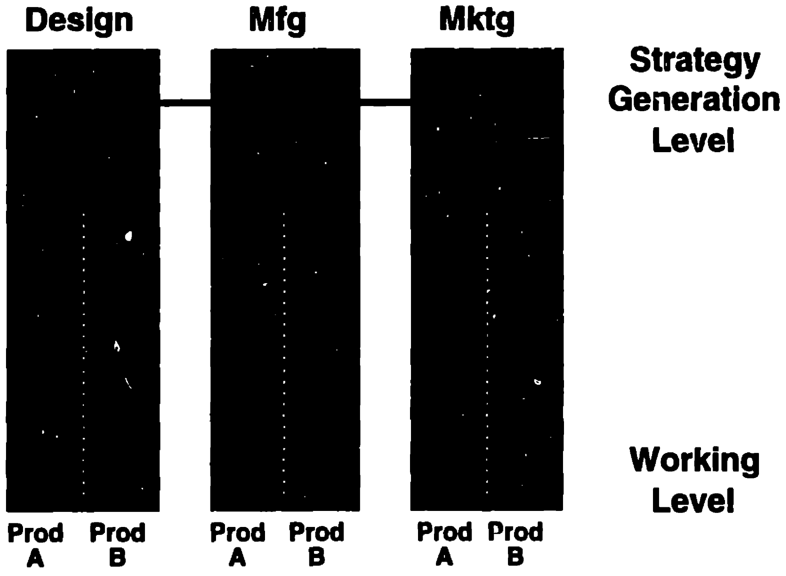

Figure 1-1. Information Flow in Functional Organizations
[Primary cross-program information flow takes place at strategy generation level.]

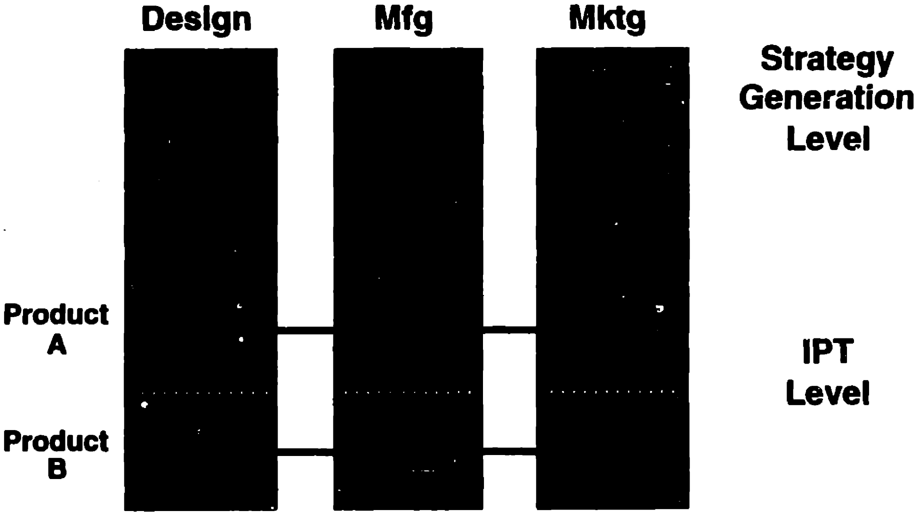

Figure 1-2. Information Flow in IPPD Organizations
[Primary cross-program information flow takes place at IPT level.]

will not pay more for the marginal improvement in fuel consumption, the financial analysis shows that the company will lose money on the technology for two years following the required R&D investment. Based on the available information, the team comes to the conclusion that the composite technology is immature and should not be pursued at this time.

Senior management, however, has already planned that the corporation should follow a first-to-market strategy for a high performance electric vehicle to be

> debuted within the next five years. The realization of this business goal requires the low weight and high strength that composite materials provide, and therefore the firm's technology strategy includes significant investment in composites. Recognizing that the refresh project provides a learning opportunity in the manufacture of composite materials, senior management decides that the need for early development outweighs current technical and cost considerations for the current car. The IPT decision is thus, after lengthy analysis on the part of the team, overruled for strategic reasons that may or may not ever filter down to the team.

Why didn't the IPT and managers arrive at the same outcome? Simple: the managers never told the team about their strategic goals: no information link was present between them, so the team didn't consider that information in their decision. Such a glib response belies the difficulty firms are observed to have in overcoming this communication gap. The research will focus on identifying mechanisms which firms can employ to ensure that information is available at the IPT level for effective technology transition and decision making.

1.5 Outline of Dissertation

The dissertation is organized in nine chapters. A discussion of the relevant theoretical background material, centered on the principles of integrated product development and the theories of organizational decision making, is found in Chapter 2. Hypotheses are developed through the application of organizational theory to the problem of technology transition. Chapter 3 outlines the research methodology used to test alternative structures of information distribution found in the manufacturing sector, including a discussion of the constructs developed to measure variation in organizational structure between firms. Data and results from the multi-year effort are found in Chapters 4 through 7, including a telephone survey of industry product development managers and case study analysis of four technology adoption decisions made by IPTs at three different aerospace firms. Chapter 8 then provides an analysis of the field data, focusing on the impact of different information structures on (1) the process of technology transition, (2) the creation and distribution of a technology strategy, (3) the ability of IPTs to make decisions about the adoption of new manufacturing technology, and (4) the effectiveness of the company's overall product development process. Finally, Chapter 9 presents a summary of the extended theory concerning the impact of organizational structure on strategic technology transition, along with a brief discussion of its relevance for future research and for industry application.

CHAPTER 2 LITERATURE REVIEW AND ANALYSIS

This chapter outlines the literature relevant to studies of product development and technology transition, beginning with the definition of basic terms and continuing through a mixed set of research activity that relates along various dimensions to questions of technology adoption, decision making, strategy, and the IPT format. Since the dissertation research involves the integration of organizational decision making theory and modern product development practice, both perspectives are addressed, with a focus on describing various disciplinary models of technology diffusion and adoption. The organizational structure of IPTs is also discussed in detail and forms the basis for a presentation of relevant literature from organizational theory at the individual, group, and organization levels. Special attention is paid to research findings on how cognitive, cultural, and structural effects impact the operation of individuals and groups as decision making entities within the organization, since this work is anticipated to lend insight into the observed problem of the lack of strategic input in IPT decision making. Existing theoretical strategies for communication and control are presented to set the context for the research. A summary of the organizational advantages and disadvantages of the IPT format is also included and serves to outline the previously explored benefits and challenges of using teams for new technology introduction. An analysis of the literature concludes the chapter, culminating in the statement of the hypotheses to be examined in the research project.

2.1 Definition of Terms

In recent years, awareness of the role technology strategy plays in the firm's success has increased within the management community, and terms such as "technology transfer" have entered the popular lexicon. In order to clarify the use of the technology strategy vocabulary in a research context, as opposed to the casual usages that can tend to be imprecise, this chapter defines terms commonly related to the distribution of technology, focusing on the identification of those most appropriate to the research situation. In addition to increasing the clarity of the ensuing discussion, a review of the semantic arguments that have surrounded these terms provides an interesting preview to the literature regarding the role of technology within organizations.

2.1.1 Technology

"Technology" can generally be classified as one of the words which everyone uses and understands in a variety of contexts but no one is able to define in a manner satisfactory to all. From the Greek roots *techne* ("art" or "craft") and *logos* ("word" or "speech"), its original meaning was "a discourse on the arts" [*Britannica Online*, "History of Technology," 1996]. The word first appeared in English in the 17th-century, used in the original context to refer to a discussion of applied arts and later to refer to the arts themselves. Modern definitions abound. According to Merriam-Webster [1996], technology is defined as "the practical application of knowledge, especially in a particular area such as engineering." This concept of technology as "applied science" is echoed in various entries from the *Encyclopaedia Britannica*, where technology is described as "the application of scientific knowledge to the practical aims of human life or, as it is sometimes phrased, to the change and manipulation of the human environment," or more simply, "the systematic study of techniques for making and doing things."

From an academic perspective, two definitions stand out as being representative of the sentiments of the those who study technology. In his work, *Diffusion of Innovation* [1995], Rogers concentrates on the impact of technology in an uncertain environment, equating technology to "a design for instrumental action that reduces the uncertainty in the cause-effect relationships involved in achieving a desired outcome." Christensen [1992] also words his definition in terms of the relationship between inputs and outputs but focuses more tightly on product development by describing technology as "a process, technique, or methodology – embodied in a product design or in a manufacturing or service process – which transforms inputs of labor, capital, information, material, and energy into outputs of greater value."

Several common themes are present in these varied definitions. First, technology is rooted in the directed, practical application of knowledge, either via design or production, allowing the discoveries arising from "pure" science to be focused on the solution of real-world problems. Secondly, technology is more than just a physical artifact; ideas and methods are encompassed by the concept as well. Finally, technology is a dynamic process in that some type of action occurs, resulting in creation or change. Note that, while Rogers and Christensen use expressions like "desired outcome" and "greater value," many other scholars feel that the concept of technology does not invoke a normative argument; technology does not necessarily have to involve a bettering of the natural world or of prior man-made mechanizations and in fact can often result in quite negative consequences.

For the purposes of this research, the term "technology" will be defined in a manner that condenses the above themes through a modernization of the original Greek definition. In this way, the "arts" under discussion are expanded to encompass any machine, process, or idea that is the result of the application of scientific principles to a real-world situation. Thus, for example, in the case of aerospace product development, a new technology could be a design feature of the physical artifact, such as a "forward-swept wing technology"; a manufacturing process, such as "composite materials technology"; or a characteristic of how the product operates, such as a "vertical take-off technology."

2.1.2 Technology Transition

The process by which a firm moves a technology from the R&D stage to a production application is termed "technology transition." This process may vary in length from months to decades, depending on the maturity of the technology when it is first adopted by the firm. One accepted model for technology transition [Roberts and Frohman, 1978] separates the process into six stages:

I. recognition of opportunity
II. idea formulation
III. problem solving
IV. prototype solution
V. commercial development, and
VI. technology utilization and/or diffusion.

This model will be used in the analysis portion of the research as the basis for tracking IPT activity and decision making over the course of a technology transition initiative (see Chapter 8).

Technology transition often involves a transfer of responsibility between different organizational entities within the firm, which can introduce managerial complexities in addition to the technical challenges of ramping up a new process to a production scale. For example, stages I through III are generally part of the early technology development performed by a central R&D group. Stage IV begins to apply the technology to specific products and therefore often brings in personnel from product development groups (i.e., IPTs). Stage V, commercial development, can be solidly placed in the product development arena, although personnel from R&D may still be involved if more technical development is still required. Stage VI brings in the production operations of the company, as the technology becomes officially adopted by the firm. The level of IPT involvement at this stage tapers off as the product enters a full production environment and the need for design and process changes is reduced.

Transfer of managerial responsibility also requires transfer of information, and so the information flow paths in the organization become an important factor in how work proceeds through the stages (see Section 2.1.3). It is these organizational issues which are of most interest in this research. Section 3.2.2 contains a more detailed discussion of the Roberts and Frohman stages and presents a modification of the model to take into account organizational variation. Section 2.2 describes several other models which have been developed to explain opportunity recognition and the overall decision making process in more detail.

Technology transition is usually considered to be the first application of a new technology in the firm. The decision to proceed through all stages of the transition process, into production, is equated with a decision to "adopt" the technology. Subsequent use of the technology on other products, which usually does not require as much involvement with the R&D group who did the initial development, is defined here as "diffusion."[1]

2.1.3 Organizational Structure

The most basic concept of organizational structure comes from Chandler's [1962] classic work, wherein structure is defined as "the design of organization through which the enterprise is administered." Other authors have explored typologies that emphasize various characteristics of the organization within its overarching design, such as bureaucratic processes [Burns and Stalker, 1961], work roles [Child, 1973; Allen, 1977; Roberts, 1979], power and status relationships [Astley and Van de Ven, 1983; Dutton and Duncan, 1987; Thomas, 1994], decision styles [Mintzberg, Raisinghani, and Théorêt, 1976], and resource allocation and dependencies [Pfeffer and Salancik, 1978; Pfeffer, 1982]. Often a distinction is made between formal and informal organizational arrangements. For example, Nadler and Tushman [1980] consider an organization to be made up of tasks, individuals, formal organizational arrangements, and informal organizational arrangements. Formal organizational arrangements are thought to consist of "the various structures, processes, methods, and so on that are formally created to get individuals to perform tasks" (p. 42). The formal arrangement includes organization design (groups of functions, coordination and control mechanisms, etc.), job design, the work environment, and human resource management systems. These characteristics of the organization are explicitly designed and specified, usually in writing, by the upper management. In contrast, the informal organization is thought to emerge over the course of business operations due to the behavior of the individuals involved, and in response to elements of the formal structure that either inhibit or promote working relationships in the company. Such informal mechanisms include leader behavior, intragroup relations, informal working arrangements, and communication and influence patterns.

In considering which definitions to adopt in a given research study, it may be wise to keep in mind Nadler and Tushman's advice on assigning typological definitions to organizational structure:

---

[1] An additional note should be made concerning the use of a particular term outside the realm of this research thread, namely, "technology transfer." This expression is best confined to represent the adoption of technology across geographic borders or between the government and commercial sectors. The spread of technology from program to program within a firm (or from firm to firm, apart from national and international interests) is best described here instead as "diffusion."

> There are many different ways of thinking about what makes up an organization. At this point in the development of a science of organizations, we probably do not know the one right or best way to describe the different components of an organization. The task is to find useful approaches for describing organizations, for simplifying complex phenomena, and for identifying patterns in what may at first blush seem to be random sets of activity. (p. 43)

The appropriate definition of organizational structure for this research project, therefore, should be one that emphasizes the elements of the organization that are of most interest to the questions being examined. Here, the research questions focus on how the IPPD environment influences the communication of information about the firm's technology strategy and the decision making process for technology transition. Teasing apart these issues, the topic invokes a range of formal and informal organizational processes, according to Nadler and Tushman's definitions:

- the IPPD environment (a formal organizational arrangement)
- patterns of communication (governed by the informal organization but subject to some formal constraints), and
- decision making processes (a combination of formal control mechanisms and informal behaviors (see description of the decision structure below)).

In keeping with this emphasis, the components of organizational structure that are most appropriate for this study are defined as falling into three categories:

- the authority structure
- the information structure, and
- the decision structure.

The authority structure is the same as Nadler and Tushman's formal organizational arrangement, that is, the hierarchical reporting system by which tasks are assigned, performed, and evaluated. It also includes incentive plans and other mechanisms designed by management to promote the effective operation of the company. The organizational design of the firms examined in the research case studies all follow the integrated product and process development (IPPD) approach, with authority structures based on the management of nested integrated product teams (see Section 2.3.2).

The information structure, on the other hand, consists of the methods and pathways by which individuals and groups in the firm communicate information within and across functional disciplines and managerial layers of personnel. In the specific case of organizational structures for technology transition, the information of interest concerns the development and manufacture of new products. Different types of information may follow different information structures in the firm, and the information flow paths do not necessarily follow the hierarchical arrangements established in the authority structure. Personal relationships (simply put, "who knows whom, who likes whom, and who talks to whom") are also part of the emergent communication network that influences the behavior of individuals in a given information structure. An analysis of information structure may consider the content of what is being communicated to be one indicator of how different groups are communicating, since the perceptions and backgrounds of the individuals who receive information color how that knowledge is contextualized in its subsequent distribution and use (see Section 2.3.3). The information structure should not be thought of as identical to Nadler and Tushman's informal arrangement, since the research proposes ways in which communication paths can be established and encouraged by the firm in a conscious manner. The informational component of the IPPD organizational structure has not yet been considered in the literature and so becomes an important focus of this research project in looking at how organizational structure influences the process of technology transition. Additional constructs related to the information structure are developed in Chapter 3.

Finally, as its name implies, the decision structure of the firm regulates how and by whom decisions are made. The decision structure is somewhat linked to the information structure, in terms of who receives information and how it is interpreted to make choices about the firm's activities. It is also linked to the authority structure, since the formal arrangement of groups and subgroups in the firm usually implies some distribution of decision making power. Decision processes in the research cases span the boundaries of formal and informal arrangements due to the unique nature of the IPPD management philosophy. In encouraging decisions to be made at the lowest level possible, managers are establishing a formal framework for decision making while simultaneously allowing informal working relationships to enact those decisions.

In summary, the structures of an organization regulate not just the hierarchical arrangement of workers within the firm but also the means by which they interact with each other to complete their tasks. These definitions are applied to the problem of technology transition in Section 2.4. This study primarily focuses on the information structure and its impact on the effectiveness of technology transition initiatives. Although Nadler and Tushman consider communication patterns to be informally constructed, and therefore outside the conscious control of the firm's management, the research examines how specific information flow paths can be encouraged in the firm by virtue of the benefits they impart to the technology transition process. The authority and decision structures are referred to where necessary when distinctions are made between information flow paths and other organizational patterns.

2.1.4 Technology Strategy

The basic message in Chandler's [1962] classic contribution to organizational theory is that "structure follows strategy" (p. 14), a rational choice perspective that contends that those who set the goals of the organization in turn shape its organizational form. Although others have argued conversely that organizations and the environment in which they operate determine a business outcome apart from the agency of upper management [see, for example, Hannan and Freeman, 1977; DiMaggio and Powell, 1983], Chandler's work succeeded in establishing a link between strategy and structure that has remained intact in the decades that followed. He defined strategy as "the determination of the basic long-term goals and objectives of an enterprise, and the adoption of courses of action and the allocation of resources necessary for carrying out these goals" (p. 13). The pattern of decisions made by the firm can be thought either to demonstrate the application of a previously formulated strategy or to form an emergent strategy through the implementation of the decisions themselves [Mintzberg, 1978]. Building upon Chandler's definition, Hickson *et al* [1986] consider a "strategic decision" to be "one in which those who are involved believe will play a bigger rather than smaller part in what happens for a long time after" (p. 27). Such decisions, representing a commitment to action and often a commitment of resources, tend to occur rarely in organization and have lasting consequences, setting precedents that make subsequent decisions along that path more simple by establishing parameters that constrain future choices. For example, once a decision has been made to adopt the next generation of a particular technology for one project, subsequent projects will be able to use the results of the earlier analysis to justify the use of the newer technology for their own purposes.

Many components of business strategy have been identified in the literature, including the particular subdivisions of interest here: manufacturing strategy and technology strategy. The former consists of goals and plans for the operation of the manufacturing facility, including capital equipment investments, capacity issues, human resource management, process quality, and production scheduling priorities. Technology strategy, on the other hand, focuses on the development and implementation of new technologies for both the firm's portfolio of products (i.e., "product technologies") and for the techniques by which those products are manufactured (i.e., "process technologies"). This planning can include the selection of technologies to be pursued, the allocation of R&D investment, the timing of new technological introductions, the pursuit of external technology acquisition, and the scanning of competitor development [Pappas, 1988; Hax and Majluf, 1996]. The distinction between the two types of strategy lies principally in the level of analysis and the temporal outlook: technology strategy involves choices between competing technologies for future development, while manufacturing strategy generally concerns a more immediate implementation of a specific technology already selected for production [Maidique and Patch, 1988].

While a firm's choice of technology strategy is obviously a complex matter highly dependent on the specifics of the organization and the competitive climate, most strategies address issues such as the following [Hax and Majluf].

- Technology intelligence (how the firm learns about the latest innovations)
- Selection of technologies
- Timing of new technology introduction
- Modes of technology acquisition (internal development or external subcontracting)
- Technology horizontal strategy (internal transfer of innovation)
- Project selection, evaluation, resource allocation, and control (R&D funding plan)
- Technology organization and managerial infrastructure.

Several authors have constructed typologies to distinguish different types of technology strategies [see, for example: Kantrow, 1980; Hickson *et al*, 1986; Maidique and Patch, 1988; Pappas, 1988; Hax and Majluf, 1996]. One such classification system [Maidique and Patch] is outlined below, along with the key resource requirements of each strategy and an example from industry.

- Leader – first-to-market to gain temporary monopoly advantage; requires high R&D investment (e.g., Intel microprocessors)
- Fast Follower – second-to-market to gain market share without risk; requires strong and nimble development capability (e.g., Zenith consumer electronics, now defunct)
- Cost Minimizer – late-to-market to reduce development costs (and therefore undercut market price) through imitation of leaders; requires process engineering skills to lower manufacturing costs (e.g., General Motors compact cars)
- Market Segmenter – creates niche markets not met by previous entrants; requires flexible manufacturing capability (e.g., Silicon Valley Specialists high performance integrated circuits).

These four categories, while perhaps an over-simplification of the many nuances in corporate strategy, will suffice to describe differences in technology strategy between firms for the purposes of this study.

2.2 The Technology Transition Process

The transition of a technology through a firm is usually initiated by a product development group which finds itself in need of a solution to a manufacturing problem.[2] The process can be thought of as having two major organizational events: the motivation for considering a new technology (Stage I from the Roberts and Frohman model) and the ensuing decision process that leads towards the adoption or rejection of that technology (i.e., the decisions to proceed between stages). The first part of this section covers several models describing how the impetus for change is generated within an organization, followed by a description of models that address the decision process itself. Several models of decision making are presented, including representatives from both choice-based and rule-based theory.

2.2.1 Models of the Impetus for Change

The process by which an innovation becomes known to individuals within an organization and prompts the recognition of the possibility for change has been modeled by researchers in many fields. At the heart of the discussion is the need for a technology to be recognized by the organization before it can be considered. Regardless of its technical merits alone, a technology will not be adopted until a political process occurs to generate awareness of the technology's existence and awareness of the need for a change in the current mode of operation [Thomas, 1994]. Two models arising from analogies to the physical concepts of momentum and force are described below in order to illustrate some of the temporal and political issues surrounding the ability of an organization to change its current patterns of technology use.

2.2.1.1 Momentum for Change

The physical concept of momentum has been used to describe the means by which a new innovation in an organization emerges, gains viability, and is adopted. For example, Dutton and Duncan [1987] consider change in the organization to stem from the firm's recognition of discrepancies between desired and actual performance and its attention to stakeholder demands. These "triggering mechanisms" initiate an assessment of the urgency for action and the feasibility of doing so, as shown in Figure 2-1. Together, the strength of these assessments build momentum for change, the level of which determines whether incremental or radical changes will be pursued to retain a strategic position in the market.

---

[2] The origination of technology transition in the product development side of the organization assumes a "technology pull" arrangement, whereby R&D projects are undertaken in response to specific or anticipated product needs. This is in contrast to a "technology push" environment, where the R&D group would be working on the development of new technology without having a specific application in mind. In today's cost-driven market, investment in projects according to a technology push mentality is on the decline in manufacturing companies.

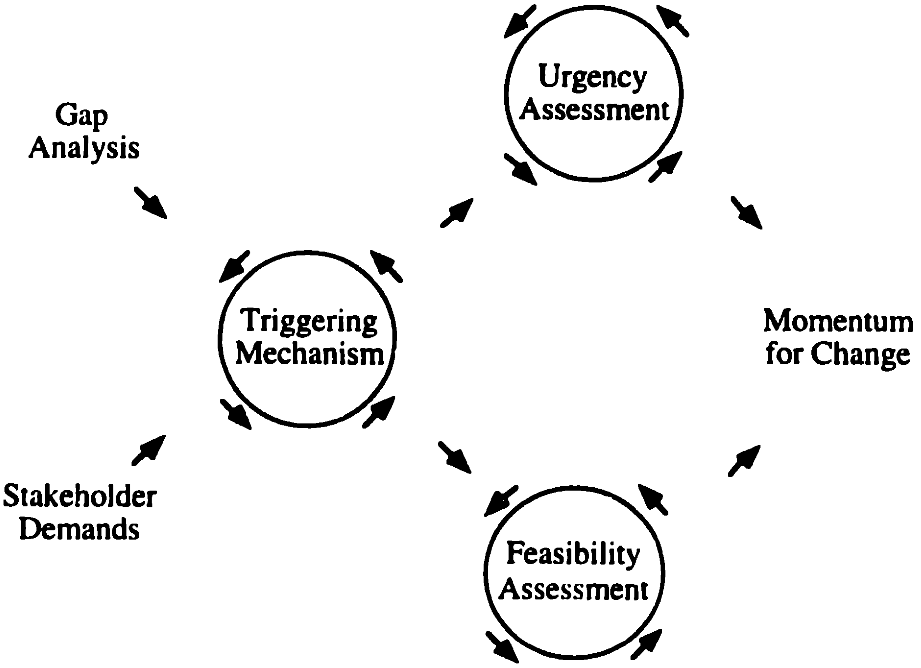

Figure 2-1. Momentum Model [Dutton and Duncan, 1987]

Fitting within the rational choice framework of organizational change, the momentum model regards the response of the firm to be analytically grounded and based upon managers' autonomous assessments of how best to proceed. At the same time, the model recognizes that both individuals and organizations, especially large ones operating under a high degree of oversight, are inherently reluctant to change their standard operating procedures. It is extremely rare for a new idea to emerge and immediately be adopted, since a great many individuals in the organization need to be convinced that the change is beneficial. Application of this model to a decision situation would therefore require input as to the needs of potential customers and the capabilities of the competition. If the pressure from the stakeholders (both customers and shareholders) were high enough, and if a technical assessment of the design requirements indicated that current technologies were not capable of meeting performance requirements, the change process would be triggered. At this point, extensive analysis of both technologies would be undertaken to determine the urgency of making the decision and the capability of the organization in following through with the required development and implementation. If these analyses proved positive, then momentum for change would build, and the organization would be highly likely to adopt a new technology.

2.2.1.2 Force Field

Newton's concept of equal and opposite reactions influenced the development of Lewin's [1947] force field model of organizational change, of which technology adoption can be considered a part. Figure 2-2 presents the basic argument of the model: the current state of the organization, in terms of its operating procedures and technological base, is in equilibrium. Forces exist that both inhibit and promote a change to this balance, and so if any change is to take place, the driving forces must overcome the restraining forces. These forces, which may originate both internally and externally to the organization, are present in many forms, including the following [modified from an application of the model by Levi and Lawn, 1993]:

- Technological: organization's existing technology; new technologies available
- Financial: costs to adopt and implement the innovation
- Marketing: impact on organization's market image
- Strategic: competitive advantages and disadvantages
- Organization: structure and processes; company culture; role of champions; concerns and interests of management and employees; effects on authority, control, and communication.

2.2.2 Models of Decision Making: Choice-Based Theory

A great deal of work has been done concerning how decisions are made by individuals and organizations, and only a brief description of the most relevant issues of IPT decision making is presented here.[3] Although models vary depending on disciplinary perspective, many have in common some path of "rational" action by which the decision evolves. For example, March [1997] describes a four-step process of decision making:

- knowledge of alternatives
- knowledge of consequences
- determination of consistent preference ordering, and
- application of decision rules.

Another model [Mintzberg *et al*] divides the decision making process into three stages, each with characteristic activities that are performed:

- identification: recognition of the need for a decision or change; diagnosis of the situation
- development: search for alternatives; design of solutions
- selection: screen solutions for feasibility along important dimensions; choose among solutions; gain authorization for the decision outcome.

---

[3] For greater depth on the topics of organizational decision making and decision research, see: Alexis and Wilson, 1967; Mintzberg, Raisinghani, and Théorêt, 1976; Carroll and Johnson, 1990; March, 1994; Shapira, 1997.

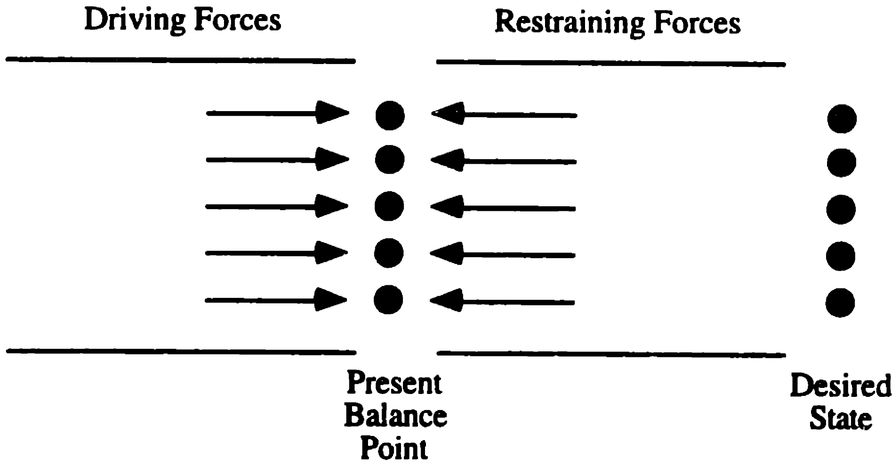

Figure 2-2. Force Field Model [Lewin, 1947]

Such systematic and linear approaches, albeit with some required iteration, have served as the model for rational decision making in many disciplines, especially in traditional engineering problem solving techniques. For example, the process of technology adoption can be related to the process of creating a technical design. Just as there are numerous options to choose from along the path to a completed engineering design, there are many conflicting issues, usually with complicated interdependencies, to take into consideration when deciding whether or not to adopt a new technology. Engineers have developed a wide variety of models to aid in this decision process. Two of these are presented below, one employing a decision tree approach and one using a flow diagram methodology.

2.2.2.1 Decision Trees

The decision tree is a long established method for analyzing complex, multi-dimensional problems involving choices among a large number of possible outcomes [see, among others: Marples, 1961; de Neufville, 1990]. Since it is not feasible to attempt to solve the entire system of issues at one time, the problem is decomposed into a "tree" of alternatives, with each major decision point "branching" into sub-tiers of options (see Figure 2-3). At the upper levels, the problem and its accompanying decision points, or nodes, are often described in a rather abstract manner, becoming more focused and detailed as the tree branches out. For example, in deciding between two competing technologies, engineers can not possibly hope to answer the question of "which one is best" all at once; issues of cost, performance, and business strategy are intertwined and must be addressed systematically. In using the decision tree approach, the engineers might assemble a tree whose top-most nodes represent major decisions about the nature of the choice between technologies, such as "determine lowest cost" and "determine highest performance." Lower down,

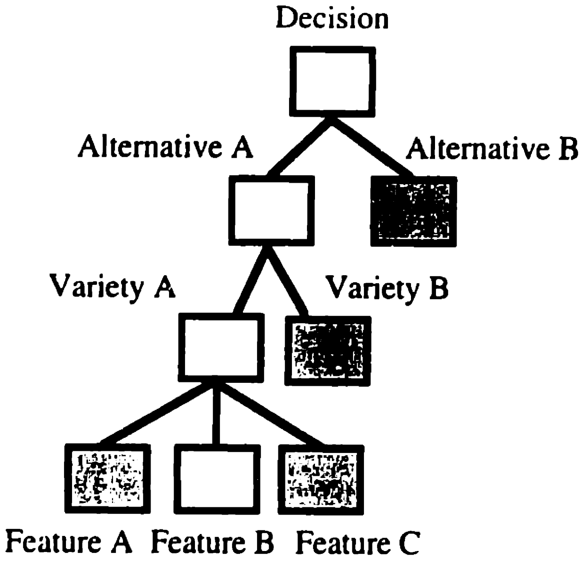

Figure 2-3. Sample Decision Tree

the "cost" branch may subdivide into the critical issues associated with this aspect of the decision, such as "determine required R&D investment" and "determine change in operating cost." At the lowest level, the firm would evaluate quantitative nodes such as "estimate number of research hours for internal development of components."

Each branch point has an effect on the resultant benefits and costs of choices above. For a very complex, large-scale problem, the tree may branch many times and grow to many levels before the details of an individual decision are independent enough to be tractable. In searching for an overall solution to the system, the tree is typically approached from the bottom up; that is, alternatives at the lowest level are compared to see which presents the most nearly optimal solution.[4] The remaining options are then "pruned" from the tree and eliminated from further consideration, as indicated by the shaded boxes in Figure 2-3. The final outcome of the process, which technology is selected, depends on the results of the analyses at each branch point. This decision model therefore does not favor either established or novel technologies in the way that other more

---

[4] Note that decision trees are often used as an aid in performing risk analyses, such that the search concentrates on identifying Pareto optimal, or non-inferior, solutions. A probability assessment can then be performed to judge the solution that most exceeds the expected value. See de Neufville [1990] for a complete discussion of the use of decision trees under these conditions. Note, however, that the focus of this research lies more with the cognitive and organizational elements of decisions taking place within the IPT format, not with the application of such quantitative models for decision optimization.

subjective methods can when top-level decisions are made without quantitative analysis of the component elements.

2.2.2.2 Flow Diagrams

Flow diagrams capture essentially the same elements as the decision tree but concentrate on the logical nature of traditional engineering thought processes to achieve the same systematic pruning of the solution space. Instead of listing every alternative in the tree structure, the flow diagram attempts to organize the decision process of technical problem solving by segmenting the problem into a series of feedback loops that concentrate on the most important measures of merit first so as to quickly focus the problem on the critical dimensions under scrutiny. Frischmunth and Allen [1969] demonstrate this technique as a process of evaluating alternatives on a series of critical dimensions, and then modifying both the alternatives and the dimensions to achieve the most acceptable overall solution (see Figure 2-4). In employing a decision methodology that encourages assessment and creativity during the course of the process, engineers are better able to approach problems that have no single clear solution.

Using the flow diagram approach, the firm would map out the same basic decision areas – cost, technical performance, market reactions, etc. – as for a decision tree model but would attempt to specify measurable criteria for acceptable performance. For example, instead of merely comparing the estimated number of development hours for various technology options, engineers and managers would set a target number of hours that each technology would be required to meet in order to be selected. In the result of a tie between the two technologies or in cases where neither technology was able to meet the target, the engineers would brainstorm for ways to reduce the number of required hours (modify the alternative) or to create feasible solutions with a less stringent target (modify the criteria). Like the decision tree methodology, this approach is not inherently biased towards either newer or older technologies but instead relies upon logical consideration of all alternatives based on pre-established criteria.

2.2.3 Models of Decision Making: Rule-Based Theory

While the above decision models represent primarily "choice-based" strategy, in which the decision maker relies upon the so-called rational evaluation of alternatives in order to chose among them, other researchers recognize the impact of "rule-based" theories of decision making, in which the individual's knowledge of past preferences and experiences (i.e., cognitive schemas, see Section 2.3.3) help to justify a particular outcome. People's decisions therefore are not solely based on objective comparisons of key metrics but instead depend to some extent on their personal biases. In addition to the cognitive impacts on decision making, March and Olsen [1989] note the cultural

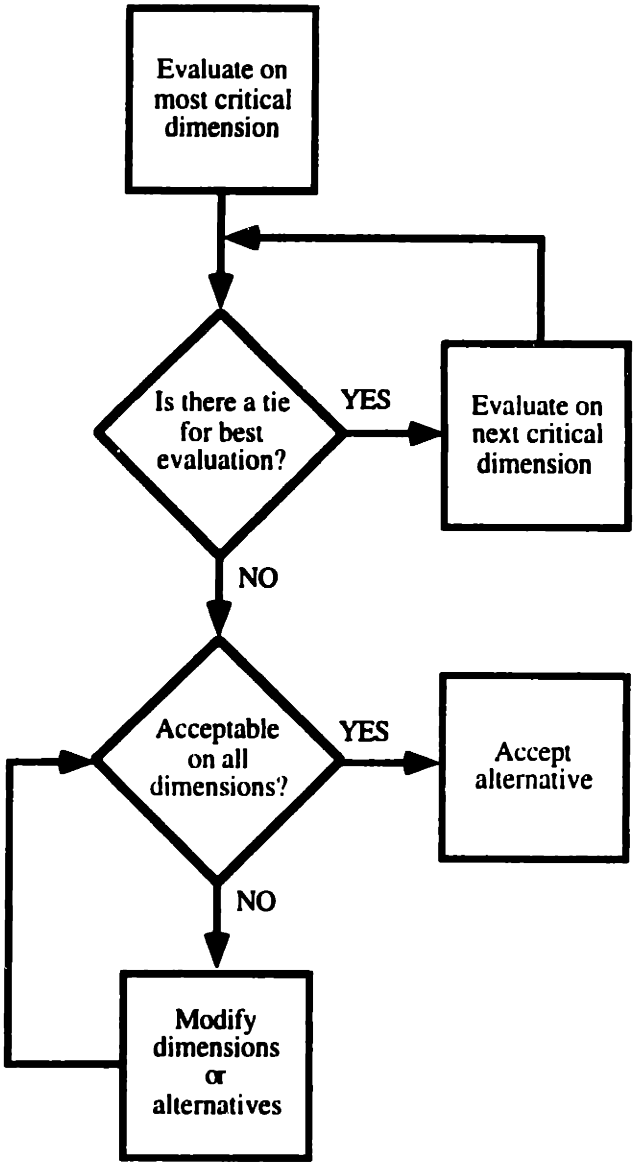

Figure 2-4. Flow Diagram [adapted from Frischmunth and Allen, 1969, p. 60]

and political influences in the organization that shape decisions made within its walls, stating, "Action is often based more on identifying the normatively approximate behavior than on calculating the return expected from alternative choices" (p. 22). This theoretical approach serves to contextualize decisions within the organization.

The theory of social networks also aids in describing decision processes within product development groups. Research has shown that employees' attitudes about new technology are similar to the attitudes of those with whom they communicate [Rice and Aydin, 1991].

Communication is in turn dependent upon proximity between individuals, either through the physical closeness of being located in the same area or the relational closeness of being assigned to the same work group at the same structural level. Individual attitudes are thus formed, not in isolation, but through contact with others, most notably co-workers and supervisors. The choices made by individuals depend on how they fit into their work group and how that group fits into the organization; it is no longer just a question of personal knowledge and preferences but those of other players as well. The acceptance and implementation of individual or group level decisions therefore takes a political effort to convince others that the decision is in the best interest of the organization as a whole, or at least, given the multiple perspectives and substrategies present within the community, in the best interest of whoever has final approval power. With such organizational shaping influences at work, the decision process for groups engaged in product development is perhaps better described as a spiraling path alternating in focus between action at the project level and consensus building at the management level, instead of the linear path suggested by choice-based theory (see diagram in Figure 2-5). Gladstein and Quinn [1985] refer to this process as the alternating dominance of "action rationality" and "decision rationality" in governing the group's strategic objectives. IPTs therefore face the challenge of making technical/rational decisions in a group of cross-functional team members and in the larger organizational context of the firm. More research is needed to examine how teams are able to deal with conflicting perspectives and competing product development requirements while still espousing the IPT philosophy of consensus decision making at the lowest possible organizational level.

As the above discussion shows, the rule-based perspective serves to situate individuals and their decisions within a broader social context, making the sociological literature home to several such models of decision making. Two such representations are described below, Van de Ven's [1986] theory of sociopolitical events and Rogers' [1995] theory of adoption via communication. Although they do not provide any details as to the analysis of technical and strategic factors that contribute to the evaluation of candidate technologies, these models are valuable due to their inclusive perspective concerning the cultural, political, and organizational issues that surround technology decision making.

2.2.3.1 Sociopolitical Events

Sociological research on innovation concentrates on the aspects of human nature that influence the technology adoption process. From this perspective, it is the personal actions and reactions of individuals that determine the decisions made by the organization, as stated Van de Ven's [1986] work on the management of ideas:

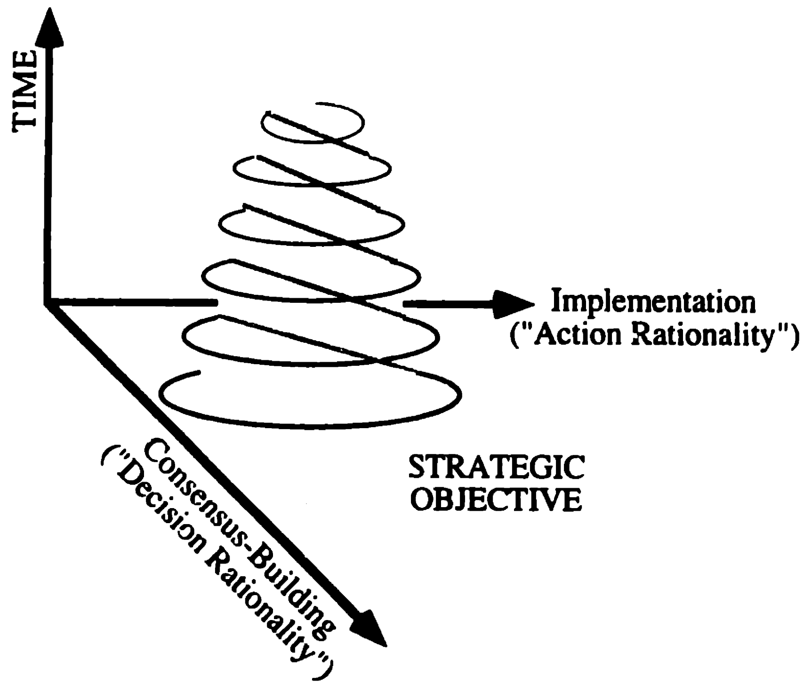

Figure 2-5. Organizational Process of Decision Making in Groups
[adapted from Gladstein and Quinn, 1985, p. 212]

> People develop, carry, react to, and modify ideas. People apply different skills, energy levels, and frames of reference (interpretive schemas) to ideas as a result of the backgrounds, experiences, and activities that occupy their attention. People become attached to ideas over time through a social-political process of pushing and riding their ideas into good currency. (p. 592)

Figure 2-6 depicts Van de Ven's concept of how the currency of an idea (or, for the purposes of this paper, the technology) evolves from low to high, leading to what our terminology refers to as the adoption of the idea/technology. The process is precipitated by an event that disrupts the status quo and stimulates an appreciation among people of the need for change. This disruptive event (which in the case of a technology development firm could be in the form of poor market response to the current product, a competitor's release of a new technology, or a failing internal R&D effort) must be significant enough to fall above the "threshold of dissatisfaction" and thereby create

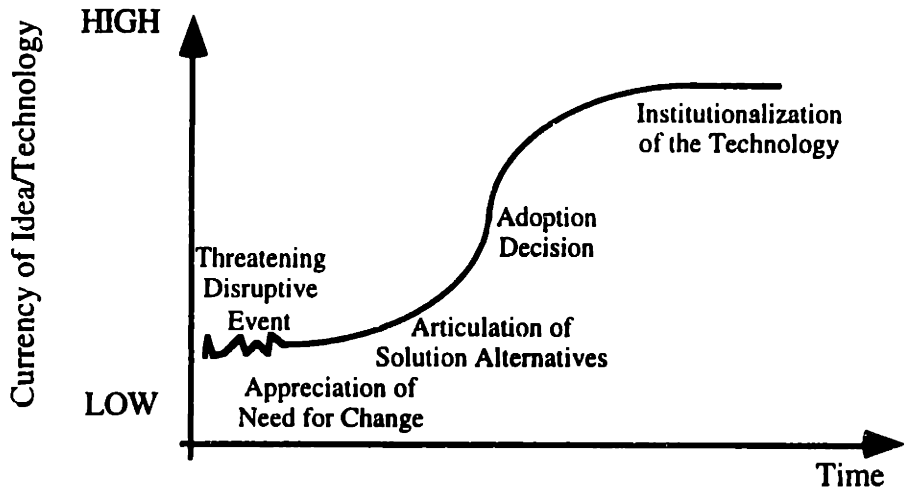

Figure 2-6. Adoption of New Ideas via Sociopolitical Events
[adapted from Van de Ven, 1986, p. 593]

motivation for change.[5] At this point, the individuals involved are able to appreciate the severity of the situation and the ensuing need for change. Ideas for potential solutions are then articulated, and the originating parties attempt to gain support for their particular technological solution by advocating its adoption within the organization. Networks of individuals gravitate toward specific solutions, often using their influence and support to further develop and adapt the technology totheir own interests. A political debate takes place within the organization, with the various camps vying for power, influence, and, more concretely, financial resources to implement their ideas. The social structure of the organization dictates the outcome of the decision process, with the technology which galvanizes the most politically powerful individuals typically being the one selected. Once an option has been established as the mode of choice, a gradual process of institutionalization occurs, such that the use of the technology is taken for granted in the organization and becomes part of the status quo.[6]

---

[5] Van de Ven contends that individuals unconsciously adapt to conditions which change over longer periods of time and therefore do not recognize the resulting state as threatening. He draws an analogy to the classic "frog story" (credited in his work to Gregory Bateson):

> When frogs are placed into a boiling pail of water, they jump out – they don't want to boil to death. However, when frogs are placed into a cold pail of water, and the pail is placed on a stove with the heat turned very low, over time the frogs will boil to death.

This macabre but illustrative story reflects the ability of crisis situations to overcome human nature's reluctance for change in a way that daily events or gradual evolution cannot.

[6] Van de Ven concludes his description of the evolution of an idea's currency in the organization by following the institutionalization period with a "decay" phase, during which time the idea gradually loses relevance to the organization's situation and is in need of replacement. The decay phase is not within the scope of the dissertation research thread, other than cases in which the decay of the usefulness of one technology contributes to the likelihood that a newer competing technology is adopted.

2.2.3.2 Communication Issues

Empirical work in a variety of industries and social communities led Rogers [1995] to propose a model for the diffusion of innovation similar to the choice-based theories but based on verbal and written communication among individuals. A five-step process (Figure 2-7) is used to indicate the stages that individuals go through during the decision process concerning the adoption of a new innovation. The process applies either when an individual is personally considering adoption or when the individual is part of a greater organizational unit faced with an adoption decision. The first stage, knowledge, takes place when an individual becomes aware of the existence of an innovation and begins to understand its function and operation. Knowledge can be gained through exposure to other adopters, contact with vendors, media reports, or an active search for solutions to unmet needs. Rogers notes that the human tendency to ignore information that does not conform to their current behavior or beliefs makes passive encounters with innovations unlikely. That is, people tend to assume that other individuals are using the same technology to which they are accustomed, and therefore they are unlikely to notice products or activities that run counter to their personal system of operation [see also: Frischmunth and Allen, 1969; Thomas, 1994]. This institutionalization, as noted in Van de Ven's model, means that direct verbal or written communication to the individual must take place in order to trigger the knowledge stage.

Once the individual is aware that an innovation exists, he or she enters stage II - persuasion. This does not imply the exertion of pressure from advocates of the innovation but rather refers to the process by which the individual forms an opinion (favorable or not) of the innovation. This stage typically includes data gathering about the technology, considering factors such as the relative advantage of the innovation over previous technologies, its compatibility with associated systems and current conventions of operation and thought, and its complexity. The individual may also communicate with earlier adopters, making observations about their experiences and, if possible, trying out the technology on a limited scale (for example, through the use of trial sizes or introductory offers). Once this evaluation process is complete, the individual makes a decision to either adopt or reject the innovation (stage III). Psychologically, the individual's decision may be affected by the prior decisions and opinions of peers or influential leaders in the community (a phenomenon commonly referred to as the bandwagon effect). If the resultant decision is positive, the individual proceeds to put the innovation into use (implementation - stage IV). At this point, some uncertainty about the practical application may still exist and so a final confirmation (stage V) of the innovation's actual net benefit is required. This last stage is especially important when the adopter is an organization, since the component members (or at least those with political and social power) must be convinced that the decision was correct before it is institutionalized within the population as a whole. The confirmation phase may result in a reversal of the initial decision,

I. Knowledge ⇒ II. Persuasion ⇒ III. Decision

⇒ IV. Implementation ⇒ V. Confirmation

Figure 2-7. Diffusion Process [adapted from Rogers, 1995, p. 163]

whether that means discontinuing use of the innovation (due to dissatisfaction with long-term performance ["disenchantment"] or the availability of a superior substitute) or deciding to adopt it after new information identifies unanticipated benefits.

2.3 Organizational Structures: The Integrated Product Team

Conventions in organizational design have evolved over time, often exhibiting short-lived waves of popularity, but with a general progression from small family-owned businesses, through a period of industrial growth and centralization, into vertically integrated, multidivisional organizations. While a complete history of industrial organization in the manufacturing sector is outside the scope of this research [see, instead: Chandler, 1962], it is important to recognize the gradual transference of authority and responsibility from upper management down into the ranks of project-level workers that has taken place over time in American factories. While 19th- and early 20th-century factory workers were depended upon for their subordination and mechanistic assembly line work, today's "empowered" employees are permitted far more input to the manufacturing process and are chosen for their ability to promote continuous improvement within the organization [Womack, Jones, and Roos, 1990; Clark and Fujimoto, 1991; Wheelwright and Clark, 1992]. Over the past decade, the concept of integrated product and process development has become the accepted method in American manufacturing organizations for implementing these goals. One of the key aspects of this new philosophy is the organization of personnel into integrated product teams (IPTs). Contrary to the traditional segmentation of product development into separate design and manufacturing stages, with little or no communication between the two once a design was "thrown over the wall" to be produced, the typical IPT is dedicated to a single product or subsystem of a complex assembly and is responsible for all activities from the initial concept development through the production phase. With members drawn from such disparate functions as engineering, manufacturing, marketing, and finance, the matrix team is gathered under the direction of a managerial team leader typically heralding from one of the technical areas. Team members are selected in order to bring together multiple viewpoints and solve interdependencies and conflicting requirements at a low level in the organization. By drawing members from multiple stages of the product development process into one concurrent development activity, the team seeks to both create a more well integrated final product and to do so more quickly and at a lower cost.

Most manufacturing firms today use IPTs for their new product development programs, but academic attention to the use of teams in product development has been somewhat piecemeal. This section attempts to place the IPT concept within a more complete framework of organizational and technical performance by summarizing recent research and writing devoted to the use of teams in product development, beginning with a discussion of the evolution of the IPT form. Introductory material on the organization of IPTs and a list of their typical product development activities are also included, along with a summary of prior research on IPTs in the aerospace industry. A summary of the organizational advantages and disadvantages of the IPT format concludes the section, to be expanded upon through the ensuing research project results.

2.3.1 Basic Concepts

This section serves to introduce the concept of the integrated product team, beginning with a look at the organizational history behind the formation and use of IPTs. A formal definition of the IPT, to be applied later in discussions of relevant group and team theory, is also presented. A brief outline of typical IPT activities and the major motivations for the use of the team-based approach is also included.

2.3.1.1 History of IPT Evolution

The development of a complex technology or product benefits greatly from taking place in the appropriate organizational structure, whether the firm is a large one juggling many competing projects or a brand new firm struggling to release its first product. To some extent, the current mode of technological growth that the company is experiencing dictates the organization of its product development. Many entrepreneurial organizations start as a collaborative effort between technical specialists and business managers (or venture capital investors who perform this role), a mix that in essence makes the entire company a single multifunctional team. On the other hand, a large established firm with a stable product line that requires only sustaining engineering efforts for occasional updates may find an organization based on traditional functional boundaries (engineering, marketing, manufacturing, etc.) to be quite sufficient [Burns and Stalker, 1961]. However, as the rate of technical change increases, this formal authority structure may prove confining. Employees become segregated into "functional silos," such that each group of specialists becomes isolated from the others and more concerned with its own growth than with the close communication necessary for the development of new complex technologies. Many problems can arise, for instance:

- Two functional areas may be working on the same process idea without knowing it.
- Product designs may be impossible to produce with the available process technologies.
- The many subsystems of a complex product may not assemble into a complete working device because the interfaces are incompatible.
- The product that results may not be marketable.

The result may be duplicated effort, production rework, and antagonism between engineering, manufacturing, and marketing – not the qualities necessary for growth in a competitive industry.

"Matrix" style management has been in existence since the 1950s as a means to coordinate the many functions necessary in product development by assigning each employee to both a functional discipline and a project [Galbraith, 1971; Katz and Allen, 1985]. This approach, first adopted in the aerospace industry, was intended to break down the dependencies associated with functional silos by creating a dual chain of command [Davis and Lawrence, 1978]. The method of integrated product and process development (IPPD) that has emerged over the past decade takes the concept one step further. Rather then merely assigning people from different disciplines to the same project and then having them serve out their function sequentially from marketing to design to production, IPPD attempts to coordinate the efforts of personnel across the organization in a concurrent, co-located, and proactive manner.

Under the traditional segmented product development process in matrix organizations, the engineering department would create a new design for a product then pass it on to the manufacturing division, which was in turn responsible for coming up with a way to produce it. In (not so rare) cases where the engineers had designed a product beyond the existing manufacturing capabilities of the organization, the design would be passed back to engineering, without much feedback or any coordinated attempts to anticipate problems before they occurred. As products became more technologically complex, the inefficiencies of this system were recognized, and an attempt was made to bring the two functions together [Whitney, 1988]. The goal was a single design and build stage in which engineers and manufacturers would work side by side to come up with the best possible product quickly and to take into account the best combination of product and process technology available. Initially known as "concurrent engineering," the simultaneous execution of product and process design has been extended to include up-front input from marketing and finance personnel as well, thus ensuring that the resultant product is both in agreement with market needs and profitable for the firm [Nevins and Whitney, 1989; Ulrich and Eppinger, 1995]. Today, the majority of manufacturing firms use IPTs for their new product development projects, and, in fact, those that deal with the United States government as defense contractors have been directed to do so by the Department of Defense since 1995.

2.3.1.2 Definition of an IPT

IPPD has come to rely on the use of integrated product teams (IPTs) as the primary authority structure for product development projects involving personnel from multiple disciplines. Thus the typical IPT in the manufacturing sector contains members from both technical (engineering, manufacturing) and non-technical (finance, marketing, sales) areas, with a team leader to coordinate their efforts over the lifetime of the project. With the increasing popularity of lean manufacturing and other modern manufacturing concepts, many companies have been led to label various groups as "teams" or "IPTs" without espousing the accompanying philosophies of empowered decision making and self-management. It is important, therefore, to begin the discussion by defining what is meant by a "team." According to Katzenbach and Smith [1993b]:

> A team is a small number of people with complementary skills who are committed to a common purpose, performance goals, and approach for which they hold themselves mutually accountable. (p. 45)

This definition works well with the traits reflected in effective product development, especially as related to the IPT concept. More specifically, Klein and Sussman [1995] define four criteria required for a team to be properly called an IPT:

1. finite mission to develop a product or process (or a component of a larger system)
2. cross-functional membership, with a core group of team members who follow the product through the various product development stages
3. defined and measurable performance outcomes
4. single team leader.

These criteria distinguish the IPT, with its focus on multidisciplinary product development activity, from other group organization formats.[7] Portions of the literature examined subsequently in this paper stem from research pertaining to teams or groups in general. Where appropriate, this broader material is included to serve as a contextual base for applying the theory to issues relevant to the organization of IPTs. In such cases, Klein and Sussman's criteria have been employed as the definition of the specific types of teams or groups of interest.

---

[7] For more information on other types of industrial teams, such as the generic cross-functional team or the manufacturing self-managing work team, see: Beyerlein and Johnson, 1994; Beyerlein, Johnson, and Beyerlein, 1995. Hackman [1976] and Ancona [1987] also provide excellent broad-based introductions to group theory.

2.3.1.3 Typical IPT Activities

As noted in Klein and Sussman's criteria, the premise behind the IPT format is that the team will be responsible for all of the product development activities from start to finish. While membership may vary from stage to stage depending on which skills are most in need at that time, the core team members work together to jointly perform all of the product development steps.[8,9] Consequently, IPT activities follow the major stages of the product development process. Most product development projects can be divided into five major stages [Ulrich and Eppinger, 1995]:

1. Concept development
2. System-level design
3. Detail design
4. Testing and refinement, and
5. Production ramp-up.

The team starts with a mission statement or list of customer needs for the product and finishes with the product launch (also know as Job 1, the first production article, or when the product is first available for purchase in the marketplace). Typically a transition phase follows wherein the IPT members (especially manufacturing engineers) work with the operations floor personnel to help them achieve volume manufacture of the product at the desired quality and cost levels.

For a complex product, many tasks and subtasks make up these process steps. Table 2-1 contains a list of the most significant activities for each stage, organized by the function having primary responsibility.[10] The IPT philosophy suggests that each activity be performed as a team while taking into account cross-functional diversity. To this extent, the functional member(s) with the most relevant skills and experience to a given task might perform the initial assessment or analysis and then present this information to the group as a whole. Other team members can then coordinate the emerging design with their own specialized activities and identify areas where tradeoffs need to be made between competing requirements. The team leader typically facilitates communication between the functional members and coordinates the system-level integration of the design. The scope of an IPT's efforts vary with the complexity of the product. A single IPT may perform all of the design and process development for a small and simple product. For a larger or more intricate

---

[8] See Section 2.3.2.1 for more information on IPT membership.

[9] Note that practices can vary by company. Some organizations designate a separate marketing-focused team to perform concept development work for the company, after which product development IPTs take over the design and manufacturing of the product.

[10] The process steps and tasks shown here are based on a generic commercial product development project. Additional steps, subtasks, or review milestones may also be included depending on the nature of the product and the level of customer involvement (for example, to meet government requirements in military contracts).

Table 2-1. Activities in the Product Development Process Performed by IPT Members [Ulrich and Eppinger, 1995, p. 15]

Concept Development	System-Level Design	Detail Design	Testing and Refinement	Production Ramp-Up
Marketing • Define market segments • Identify lead users • Identify competitive products	• Develop plan for product options and extended product family	• Develop marketing plan	• Develop promotion and launch materials • Facilitate field testing	• Place early production with key customers
Design • Investigate feasibility of product concepts • Develop industrial design concepts • Build and test experimental prototypes	• Generate alternative product architectures • Define major subsystems and interfaces • Refine industrial design	• Define part geometry • Choose materials • Assign tolerances • Complete industrial design control documentation	• Do reliability testing, life testing, and performance testing • Obtain regulatory approvals • Implement design changes	• Evaluate early production output
Manufacturing • Estimate manufacturing cost • Assess production feasibility	• Identify suppliers for key components • Perform make-buy analysis • Define final assembly scheme	• Define piece-part production • Design tooling • Define quality assurance processes • Begin procurement of long-lead tooling	• Facilitate supplier ramp-up • Refine fabrication and assembly processes • Train work force • Refine quality assurance processes	• Begin operation of entire production system
Other Functions • Finance: Facilitate economic analysis • Legal: Investigate patent issues	• Finance: Facilitate make-buy analysis • Service: Identify service issues		• Sales: Develop sales plan	

product, an IPT may focus only on a single subsystem or component, with multiple layers of teams working together to integrate their designs into a complete system.

2.3.1.4 *Motivation for the Use of IPTs*

At the heart of the IPT concept lies the desire to save time and money in the process of developing effective products, while at the same time maintain or improving quality and product performance. Section 2.3.5.1 contains a comprehensive list of the benefits of IPTs, but the central motivation for the use of IPTs is described briefly here to provide an introduction to the subsequent discussions of the integrated team approach. As described above, the traditional functional organization involved a very distinct transition between the design and manufacturing phases of the product, which often resulted in necessary re-work and rationalization of the design after production had already started. As shown in Figure 2-8, engineering effort (and consequently cost) in this functional arrangement was centered around Job 1, the creation of the first production article. Although the majority of the design effort was accomplished before Job 1, significant work remained to modify the design to be compatible with the manufacturing process and to rectify any quality problems that showed up in the first batch of products. Under this arrangement, manufacturers commonly made major design changes after Job 1, necessitating expensive re-work on the articles already fabricated and delaying further production.

Under the IPT or concurrent engineering approach, however, the peak of the cost curve is shifted earlier in the product development process, since the manufacturing engineers start collaborating with the design engineers essentially from the start of the development schedule. This leads to higher costs in the early phases, compared to the functional organization, but saves money in the long run due to the better design quality and manufacturing planning that comes with cross-funcational integration. While re-work may still be necessary over the course of iterating between design and manufacturing requirements, errors are discovered and rectified earlier. The IPT format therefore helps to ensure that the major product development activity is essentially complete at Job 1, instead of peaking there, so that even early production articles are of high quality.

2.3.2 Team Organization

Given this background on the basic format of the IPT, one question of particular importance in the implementation of a team approach is how the company and the team itself are best organized to take advantage of the cost- and time-reducing benefits. This section presents the basic organization of the integrated product team, starting with a description of the typical team membership. The important role of the team leader is also included, along with an outline of research documenting the informal integrating functions that aid in communication within and without the team boundaries.

2.3.2.1 Core IPT Membership

As indicated above, IPTs draw their membership from the various functions involved in the product development process. Most teams working on a single design component have a set of six to twelve core members who follow the product from start to finish, with assistants and experts in other functions temporarily assigned to the team during those stages of the process where additional resources or the expertise of a particular subspecialty are required. Teams assigned to larger systems will have correspondingly more members. As noted in Klein and Sussman's

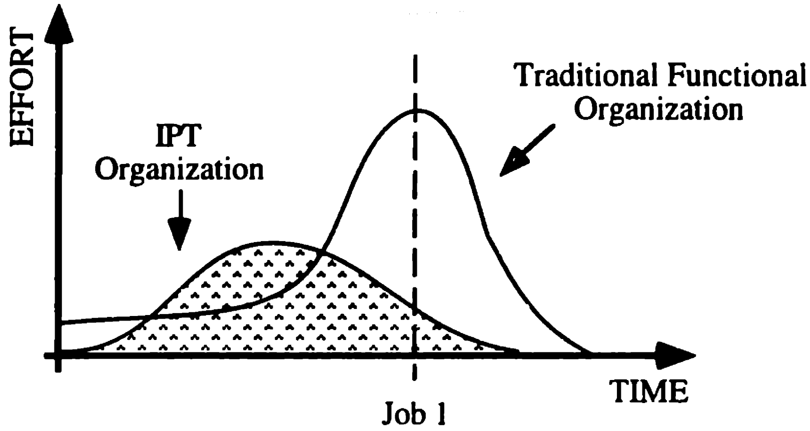

Figure 2-8. Comparison of Product Development Cost over Time for the IPT and Functional Organizational Designs
[notional diagram; not to scale]

definition, a single IPT can be associated with an entire product or with just a component or subsystem of a product. For example, Figure 2-9 shows the organizational make-up of an IPT that is responsible for the development of a relatively simple product, a ball-point pen. Since the product is small and not very complex, a single team can handle all of the product development tasks from start to finish. Larger or more complex products may require decomposition into multiple nested IPTs, as in the airplane development plan shown in Figure 2-10. In this case, the IPTs at each level provide components to make up the next-highest level. IPT activity therefore includes the coordination of lower team activity, the integration of the resulting subsystems, and the delivery of the team product to the next higher level. In most such multi-tiered approaches, the team leaders at one level serve as team members in the next-highest level.

Although team membership will vary by company and by product, core membership on the IPT should always include representatives from design engineering and manufacturing engineering. Additional team members are often drawn from other functions, such as:

- hardware or software design specialties
- process engineering or industrial engineering specialties
- materials engineering
- quality assurance
- marketing
- accounting/finance
- procurement/materiel
- human relations

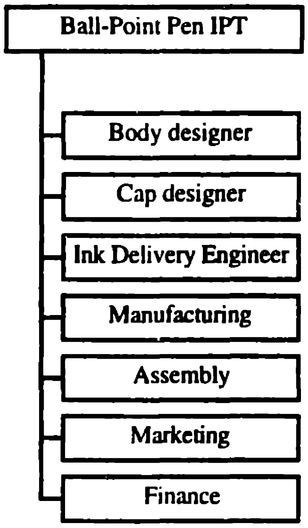

Figure 2-9. Organization of a Single IPT for a Small, Simple Product

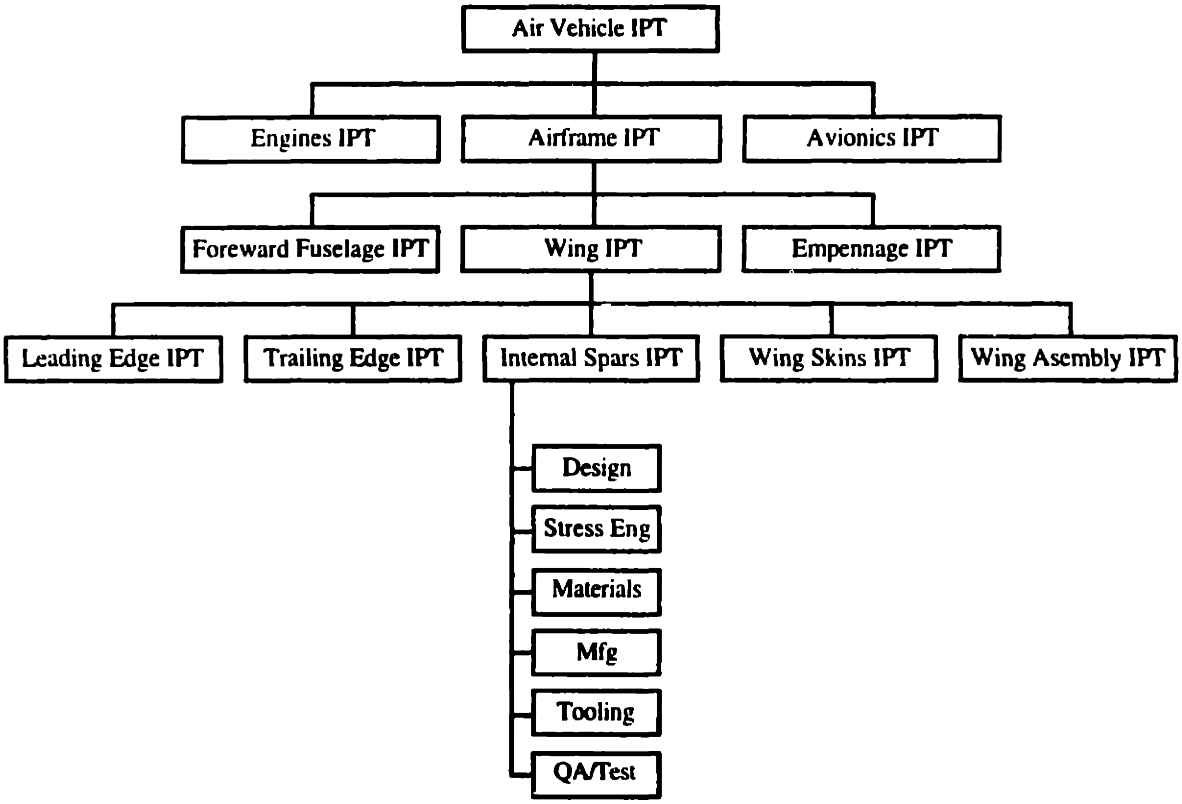

Figure 2-10. Multi-Tiered IPT Format for a Large, Complex Product
[Note: Not all teams are shown.]

- maintenance and spares support
- safety and environment, and
- user training.

Some companies choose to have only technical personnel dedicated to teams, with representatives from other functions, such as finance or marketing, supporting one or more teams on an as-needed basis while they remain organizationally in their functional slot. On the supplier side, in recent years, more companies have started to include engineers from subcontracting firms on their product development teams, thus extending the concurrent engineering concept to include purchased components and subsystems. Customer representatives can also be included, especially in the defense acquisition environment, as can regulatory bodies (e.g., the Federal Aviation Administration, in the case of aerospace product development).

Each of the IPT members is responsible for contributing expertise from their functional area to the product, as well as for contributing more broadly to the overall system integration and coordination. High performing team members therefore are ones that are able to anticipate how their part of the project impacts other functions and to resolve conflicts creatively to make optimal tradeoffs between competing performance, cost, and schedule requirements [Pugh, 1996]. This systems engineering skill is especially important for the team leader, who is responsible for facilitating communication between the team members and for coordinating the product development process as a whole (see Section 2.3.2.2). Some companies also designate an executive sponsor to champion the team; vice presidents of engineering, manufacturing, or marketing often hold these positions in the organization.

2.3.2.2 The IPT Leader

Klein and Sussman's fourth criteria for IPTs – a single team leader – is of particular interest to the study of team organization and membership. Figure 2-11 presents a graphical representation of three organizational approaches to project management. In the first, a traditional functional organization, tasks are performed within the functions and coordinated by functional managers, each of who may deal with multiple projects at any given time. The second figure represents a matrix format, in which individual functional workers are assigned to be liaison to specific projects. Project managers receive and coordinate information coming from the liaisons and functional managers, without the working level functional representatives having much direct contact themselves. In this "lightweight team" concept [Wheelwright and Clark, 1992], the project manager serves as the integration point at the top of multiple distinct chains of command but does not have much influence over the work being done in disparate departments. IPTs, however, rely on "heavyweight" project managers who seek input from and facilitates direct interaction between

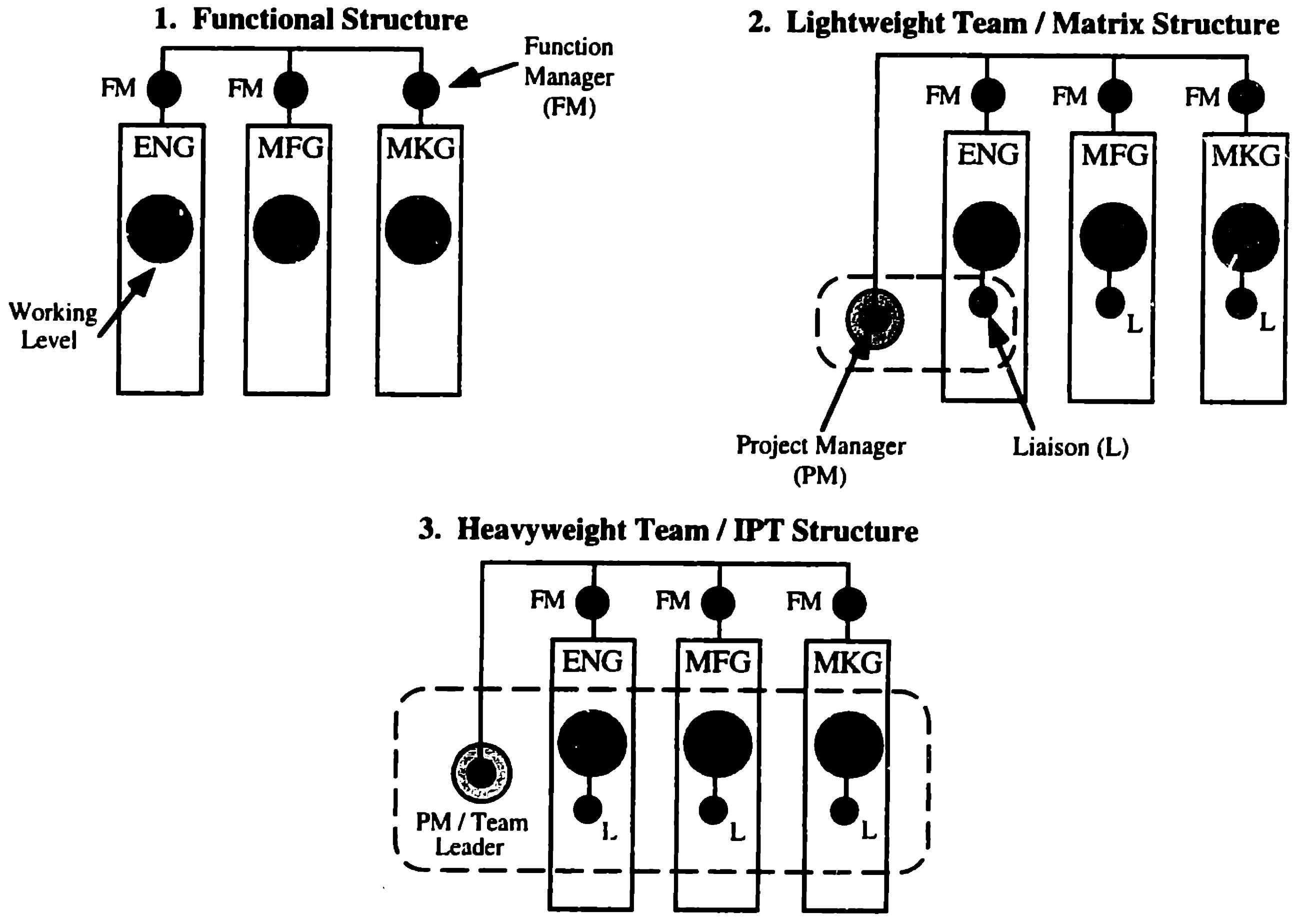

Figure 2-11. Different Organizational Formats for Project Management
[Adapted from Wheelwright and Clark, 1992, p. 191. Note that, for clarity, only three functional areas (engineering, manufacturing, and marketing) are shown. Actual teams may include representatives from many other disciplines.]

the team members [Wheelwright and Clark; Klein and Maurer, 1995], essentially linking multiple command chains at the lowest level. In this third authority structure, project managers, usually known as team leaders, serve as the translator between the different "languages" of engineering, manufacturing, marketing, and finance, allowing multi-dimensional tradeoffs between competing parameters to be made on a comparative basis. The team leader also provides a systems perspective, ensuring that the subsystems of the product harmonize into a saleable product that meets customer demands. These individuals are typically engineers promoted from within one of the technical disciplines. One key difference between the heavyweight manager and previous incarnations of matrix project leaders is that the former not only manages the project but also manages the people by being responsible for the evaluation and resource allocation of the IPT members. Depending on the complexity of the team's task, liaisons may still be required to coordinate tasks within the functions, but all personnel at the working level are considered equal team members.

The extent of the team leader's power is disputed in the literature, with some sources denoting heavyweight project managers as the "ultimate decision makers" [Wheelwright and Clark] and others advocating a role more in line with a facilitator of team-generated decisions [Klein and Maurer]. This distinction becomes important when considering the role of the IPT leader as a representative of firm management. In either case, the leader, as a mid-level manager, is generally considered to serve as a conduit between the demands of upper management and the activities of the team. Note that, unlike the direct representation present in the areas of manufacturing, engineering, finance, and marketing, there is no prescribed direct link between the strategic management of the organization and the IPT other than what is transmitted through the team leader. The literature is strangely silent on this question, other than Roberts' [1979] "critical functions staffing" method that advocates having a "program manager" who is responsible for managing day to day team activities and a senior management "sponsor" who acts as a mentor and provides leverage in the political hierarchy. More research is needed to determine whether IPTs in industrial settings make use of such a link or have found other means to communicate strategic information to the team level.

2.3.2.3 Integrating Functions

Since the IPT format promotes a team-centered focus, the maintenance of communication between the team and the rest of the organization is extremely important in order to prevent the smaller group from becoming isolated. Team members need to have regular interaction with others from their functional areas in order to maintain a high level of disciplinary expertise and to introduce innovations occurring outside the IPT boundary [Wheelwright and Clark, 1992]. In addition, the team is influenced through interactions with its external environment, including supervisors, upper management, competitors, and the market. From an organizational perspective, Ancona and Caldwell [1992] note that the informal and formal "boundary spanning" roles team leaders and members have with other individuals inside and outside the organization can impact project performance. In a five-year study of 45 new product teams, Ancona and Caldwell examined the activities teams use to manage their external environment and identified a set of fifteen distinct boundary activities that affect how the team and the organization perceive each other. These activities consist of the following behaviors:

- mapping (identifying allies and trouble spots in the environment)
- gathering information and resources

- scanning (actively searching for information related to the product development project, either within the organization or in the external market)
- feedback seeking
- opening up communication channels
- informing (providing updates on group performance)
- coordinating
- negotiating
- molding (attempting to shape the beliefs and behavior of those outside the group in order to garner the resources or support the team needs)
- allowing entry (providing external access to the team's activities)
- translating (communicating the group's activities or results to people in different functional areas or at different managerial levels)
- filtering (taking information from outsiders and delivering only a subset to the group in order to buffer the team from external politics or information overload)
- classifying (analyzing external attitudes and behavior in order to make sense of the external environment)
- delivering (transferring finished portions of the product development activity to other organizational groups), and
- protecting (prohibiting access to the team's activities).

Ancona and Caldwell analyzed how teams employ these activities and identified different communication strategies that teams use to deal with their external environment. In their research, successful product development teams were shown to have high levels of "ambassador activity," in which the team communicates with managers in the hierarchy above to garner support for their actions and lobby for resources. The ambassador strategy, which revolves around frequent communication with those above in the company hierarchy in order to manage the authority structure, was shown to have a positive impact on the team's performance in meeting budget and schedule goals. Team leaders and members in this strategy used the filtering, molding, and mapping activities to communicate vertically through the organization in a way that both created support for their team mission and allowed them enough autonomy to think creatively in the product development process. In other cases, a "task coordinator" strategy, focusing on the feedback and coordination activities that create strong horizontal communication links between the group and related functional areas, was shown to have a positive affect on the team's innovative ability.

In addition to such organizational approaches to communication issues, several researchers have described integrating mechanisms for coordination between different development teams within the organization, such as in the instance of multiple IPTs working on subsystems of a very complex product that requires the coordination of interfaces and system-level optimization of technical and cost requirements. For example, McCord and Eppinger [1993] suggest tools to help coordinate the activities of separate IPTs, including the use of network technology for electronic distribution of information, liaison engineers who serve on multiple teams, and town meetings to convene larger numbers of personnel. Further research by Browning [1995] has focused on the use of analytical mapping tools, such as design structure matrices, for the evaluation and structuring of inter-team coordination on complex product development projects. Similarly, Haddad [1996] advocates the use of "enabling practices" when implementing a concurrent engineering approach, requiring changes to both the organizational and technical practices of the company. Organizational enablers to IPT performance include the establishment of cross-group communication paths, decentralized (team-centered) decision making, and the use of performance evaluations to create a culture of teamwork. On the technical side, computer networking, a shared CAD database, and a team-friendly building design all contribute to the desired output of functional integration, information sharing, and collaborative problem solving.

2.3.3 Group Processes for Communication

As defined in Ancona [1987], a group is "a set of interdependent individuals who view themselves as a group and who have common goal of producing something" (pp. 208-209). The process of "producing something" involves not just the intellectual effort required for technical design but also a complex set of individual- and group-level tasks associated with working together as a team. The previous section focused on communication between the team and its external environment; this section concentrates on the communication and interpretation that occurs *within* the team itself. A great deal of research has been done in the area of group processes, and two topics important to cross-functional teams developing complex technical products are introduced here: information processing and intra-team communication.

The concept of bounded rationality [Simon, 1957] conveys the notion that individuals are limited in their cognitive ability to make decisions based entirely on rational analysis. Since the capacity and computational power of the human brain is finite, not every constraining factor of the problem can be known or assessed. External barriers, such as the boundaries of the authority structure, may influence the extent and direction of information coming into the individual's sphere of awareness. Individuals within the IPT struggle not only to perform their project task, but to communicate with team members in other disciplines, cooperate in a diverse environment, and assume higher levels of authority than they experienced in their functional group [Loehr, 1991]. The brain's cognitive systems also act to constrain the selection of future alternatives to those already experienced, through the formation of "schemas" that simplify a complex world by storing and organizing knowledge in larger blocks rather than by remembering every specific circumstance in detail [Fiske and Taylor, 1991].[11] Application of schemas tends to reduce the variability one sees in encountering new situations, as the brain is quick to mold perceptions to fit the pre-established schematic scenarios. The combination of bounded rationality, organizational diversity, and cognitive schemas therefore limits the amount and kinds of information that individuals are able to process and use at various levels of the organization.[12]

The hierarchical authority structure of complex organizations also contributes to variation in the nature and extent to which individuals are exposed to information. While Ancona and Caldwell's research does not specifically address communication between team leaders and upper management, excerpts from their field notes record instances of "filtering" behavior on the part of leaders, such that they take information from outside the group and deliver only a subset to the team. This buffering can serve to prevent team members from being distracted by troubling news, overwhelmed with the sheer volume of information passing through the team leader, or embroiled in the politics of the organization. The filtering concept is also invoked when it comes to strategy formation. For example, Wrapp [1984, cited in Hax and Majluf, 1996] suggests that the strategic goals of the organization be made more or less explicit depending on the intended audience. While the CEO and executive team require high levels of detail for their planning purposes, Wrapp prescribes less comprehensive and more sanitized strategy statements be provided to groups such as the Board of Directors and middle managers, with issues framed with a positive bias so that the readers are convinced that the company is pursuing an intelligent and successful direction. This process provides the managers (and subsequently the team, informed to some extent through the filtering process) with more inside information than is given to, say, readers of the annual report, but still leaves a great deal of the strategic planning unarticulated at lower levels of the organization.

---

[11] See also the concept of "gap-filling" [Dutton and Jackson, 1987], another cognitive short-cut in which the fact that an individual belongs to a given category (such as a particular occupation or job level) is used to infer the presence of specific attributes stereotypically associated with category membership.

[12] It is interesting to note that, at the group level, research by Gersick and Hackman [1990] has shown that the effects of individual schematic application can be extended to describe the behavior of teams. Just as an individual carries mental representations of how to respond in certain situations, a group can develop "habitual routines" that will be applied when a familiar stimulus reoccurs. These self-sustaining responses reinforce and perpetuate existing behaviors since alternate ways of behaving are not ever consciously considered. While habitual routines can improve the efficiency of the group by saving them from having to create a plan of action for every task that comes their way, they can also reduce the group's creativity and lead to stagnation or "groupthink" [Janis, 1985], so that the group fails to recognize when they could benefit from changing the routine.

The diversity of membership within the IPT brings with it challenges of maintaining effective communication within the group. Teams do not always explicitly recognize and discuss the different "languages" and processes associated with the various functional areas brought together on the team, which can result in apparently inexplicable discrepancies in work relationships, levels of power, and even writing or speaking styles. As Loehr [1991] comments, "Functionally diverse specialists often define or frame problems according to their functional specialties, individual levels or perceptive ability, or world views" (p. 51). The asymmetrical distribution of information across structural levels, coupled with the varying backgrounds and experience of the many workers, makes the organization a collection of "worldviews" [Thomas, 1994] or "thought worlds" [Dougherty, 1992] rather than the embodiment of a single perspective. Cognitively, individuals thus tend to selectively filter the information they encounter in the team, ignoring information outside their functional perspective since it appears irrelevant to the issue as they perceive it. These communication problems may not even be consciously recognized by the team, since conflicts in assumptions are extremely hard to articulate. As Wynn and Novick [1995] write:

> The very perspective differences that constitute the value-added of such [cross-functional] groups are also a source of confused conventions within the structure of group discourse that can short-circuit the purpose, lead to standstills, and allow important contributions to be overlooked (p. 251).

For an IPT, intra-team communication problems may mean that the various functional specialists have different understandings of what is critical to the design requirements, how the development task should be performed, and where the greatest uncertainty of risk lies [Dougherty, 1992]. In order to manage these differences, team members must learn to work as a group to resolve differences and create an environment of mutual equity, trust, and authority. The collection of functional specialists can then become a true working unit that best takes advantage of the IPT format of consensus decision making and integrated knowledge. As Dougherty explains, what is required is collective action (that is, the coordination of disparate expertises), not just the additive action of having multiple personnel on the team.

2.3.4 Prior Research on IPTs in the Aerospace Industry

The most comprehensive study of IPT use in defense aerospace firms was performed by Klein and Sussman [1995], who analyzed written responses from almost 600 defense and commercial aerospace personnel from over 60 IPTs in their survey of organizational and human resource practices. One of the most useful aspects of their research was the establishment of a typical aerospace team profile. The survey results showed that IPTs are indeed becoming the dominant organizational design for product development within the defense aerospace sector. The first IPTs in the industry were formed in the early- to mid-1980s, with the bulk of the firms adopting the format during the early-90s. Team size averages 26 full-time members (with an average total of 40 full- and part-time members), with core team members drawn mostly from the engineering, manufacturing, and program management areas. The background of the team leaders in the study varied equally between the engineering and program management functions, with only a small percentage having been assigned from the manufacturing and logistics areas. In the area of team performance, the survey tracked the relationship between how well the team met their goals (with respect to cost, schedule, and quality) and how the team was managed. Heavyweight team leaders were found to be highly effective in integrating the disparate functional areas and encouraging group decision making, and teams whose members felt satisfied with the amount of influence they had in the product development process were found to perform better. At the same time, for high-risk projects, increased focus on the demands of functional management (up to a 50/50 split with the team leader) was found to increase success in solving technical problems.

2.3.5 Summary: Advantages and Disadvantages of IPTs

Although IPTs have become the standard organizational format for product development in the aerospace and other manufacturing industries, the approach still has its disadvantages. This section summarizes the literature of IPT implementation, describing some of the typical benefits achieved by companies using IPTs, plus a list of possible negative side-effects. Solutions to these problems, taken from literature sources which describe real company experiences, are included where possible to provide insight into some of the emerging best practices for IPT implementation.

2.3.5.1 Advantages of Teams

As shown in Section 2.3.1.4, the primary motivation for using IPTs is to improve product quality, cut costs, and shorten the development time. Since the entire team works together from the start, IPTs tend to encounter fewer "surprises" in the design process, since each of the different functional disciplines are able to provide feedback on the evolving design as to how it fits the requirements for their area. This early coordination also leads to fewer design errors, so that problem issues are noticed and addressed before they become too deeply embedded in the process. Research by Cleland [1996] has shown that the concurrent engineering approach can reduce the number of engineering change orders by as much as 50 percent, thereby providing significant savings on configuration control. Finally, the tight coordination between functions during the design and manufacturing phases eliminates the need for numerous and time-consuming formal design reviews, which also leads to cost and schedule savings.

Since the IPT format generally results in a more robust and coordinated design process that addresses manufacturing issues up-front, it also provides significant benefits on the manufacturing side. The fact that the IPT stays together as a team throughout the production ramp-up phase of development ensures that the design of the product takes into account fabrication and assembly requirements. For example, fewer changes to the design, especially after production Job 1, result in far less manufacturing scrap and rework (as much as a 75 percent reduction, according to research by Cleland). In addition, designs done by teams are usually simpler, since the IPT members are aware of all performance and manufacturing requirements up-front and are thus able to design the product as a system rather than merely a collection of individual components. The number of parts to be manufactured is therefore reduced, which in turn simplifies the fixturing requirements and allows for easier assembly.

The design and manufacturing benefits described above lead directly to cost reductions. Increased productivity due to co-location of functional specialists at the design/manufacturing interface lowers costs during the development phase. In turn, reduced scrap and rework and simplified assembly can lead to reduced unit manufacturing costs, estimated to be as much as 30 to 40 percent lower than those achieved under traditional organizational designs [Cleland; Hernandez, 1997]. Time savings stemming from increased productivity, reduced oversight, and team coordination also translate into cost benefits. Product development time has been shown to be reduced by as much as 40 to 50 percent [Cleland] with the IPT format, in part because design and manufacturing tasks are performed in parallel instead of sequentially.

On the organizational side, using IPTs can foster learning, job satisfaction, and customer satisfaction. Bates *et al* [1995] have shown "well-aligned and implemented manufacturing strategy" to coexist with a "clan-oriented," or team-centered, organization (p. 1576). This culture, as opposed to a hierarchical one, exerts control over project level decisions through the construction of shared values and beliefs across the organization. The clan-oriented environment is characterized by coordinated decision making, use of small groups and teams, decentralized authority, high employee loyalty, and shared plant-wide philosophy – all good descriptors of how an ideal IPT works. The format provides organizational benefits at both the team and company levels, providing several of the characteristics set out by Galbraith [1973] as being necessary for the reduction of task uncertainty. Within the team, information is more easily exchanged, and the group has the cross-functional resources it needs to complete the task on a relatively autonomous basis, a situation that reduces the uncertainty of the process. Similarly, within the organization, the IPT and the team leader cut across functional lines of authority, creating the lateral relationships that move decisions about product development down to the level where detailed design and manufacturing information exists.

Since team members are more involved in the product development process than they would be if they were just employees receiving isolated task assignments, their knowledge of the process is improved, and they gain experience with producing tangible results. Once the functional barriers between departments are removed, team members are able to "harness their collective strength" to speed decision making and proactively improve business processes [Hutt, Walker, and Frankwick, 1995, p. 22]. Improved communication is one of the most significant organizational benefits of teams, and the IPT format improves relationships between individuals from different backgrounds in a variety of ways. Engineers from different areas are linked by a team-centered network so they have access to specialists in a wider variety of fields. Technical and non-technical personnel alike are able to gain appreciation for the many different skills and contributions available in the community, thus fostering a culture of teamwork, respect, and trust. Customers also gain with the IPT format, since the presence of marketing and sales personnel on the design team serves to incorporate the needs of the user into the product. Customers also share in the benefits of lower cost, faster delivery, and higher quality. Finally, when engineers from supplier organizations are included on the development team, the firm is able to establish a long-term working relationship with its vendors, both to help the supplier customize its service to fit the needs of the prime contractor and to help the designers take advantage of technological innovation in out-sourced components and processes.

2.3.5.2 Disadvantages of Teams

Unfortunately, not every aspect of IPT implementation is positive. The disadvantages of the approach may include communication problems and a loss of technical excellence, both serious issues for product development performance. For example, one of the most interesting results in Klein and Sussman's study of product development teams was the prevalence of organizations that use groups for product development, and often refer to them as "IPTs," but do not meet the four criteria defined in Section 2.3.1.2. In fact, only 31 of the 55 teams Klein and Sussman studied were "intact IPTs" by their definition. They also encountered situations where team members gave different answers as to exactly who was on their team and how big it was, indicating that those groups did not have a sense of themselves as a closed team. Similarly, some groups reported their team size as over 100 members, certainly outside the bounds of how many individuals can realistically work together and make decisions by consensus. As these results show, companies may dub their teams IPTs when they are not, or implement the IPT concept poorly, without making the fundamental changes required to remove the existing product/process split in the organization. Employees may then feel either discouraged that their best efforts are not enough or disillusioned that they are in the midst of yet another reorganization fad that introduces new buzzwords without really changing anything.

While it is hard to transform a poorly functioning organizational structure once it has been established in the company, it is also extremely difficult to implement a good process in the first place. One possible approach to making sure that the IPT is able to avoid the failure modes described above, aside from rigorously adhering to the four definitional characteristics, is the use of kaizen-like team problem solving [Womack, Jones, and Roos, 1990]. "Design for manufacturing" (another name for concurrent engineering or integrated product development) can sound like the design engineers are giving all the answers to the manufacturing engineers.[13] To avoid this reinforcement of functional boundaries, companies may chose to convene pre-production team working sessions where the entire IPT spends a week in the production cell. Their goal is to solve all of the manufacturing issues necessary to achieve the customer's requirements within the capabilities of the machines and the desire for cost effectiveness. This total team immersion fosters innovation and reinforces the concept of the team as a unit for joint problem solving. Similar design shake-down meetings could also be effective during the earlier phases of a development project.

Another problem connected to the poor implementation of IPTs concerns the project cost profile. Managers accustomed to a functional organization may be reluctant to approve at the higher outlays in the design phase that stem from the early involvement of manufacturing personnel (see comparison plots in Figure 2-8). Teams struggling with the design of an intricate product and a complex manufacturing process may also appear to be going through a more tempestuous design phase than previous design engineers who had no restrictions as to what they could "throw over the wall" to their unsuspecting manufacturing counterparts. In order to take advantage of the many downstream benefits of the IPT system, managers must be sure not to punish teams for up-front struggles or expenditures. The time frame used to evaluate projects should therefore be extended to take into account long-term payoffs.

As described in Section 2.3.3, communication problems can be one of the sore points of group interaction and indeed can be a challenge for IPT members. Research has shown that greater functional diversity, measured by the degree of representation of multiple functions and the variability of tenure among team members, has a negative impact on internal group processes, resulting in increased conflict and decreased coordination and group unity [Ancona and Caldwell, 1991]. In organizations where the functional departments contribute to individual performance evaluations, the demands of the "home room" manager may put pressure on IPT members to avoid

---

[13] This sentiment was expressed by one of the manufacturing managers interviewed in Phase I of this research (see Chapter 4).

design compromises that conflict with functional priorities, even if they would result in a better design and an overall benefit to the firm. As a result, IPT members feel a combination of internal and external pressures. In order to overcome these sources of miscommunication, an IPT system requires both team members and managers to adjust the mental models defining their functional orientation and commit to a more integrative model of interaction. Training in group dynamics, negotiation skills, and conflict management prior to IPT formation could improve individuals' ability to work as a team and manage their functional diversity. Also important is special training for team leaders, who are often ill-equipped by their backgrounds of technical specialization to act as good managers. For them, training in facilitating the product development process and translating between the languages of design, manufacturing, marketing, and finance would be highly beneficial. Finally, the organization can seek to improve all individuals' ability to understand different functional perspectives by rotating employees across functions as part of their on-going career development. This imparts a two-way benefit: (1) individuals are exposed to the languages and "thought worlds" of other disciplines, and (2) expertise from one area spawns innovation in another through the merging of perspectives and experience [Cohen and Levinthal, 1990; Thomas, 1994].

As employees become identified as team members rather than functional specialists, however, other side-effects may kick in, one of the most critical being the loss of technical excellence. This problem is also multi-faceted. As Klein and Maurer [1995] point out, a company whose employees can all be described as "jack of all trades, master of none" does not have a sustainable advantage in product development. Group problem solving may lead to lowest common denominator solutions when the team members compromise too much in their attempt to include all viewpoints equally. The focus on project teams may erode the functional disciplines to the point where the company is no longer at the technological forefront. In a less dramatic situation, at best the remaining technical experts are spread very thin by serving as consultants to multiple teams. In times of industry down-sizing, teams may be limited in how many specialists they can commit to a team; "manufacturing engineers" may be responsible for informing the team on fundamentally different manufacturing processes, in which they may have no training (such as composite materials expert who is asked to design a high-speed machining tool). Finally, IPTs contribute to the loss of functional communication paths, especially among new hires who, having served in team-based assignments for their entire career instead of identifying with a functional department, aren't aware of who the experts are on other teams [Haddad, 1996]. Since the engineers in a particular discipline are no longer co-located, they miss out on interacting with others in their function and learning about the latest innovations in their field through the professional communication that comes from disciplinary association.

As Katzenbach and Smith [1993a] put it, integrated product development requires "preserving functional excellence through structure while eradicating functional bias through teams" (p. 119). Several strategies to overcome the erosion of technical excellence are available. As a first step, the IPT can use prototyping and testing to make sure that errors due to inadequate technical design are caught and fixed. Quality assurance reviews by dedicated engineering specialists can also be effective [Wheelwright and Clark, 1992]. Decision tools, such as quality function deployment [Clausing, 1994] and design structure matrices [Eppinger *et al*, 1994], may also be employed to help the team identify the most important design requirements, balance the system trade-offs, and ensure an integrated final product that meets customer demands. The firm may also choose to retain some functionally-based management, such as the designation of executive-level chief scientists in each major technology competency who are responsible for maintaining technical excellence in their area across all teams. Other useful mechanisms suggested in the literature as ways to keep engineers up to date on technological advances include intra-company technology symposia, weekly brown-bag seminars, written R&D progress updates, and company-paid attendance at professional conferences. Training sessions and technical sabbaticals can also be offered as a means for engineers to refresh their knowledge base and keep up to date on technical advances. In short, the company should strive to create employees who are integrators instead of generalists [Klein and Maurer], such that team members are able to communicate with and understand the work of other functions without losing their individual technical specialization. This research project focuses on the identification of ways in which the firm can create an organizational climate that both promotes functional excellence and maintains the interdisciplinary communication paths necessary for effective technology transition by the IPT.

2.4 Literature Analysis and Hypothesis Development

Combining the elements of technology transition, organizational structure, and strategic decision making, the literature review points out several areas in need of further research, especially in relation to the role of the IPT in making decisions about the strategic adoption of new technology. Interviews with managers in manufacturing firms also indicate that coordinating the flow of information for decision making within an IPT format can be a challenge (see the description of the Phase I research results in Section 4.1). In addressing this problem, the research frames the issue of technology transition in the context of organizational structure. The section begins with the presentation of two relevant theoretical applications. The first examines applies the definitions of authority, information, and decision structures presented above in Section 2.1.3 to the specific issue of technology transition. The second demonstrates how organizational and cognitive issues can limit the distribution of strategic information in a firm. In both cases, the theoretical concepts of organizational structure are applied to the process of technology transition. From this vantage point, a set of hypotheses are generated to guide the research process.

2.4.1 Technology Transition in the Context of Organizational Structure

As was discussed in Section 2.1.3, the structure of an organization regulates not just the hierarchical arrangement of workers within the firm but also the means by which they interact with each other. The organizational structure of the company therefore defines the processes by which tasks are accomplished, in terms of which groups are involved, how they interact, what kinds of information flow between them, and how that information is interpreted. More accurately, a company can be thought to consist of multiple organizational structures, each of which governs how a particular task is performed. In this way, different kinds of tasks may follow different structures. For example, the company may have one structure for technology development and another for marketing. For the purposes of this study, the only organizational structure under consideration is the one that regulates the technology transition process.

The organizational structure for a given task, such as technology transition, determines the individuals or groups involved and the information flow paths by which they communicate. As explained in Section 2.1.3, the organizational structure is defined here as being made up of three subelements: the authority, information, and decision structures. For the purposes of the research case studies, the authority structure follows the principles of integrated product and process development, manifested organizationally as integrated product teams. The information structure is more complicated. While the IPT design prescribes to a large extent how different individuals and groups are to work together, a great deal of information will also be exchanged through the emergent communication channels embedded in the firm's information structure. To some extent, the content of the information is affected by the information structure as well, since the perspectives of the individuals who populate the flow path act to filter the messages being communicated [Loehr, 1991; Dougherty, 1992; Thomas, 1994; Wynn and Novick, 1995]. That is, the source of information and the individuals who receive and distribute it influence the nature of what is being communicated. For example, consider an R&D engineer who is describing a current technology development project. The level of technical detail presented in a conversation with a fellow engineer might be very different from that in a discussion with a senior executive. At the same time, the executive may decide to search out an R&D manager to receive more information about how the progress of the project affects broader cost and schedule issues. This example can also be used to illustrate how organizational structure regulates the flow path by which information is communicated: the information structure of the company would dictate whether the usual procedure was for the executive to speak directly to employees at the R&D level or whether a more hierarchical arrangement was followed (i.e., executives speak only to managers). It is important to note, however, that the information flow path does not necessarily conform to the hierarchical reporting system of the firm (that is, the information structure does not have to be identical to the authority structure). For example, R&D engineers often share information about their research with engineers from product development. That kind of information sharing may have a significant impact on subsequent technology transition initiatives, even though there is usually no managerial relationship between the two groups other than at a very high level.

Organizational structure also regulates the series of decision gates that must be passed on the way to implementation of a technology (defined here as the "decision structure"). Only on rare occasions does a new manufacturing technology enter a company in a fully completed ("turn-key") state. Usually some amount of development is required to refine or adapt the process to the particular needs of the product and the facility.[14] For example, many technology development projects begin with an R&D investment to explore the application of a potential beneficial innovation that was invented outside the company. As the development progresses, decisions are made about whether or not to keep funding the project, based on analyses of the firm's technology portfolio. As a process matures, questions arise concerning when and where to apply the technology to a new or existing product line. The process of technology transition takes place as the development project is moved from the laboratory to the product development stage and then later to the production floor. Managerial and technical decisions are made at various points in this process as the organizational dominion over the technology shifts between groups. The actions taken at these "go/no-go" points determine the outcome of the technology transition. The individual or group responsible for making each of these decisions varies, depending both on the decision structure of the company and on which stage in the technology transition is being debated. The extent of the involvement of different groups can also vary. In terms of the IPPD environment, an IPT participating in a technology transition may have a major role, perhaps by participating in the actual technical development. In other cases, the IPT's involvement may consist only of choosing the manufacturing process that best fits their needs from a repository of available R&D technologies. In either case, the technology decision can be thought of as exercising the information flow paths for technology transition that exist in the company.

---

[14] Section 4.2.2 presents a formal model that will be used during the field research to analyze the various stages of innovation and how different groups are involved over time. A simplified description of the technology development process is provided here as an introduction.

2.4.2 IPTs' Need for Strategic Information

The IPT format has been shown to have extremely beneficial results not just for product quality and cycle time but also for human resource considerations such as dedication and job satisfaction [Wheelwright and Clark, 1992; Klein and Sussman, 1995]. If the IPT philosophy of low-level decision making is to work, however, the team needs to have access to the data necessary to come up with a decision outcome that takes into account all of the relevant criteria which are important to the firm. Since a firm's technology strategy prescribes which technologies are to be pursued as candidates for later application to the company's products [Hax and Majluf, 1996], the IPT logically needs information about the company's technology strategy in order to make decisions about the adoption of new technology for their product if that technology is to be part of the company's strategic direction. The role of the IPT in the distribution of strategic information should therefore be considered.

Strategy generation is typically pursued at the upper levels of the organization [Hax and Majluf, 1996]. This point of origin assumes that only the executive level has enough knowledge of the complex activities of the firm, the competitive environment, and the market trends to assemble a "big picture" strategic direction for the firm. While the knowledge of upper management with regard to the inner workings of specific functional areas is for practical reasons more superficial than that of the individuals who spend their days absorbed solely in those subjects, managers do have knowledge about a more diverse set of areas than lower level workers do. Since strategic planning requires a wide variety of inputs, it does make sense for strategic formulation to take place at the upper management level. However it may also be extremely important for this information to be distributed through the organization so that it can be used to guide project-level activity, including IPT decision making.

The team-based format of the IPT may also have the unanticipated side-effect of isolating the team members from broader questions of how technology is being employed across the company. Engineering-level personnel have traditionally not been involved in strategic decision making. As discussed in Section 2.3.3, the presence of cognitive effects such as information filtering and schema formation [Simon, 1957; Gersick and Hackman, 1990; Fiske and Taylor, 1991, Ancona and Caldwell, 1992] imply that team members therefore may not be adept at considering strategic information in their technology decisions, nor will they necessarily notice the absence of such information. The IPT format may unintentionally act to exacerbate the weakness of strategic evaluations at the product development level. Lacking close interaction with a centralized functional department, team members may be so focused on the development of their single product that they are unaware of how the technologies they are considering could be used by other teams (see

Section 1.3). The implementation of a new technology requires significant investment in capital equipment and personnel, and so the most effective strategy would be to spread those costs across multiple product lines. Given that many manufacturing processes are common to a variety of products, it would be helpful for an IPT that is considering making changes to a process to share the costs, and consequently the rewards, across the company. Similarly, the adoption of a new technology should not be focused just on the short-term needs of a single product, but on how that technology may be used as a competitive advantage on future products. The firm's technology strategy should act as a guide for this type of cross-product technology use. Bringing awareness of the technology strategy down to the IPT level therefore becomes a critical factor in overcoming the potentially isolating effects of a team-based organization. In turn, the technical and cost analyses performed by IPTs as they consider a particular technology transition may prove to be beneficial to the formulation of future technology strategies.

The above discussion implies that, given the switch to an IPT-based organization, information about the firm's technology strategy is needed at a working level far below the traditional executive realm of strategy generation. Given their temporal and organizational position between R&D and production in the stages of technology transition, IPTs are well suited for a pivotal role in the transition of new manufacturing technology (see Section 2.1.2). Consequently, companies need to determine how best to inform IPT members of the firm's strategic objectives for technology transition so that those goals can be considered in the IPT's decision making activities. While academic research has proposed that the information contained in a firm's technology strategy should be distributed throughout the organization [Wrapp, 1984; Hax and Majluf, 1996], the literature is surprisingly silent as to how this should occur. In addition, there is no consensus in industry as to which structures of information flow will produce the most effective IPTs (see the description of the Phase I research results in Chapter 4). The dissertation research addresses these deficiencies by exploring the ways in which strategic information can most effectively enter the technology transition process at the IPT level. The next section focuses the above theoretical discussions on the specific questions of how organizational structure affects the transition of new technologies within an IPPD environment.

2.4.3 Research Hypotheses

To address these issues, a study of the organizational structures for technology transition was made, focusing on the distribution of strategic information through the firm and specifically to the IPT level. In particular, the research looks at the impact of different information structures on (1) the process of technology transition, (2) the creation and distribution of a technology strategy, (3) the ability of IPTs to make decisions about the adoption of new manufacturing technology, and (4) the effectiveness of the company's overall product development process. Based on the theoretical analysis and literature survey presented above, the hypotheses to be studied in the research project take the following form.

H1. The flow paths for information concerning the firm's technology strategy are a key component of the information structure for technology transition.

H2. Organizational structures which promote the distribution of information to and from the IPT level will contribute to a more effective technology transition process.

The research questions and hypotheses are addressed through a comparative analysis of case studies concerning technology transition. This research is paired with an analysis of the various distribution systems in use in the aerospace industry for communicating information about a firm's technology strategy throughout the firm. The research results therefore serve to describe current industrial practice for the use of IPTs in strategic technology decision making (question Q1), to assess the strengths and weaknesses of the current system (Q2), and to analyze the contribution of organizational structure to the future effectiveness of technology transition (Q3). Beyond the analysis of the hypotheses, other contributions include the identification of the important dimensions of the information distribution process, the development of analysis tools to capture and evaluate information structures, and the application of these tools to specific military aerospace industry cases of IPT involvement in technology transition. Chapter 3 contains a complete description of the research methodology, along with details of how the hypotheses will be measured and tested empirically.

CHAPTER 3 RESEARCH METHODOLOGY

This chapter presents the framework which was developed to analyze the impact of information structure on the effectiveness of the technology transition process. A research design is outlined for a two-phase study that complements a broad survey of management practices in the military aerospace manufacturing sector with a focused look at specific technology transition initiatives involving IPTs. Analytical tools for the evaluation of field data are also presented.

3.1 Overview of The Research Plan

Figure 3-1 shows a flow diagram of the research activities. The project began with the development of analytical tools for the description and evaluation of organizational structures (see Section 3.2). A quick-look survey of manufacturing firms in the defense aerospace sector was then performed to identify the variety of structures in use today in industry for the distribution of strategic information to the IPT level (Phase I: see Section 3.3). Based on the resulting set of possible information structures, four retrospective case studies were performed at aerospace firms regarding instances where IPTs made decisions about the adoption of a new manufacturing process technology (Phase II: see Section 3.4).[1] The goal of the case studies was to provide insight into the research objectives by exploring different information structures for technology transition. Details of the research plan are presented below.

3.2 Analysis Tools

Before the study of organizational structures for technology transition could be accomplished, methods had to be created to capture data at each firm and present it in an analyzable format. Two analysis tools were developed to meet this need. The first is a diagramming method for information structure, focusing on the identification of information distribution flow paths for the distribution of the firm's technology strategy. Key constructs for the process were also identified and used to make distinctions between firms. This tool was used to prepare an information structure diagram for each company in the first phase of the study. Another analysis tool was developed to capture the information flow paths exercised during a particular technology transition. Termed the organizational value chain for technology transition, the model is a matrix diagram showing which individuals or groups were involved in each stage of the technology transition. The level of participation and authority for each group are also indicated. The value chain tool was used in analysis of the Phase II case studies. A description of each model is provided below.

---

[1] These case studies took place at three different aerospace firms. At one company, two new technologies were implemented on the same product, and so the technology transitions were examined as two cases.

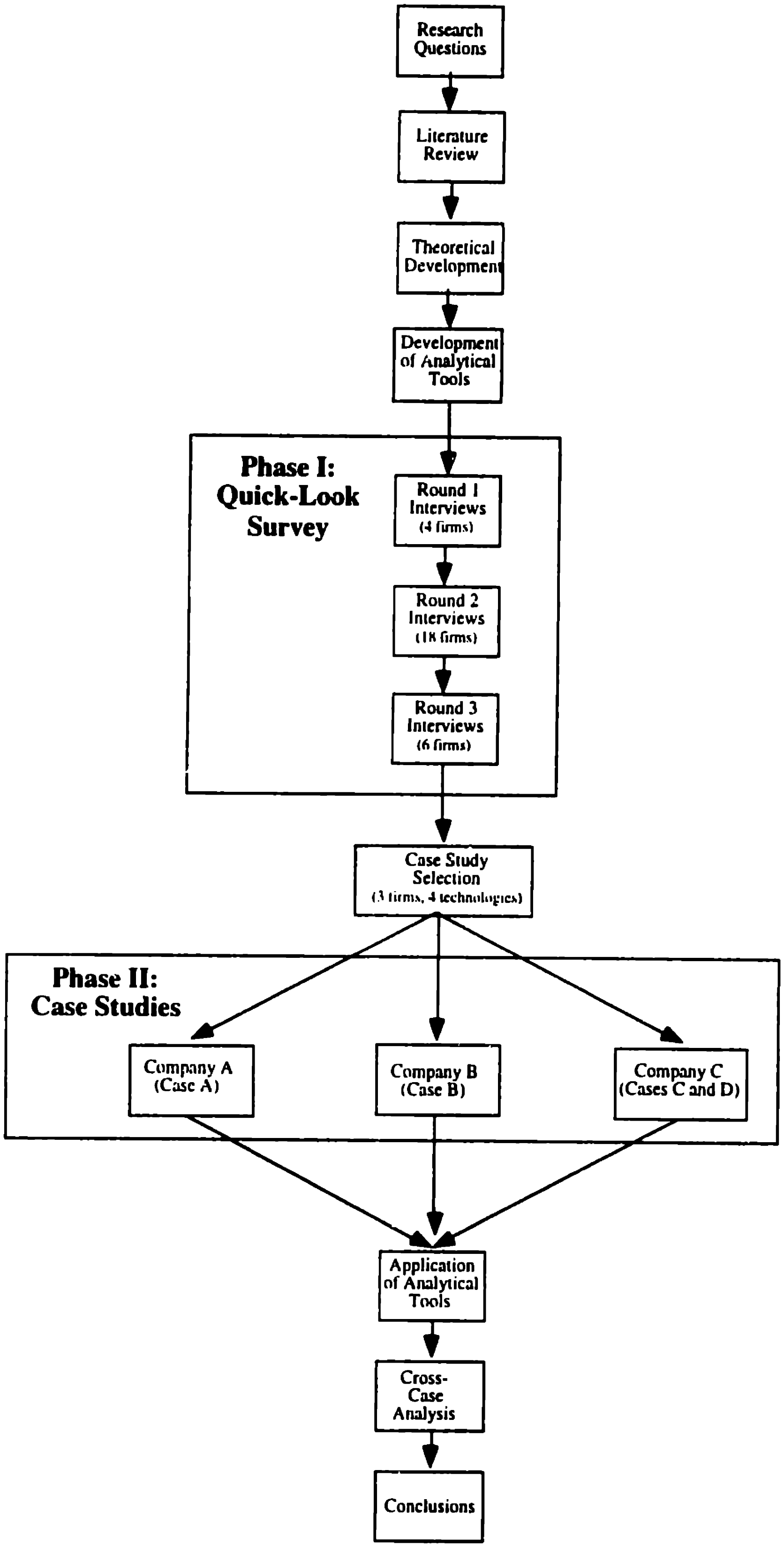

Figure 3-1. Flow Diagram of Research Activities

3.2.1 Information Structure Diagrams

In order to study the effects of different organizational structures on the distribution of information, it is necessary to capture the key elements of the process in a concise format that illustrates the various dimensions along which structures may differ. This section describes the diagramming technique that was developed to identify different information structures in terms of the information flow paths that occur between individuals and groups in the firm. The application of the model to the specific case of the distribution of information about a firm's technology strategy is also presented.

3.2.1.1 General Approach

A simplified model of information flow through the organization has been constructed to represent the primary "building blocks" of an organization. The generic template shown in Figure 3-2 models the information distribution process as consisting of four objects:

- the various organizational groups, such as senior management, middle management, R&D group, IPT leader, IPT members, and suppliers (represented as rectangles)
- the key individuals who facilitate information flow (represented as dots)
- the content of information (represented as a document[2])
- the flow of information between groups[3] (represented as arrows).

The information structure diagram for a specific organization consists of assembling these objects to represent the groups involved and the flow of information between them. Since the topic of information distribution has not been addressed in the management literature, it is expected that many different structures are in use in industry, with each firm developing its own methods based on its unique corporate and industry experiences.

3.2.1.2 Information Structures for Technology Strategy

These diagrams can be used to represent the overarching information structure of a firm, in addition to providing detail about specific tasks or information flow patterns. For the first phase of the research, the information flow paths for the distribution of information about the firm's technology strategy was of primary interest. While it is impossible to construct an exhaustive list of structures without direct observation of industry practices, firms are expected to be distinguishable

---

[2] Note that the embodiment of information, such as a technology strategy, is not necessarily a written format. Oral presentations or other forms of contact can also be used to communicate information.

[3] This represents the flow of information, which may or may not correspond to the reporting links of the organizational hierarchy.

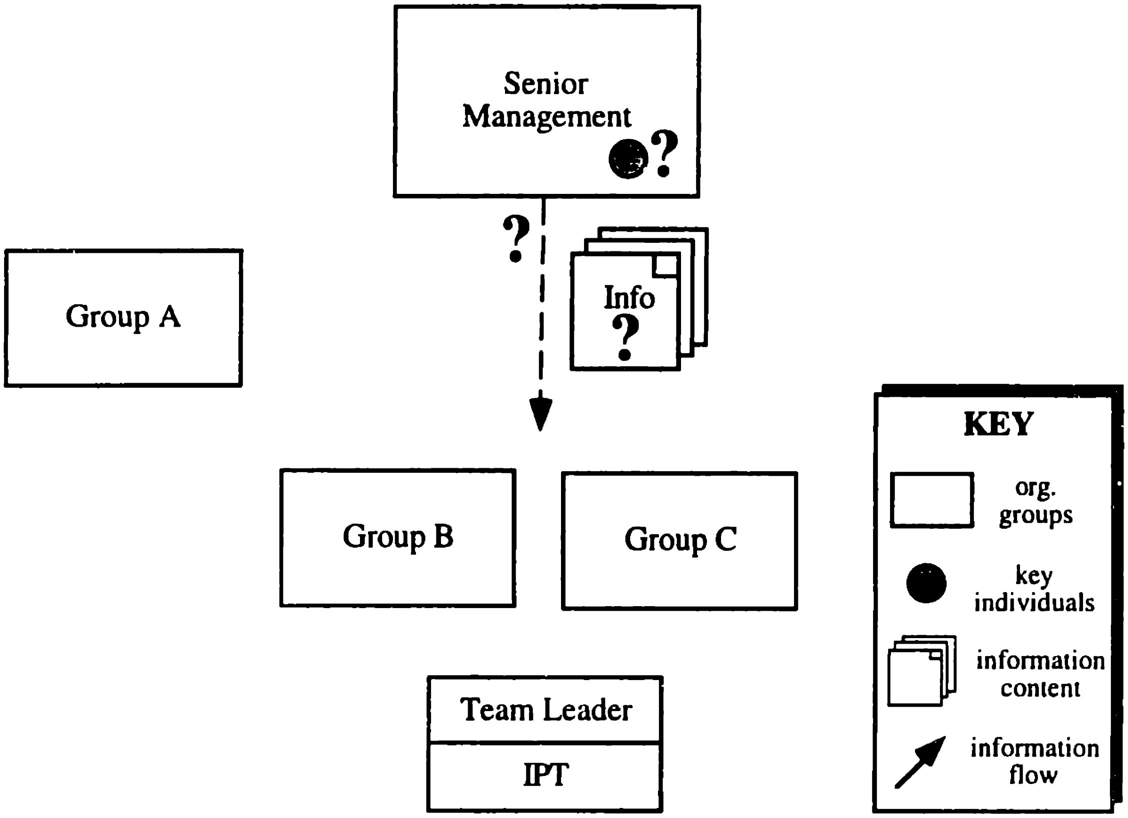

Figure 3-2. Information Structure Diagram (Blank Template)

in their information distribution systems for technology strategy by variation along seven key dimensions:

- existence
- origin
- content
- format
- attenuation
- terminus, and
- source.

Table 3-1 describes the seven dimensions and possible alternatives within each. *Existence* refers to the presence or absence of a technology strategy, since the assumption can not be made that all firms actually have a strategy in place. Given that a strategy is present, the *origin* reflects which organizational member or group is responsible for the creation of the technology strategy. The remaining constructs deal with how information about the strategy is distributed through the

Table 3-1. Dimensions of Structural Variance for the Distribution of Information about a Firm's Technology Strategy

Dimension	**Description**	**Possible Alternatives**[4]
Existence	Presence or absence of a corporate technology strategy for manufacturing (process) innovation	• presence • absence
Origin	Creator(s) of the technology strategy	• corporate level management • Chief Technology Officer • R&D management
Content	Issues addressed in the technology strategy	• high-level strategic plan • R&D funding plan • project-specific goals/directives
Format	How the technology strategy is presented to IPT members	• written reports (e.g., mission statement, shareholder report) • announcements (e.g., company newsletter) • informal presentations (e.g., town meetings) • undocumented knowledge passed deliberately between individuals • tacit knowledge passed unconsciously between individuals
Attenuation	The amount of information that is lost, removed, or "filtered" (intentionally or not) during its transmission between organizational levels	• strategic information given to the team is not filtered (i.e., the team receives all the information generated in the original technology strategy documentation) • strategic information given to the team is somewhat filtered • strategic information given to the team is highly filtered • no strategic information is given to the team

---

[4] The list of possible alternatives is not intended to be exhaustive. In fact, it is expected that field research will identify other alternatives not yet considered here.

Table 3-1 (CONTINUED). Dimensions of Structural Variance

Dimension	Description	Possible Alternatives
Source	Party responsible for distributing strategic information to the IPT members	• technology strategy author (e.g., senior management, Chief Technology Officer) • senior manager assigned to mentor the team • team leader • team member with special knowledge
Terminus	The lowest level to which strategic information is communicated intentionally and directly[5]	• IPT members • IPT leader • above the IPT level

organization. The *content* dimension assesses what issues are addressed in the strategy, while the *format* dimension deals with the physical embodiment of the strategy, be it written, oral, or demonstrative.[6] The final three constructs refer to the flow of information through the organization, designed to focus on the transmission of information to the IPT level. *Attenuation* judges how much information is lost or filtered out during transmission between levels. The *terminus* and *source* constructs are defined as the organizational groups linked by the final segment of information flow. In the structure diagrams, these are the two rectangles joined by the last arrow in the chain, such that the terminus identifies the lowest organizational level that information reaches and the source represents where that information link originated. For clarity, the dimensional constructs are mapped to a sample (fictitious) information structure diagram in Figure 3-3.

These dimensions will be used as the independent variables for the research study (see Section 3.4.3). Note that, with the exception of the existence construct, the alternatives within a dimension are not mutually exclusive. Given these constructs, a structure for information distribution is defined as the distinct combination of at least one alternative from each dimension. Note that this

---

[5] In the information structure diagram, the terminus is the last organizational group connected to an information flow arrow.

[6] Government funding contracts for industrial research and development require written documentation, so most firms are expected to have some written element to their technology strategy.

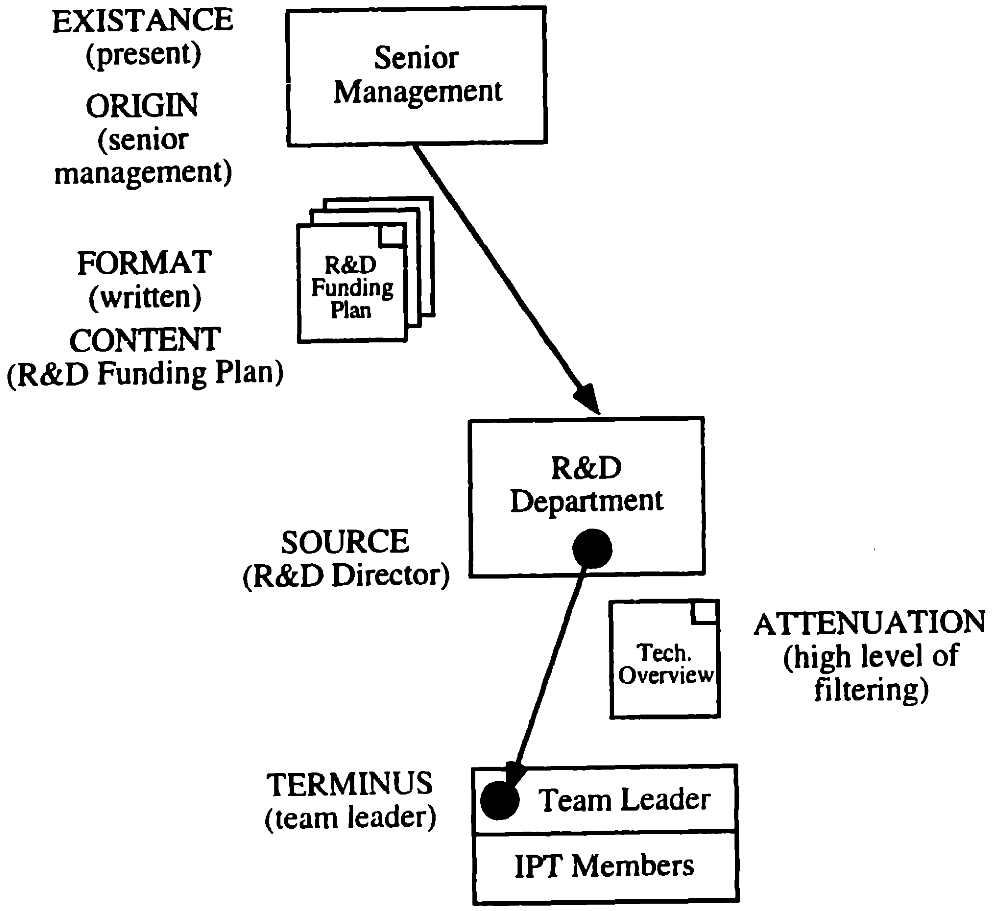

Figure 3-3. Sample Information Structure Diagram Showing Information Links, Dimensions, and Alternatives

method does not attempt to define every single aspect of a given structure but instead intends to focus on those dimensions that are most important to the research topic. Chapter 4 contains examples of the application of the structural diagramming technique and the constructs, based on the Phase I field results.

3.2.2 Organizational Value Chain for Technology Transition

This section presents the analysis framework that was developed to organize and analyze the data from the Phase II case studies. The general approach is first outlined, followed by a description of how an existing model for the innovation process was modified to take into account organizational variation over time. The ensuing new model is termed the "organizational value chain for technology transition."

3.2.2.1 General Approach

A technology transition initiative can be more broadly thought of as the decision making process undertaken to evaluate if, when, and how a technology should be transitioned from R&D to production. As such, it represents an application of the firm's technology strategy, be it a strategy that has been carefully planned and executed or one that has emerged over time as the technology development unfolds. The information structure diagrams prepared for each case study company provide a broad look at how information about the firm's technology strategy is communicated through the organization. That is, the structures identify the information flow paths for strategic information. The case studies of technology transition in turn provide a means to examine how the information flow paths for the distribution of the technology strategy have been exercised through the participation and decision making performed by the various individuals and groups of the firm. In doing so, the ability of the organizational structure to promote effective technology decision making by IPTs can be studied.

In order to study the decision process, some means of examining the information flows over time must first be developed. The Roberts and Frohman [1978] model for the stages of innovation was selected as the basic framework for classifying activity in the firm into different categories between early R&D and production (see Section 3.2.2.2). The model was expanded to identify which organizational entities were responsible for making decisions in the different stages. The model therefore contains information concerning both the information and the decision structures of the firm. (Data concerning the firm's authority structure is provided in the analysis of each case study in written form.) The resulting matrix was termed the organizational value chain for technology transition. In this way, a time-dependent map of decision making activity in the firm was constructed for each case study (see Section 3.2.2.3). With these maps, the organizational distribution of activity through the firms can be compared visually. Since each firm has a different organizational structure, the value chain maps provide a simple analysis tool for cross-case comparisons. The maps are then coupled with the information structure diagrams for each firm to trace the information flow paths used in each specific case of technology adoption (see Section 8.1). In this way, the actual information flow paths used by the IPT can be compared to those intended by management in their establishment of the distribution paths for the technology strategy.

3.2.2.2 Innovation Stage Model

Many models exist in the innovation management and product development literature to describe the various stages of technology development [see, for example, Mintzberg, Raisinghani, and Théorêt, 1976; Roberts and Frohman, 1978; Roberts and Fusfeld, 1981; Abernathy and Utterback, 1988; Roberts, 1988; Tushman and Rosenkopf, 1992; Ulrich and Eppinger, 1995]. Each presents a slightly different slant on the problem, with the models mostly differing in terms of which stages receive the most attention and where the demarcations between stages occur. However, they all represent roughly the same progression from awareness of a new invention, through some process of technical refinement, and eventually into a production application. Roberts and Frohman's [1978] model was selected for use in the research analysis based on its lasting reputation as a useful portrayal of the basic stages of innovation. The model classifies the process of innovation into a series of stages for technical and market development:

I. recognition of opportunity
II. idea formulation
III. problem solving
IV. prototype solution
V. commercial development, and
VI. technology utilization and/or diffusion.

While the model was originally designed to describe activities primarily in a science-based research environment, the stages can also be interpreted in relation to a more industrial style of product development. Table 3-2 shows the primary activities for each stage, accompanied by a list of the major decisions that are usually considered at each point. Note that the duration of each stage can vary according to the organization and to the technology being considered; some stages may last for months or years, while others are accomplished in a very short time.

3.2.2.3 Resulting New Framework

The Roberts and Frohman model describes the stages of technology transition but does not indicate which individuals or groups in the organization are involved at each stage. The linear model was therefore transformed into a matrix format, as shown in Table 3-3. The actors listed along the left-hand side of the matrix represent the major participants in the technology transition process, as identified during Phase I of the research. A collection of managers, engineers, and production personnel were selected as the actors in the process, although other participants can be identified by means of the "other" category. The matrix forms a organizational picture of the value chain for technology transition in the firm. Marks are made in the appropriate boxes to indicate which individuals or groups were involved during each stage. The marks indicate distinctions between levels of participation, according to the following code:

P: Primary participant (performed bulk of activity)
A: Auxiliary participant (assisted in performing activities)
D: Decision maker (authorized decision to proceed to the next stage).

At least one decision maker is indicated in each stage except the last one, on the premise that a decision must be made to proceed to the next stage. Some groups may be represented by more than

Table 3-2. Stages of Innovation

Stage	Name	Activities	Decisions at Conclusion of Stage
I.	Recognition of opportunity	• Awareness of an innovation by sources either internal or external to the firm	• Personal or group interest in investigation of new ideas
II.	Idea formulation	• Recognition of application of innovation within the firm • Early research into potential application to a new or existing product	• Allocation of initial R&D funding • Desire for alternatives or improvements to currently available technology
III.	Problem solving	• Continued research into potential applications • Initial estimates of costs and benefits • "Marketing" of technology to product development community • Identification of specific product development applications • Demonstration of laboratory-scale capability	• Continued R&D funding • Acceptance of technology opportunities by product development community
IV.	Prototype solution	• Application of technology to real designs • Analysis of technical alternatives for a specific product development project • Analysis of tradeoffs - performance, quality, cost, schedule, etc. • Estimation of costs and benefits for specific products	• Allocation of product development funding • Acceptance of analysis results • Assessment of application-readiness of technology • Adoption or rejection of the technology for use on a specific product
V.	Commercial development[7]	• Process refinement for specific application • Data collection on process capability • Scale up to production level	• Final approval to replace existing technology with new technology
VI.	Technology utilization and/or diffusion (Production)	• Transfer to manufacturing environment	• Start of production with new technology

---

[7] Not that the use of the term "commercial" here describes the development of a technology that can be sold in the marketplace. It does not refer to the distinction between military and commercial products in the aerospace industry.

Table 3-3. Organizational Value Chain for Technology Transition (Blank Template)

STAGE ACTORS	I. Recognition of Opportunity	II. Idea Formulation	III. Problem Solving	IV. Prototype Solution	V. Commercial Development	VI. Technology Utilization (Production)
Corporate Management						
Program Management						
R&D Group (Product)						
R&D Group (Process)						
IPT Leader						
IPT Member (Design)						
IPT Member (Mfg)						
Production						
Other						

one marking. For example, a group that both performed most of the activity at that stage and made the decision to continue to the next stage would be represented with both a "P" and a "D" marking. Similarly, more than one group can be indicated as participants in a particular stage. For example, both design and manufacturing IPT members may have been primarily responsible for activity in the commercial development stage, so both would be indicated with a "P" marking. Auxiliary participants may not be present in every stage. Often, the IPT leader is classified in the auxiliary category as one who guided the development effort but did not participate directly in the technical analysis. In terms of information distribution, the primary and auxiliary participants generally share information between them, with some information also being communicated either one-way or two-way with the decision making body.

A value chain was created for each case study, and the data were used to compare how the information flow paths in the technology transition matched with the information structure of the company identified during Phase I. Section 8.1 contains a detailed description of the results that were obtained from each case study site.

3.3 Phase I: Quick-Look Survey

The first step in studying structures of information flow for technology transition is to identify which information structures are actually in use in industry. To this end, the research commenced with a quick-look survey of aerospace manufacturing companies, not in the sense of a formally written questionnaire but as a first examination of contemporary industry practice. The intent is not to exhaustively catalog all structures existing in manufacturing firms or to conduct a statistically rigorous analysis but instead to gain an understanding of the variety of information structures in use in industry, their frequency, and their variation along the different dimensions. Consequently, this phase of the research was performed as quickly as possible in order to use this data to select case study opportunities for the primary field work in Phase II. This section describes the Phase I subjects, the case study selection process, and the question guides developed for the telephone interviews.

3.3.1 Interview Subjects and Methodology

Industry contacts were drawn from the member organizations of the Lean Aerospace Initiative (LAI), a research program based at the Massachusetts Institute of Technology.[8] Company contacts

---

[8] Researchers with the Lean Aerospace Initiative work with a consortium of aerospace companies, labor representatives, and United States government personnel to study the implementation of lean manufacturing techniques in the aerospace industry and to measure the resulting impacts on cost, quality, and schedule.

at these sites had been previously established, which facilitated data accessibility. Participating organizations are listed in Table 3-4. The telephone interviews took place in three rounds spread over a nine month period (see Table 3-5).

As part of the research topic exploration, informal conversations of approximately 45-60 minutes in duration were conducted with "friendly" informants at four aerospace organizations. (See interview question guide in Section 3.3.3.1.) These Round 1 interviews served to validate the research questions, confirm industry interest in the research topic, and refine the primary interview question guide. A formal series of telephone interviews (Round 2) was then conducted with 22 executives and managers at 18 U.S. defense aerospace firms.[9] The company representatives, selected based on their role as official Lean Aerospace Initiative "point of contact" (POC), typically were at the Vice President or divisional manager levels in the engineering or new product marketing areas, positions that afforded them enough of a firm-wide perspective to adequately describe the multi-level information structure and to be familiar with the product development process. Interviews lasting between 30 to 45 minutes were conducted, after which time the researcher analyzed the interview notes to map out the dimensional constructs of the firm's information structure. (See interview question guide in Section 3.3.3.2.) Each firm was then assigned a preliminary structural classification based on the characteristics of information flow within the organization between the creators of the technology strategy and the IPT-level engineers. Four different structures for communicating strategic information to the IPT level were identified, with many firms exhibiting variants of these core strategies (see Chapter 4).

Supplemental interviews (Round 3) with IPT members and R&D personnel at sites that appeared promising for the Phase II case study research were then deemed necessary to flesh out lower-level communication activity and to confirm the structural classifications assigned in the Round 2 interviews. Six organizations were selected as promising sites for further research, according to their representation of a strong organizational structural pattern. Follow-up interviews were conducted with both the LAI POCs and additional technical personnel across the organizational hierarchy. (See interview question guide in Section 3.3.3.3.) From these interviews, the

---

[9] As of April 1997, when the Round 2 interviews commenced, there were 18 member organizations in the LAI consortium. One of these company representatives declined to be interviewed due to lack of time. One other organization, the result of a recent merger between two large aerospace companies, was determined to still be segregated enough along the previous organizational lines to be counted as two separate entities for the purposes of this research Phase. Therefore, the complete Phase I data set is comprised of 18 different organizations. One of the "friendly" informants contacted during the Round 1 interviews also held the position of official LAI "point of contact" (POC), and so that Round 1 interview data was retained for Round 2. The other three Round 1 interviewees were not official LAI POCs, so their organizations were re-polled during Round 2 via the official POC.

Table 3-4. Phase I Participating Organizations

- AlliedSignal Aerospace, Inc.
  Phoenix, AZ
- Allison Engine Co.
  Indianapolis, IN
- Applied Materials
  Santa Clara, CA
- Boeing Defense & Space Group
  Seattle, WA
- Boeing-St. Louis
  St. Louis, MO
- Boeing North America
  Tulsa, OK
- G.E. Aircraft Engines
  Cincinnati, OH
- Hewlett-Packard Co.
  Burlington, MA
- Hughes Aircraft Co.
  Los Angeles, CA
- Lockheed Martin Aeronautical Systems
  Marietta, GA
- Lockheed Martin Aeronautical Systems
  Marietta, GA
- Lockheed Martin Electronics & Missiles
  Orlando, FL
- Northrop Grumman Corp.
  El Segundo, CA
- Pratt & Whitney
  West Palm Beach, FL
- Raytheon Aircraft
  Wichita, KS
- Sundstrand Corp.
  Rockford, IL
- Texas Instruments
  McKinney, TX
- Textron Systems Division
  Wilmington, MA
- TRW Avionics Systems Division
  San Diego, CA

Table 3-5. Phase I Telephone Interview Response Rate

Category		Round 1	Round 2	Round 3
# contacted	people	4	18	13
	organizations	4	18	6
# interviewed	people	4	22[10]	12
	organizations	4	17	5
# declined or unavailable	people	0	1[11]	1[12]
	organizations	0	1	1

---

[10] Some of the POCs invited additional personnel to sit in on their interview conference call or suggested other contacts for answers to specific questions.

[11] Declined due to lack of time.

[12] Unavailable for an interview during the Round 3 time frame.

information structure classifications were refined, and interesting technology adoption stories were identified.

3.3.2 Case Study Selection: Sites and Technologies

Based on an analysis of the information structure variation across firms (see Section 4.4), three companies were selected as final case study sites.[13] Each of these firms represents the use of a different information structure for providing the team with information on the strategic goals of the firm, so that the case study sampling was done on the independent variables. Discussions with the LAI representatives at the selected sites were used to identify examples at that firm of a decision made by an integrated product team regarding the adoption of a new generation of manufacturing process technology. The case should represent the first instance of the use of that technology in the firm on a product development program. The decision must have been complicated enough to require input from personnel in multiple functions, such as design, manufacturing, finance, and strategic planning. The technology decisions were required to have been made within the past five years so that the decision-making process was still recent enough to be assessed accurately through interviews with the major participants. The technology should also have been sophisticated enough to require significant changes to the existing design and manufacturing process. Interaction between multiple groups within the organization, including R&D and product development, should also have been part of the technology implementation process. Potential application of the technology across multiple product lines and production programs was preferable. At the same time, an attempt was made to control for other potential differences between cases, such as the industry (aerospace only), procurement environment (military market only), technical maturity (technologies all first-use in the organization), scope of the process application (to a single part of subsystem), and the size of the team (10 to 25 IPT members). Once the researcher and company POC had identified a technology of mutual interest, plans were arranged for case study site visits (see Section 3.4).

3.3.3 Interview Guides

Interview guides were developed for each round of telephone interviews and used by the researcher to guide the conversation and make sure that the important points were addressed during the limited time available. The questions of interest varied across the three rounds of telephone interviews. The Round 1 questions, for interviews which took place during the proposal-stage of the dissertation, were primarily exploratory in nature. Consequently, the questions for Round 2 were refined in order to focus on eliciting the data necessary to identify specific constructs

---

[13] To maintain confidentiality, these sites are identified as Company A, Company B, and Company C.

associated with a given organization's information structure. The Round 3 questions served to confirm the information structure assignment, to deepen the understanding of varying perceptions across the organizational hierarchy, and to identify possible case study technologies. The interview guides used in each round are presented in the following three sections.

3.3.3.1 Round 1 Interview Guide

1. Who develops the firm's strategic goals regarding the use of manufacturing process technology ("the technology strategy")?
2. How are you informed of the technology strategy?
3. How do you communicate the technology strategy to those below you?
4. When communicating the technology strategy to those below you, do you pass it on exactly as it was presented to you or leave out certain information?

    4a. What kinds of information are left out?

    4b. Why is information left out?
5. How is strategic information used at your level?
6. What types of information are included in the technology strategy?
7. Is the lack of strategic information a problem for decision-making at your level?
8. How do you assess the level of strategic information you are provided with?
9. Have decisions at your level ever been overruled by management for strategic reasons?
10. How would you rate the need for strategic information at the IPT level? (e.g., not necessary, useful but not required, mandatory)
11. Can you think of any reasons in favor of limiting the distribution of strategic information to team leaders and/or team members?

3.3.3.2 Round 2 Interview Guide

Introductory questions on IPTs:

1. To what extent does your firm use IPTs for product development?
2. What functions are represented on a typical IPT?

Questions focused on information structure diagram constructs:

3. Who develops the firm's strategic goals regarding the use of manufacturing process technology ("the technology strategy")? [Constructs of interest: EXISTENCE, ORIGIN]
4. What types of information are included in the technology strategy? [CONTENT]
5. What is the format of the technology strategy? [FORMAT]

6. As the technology strategy is communicated through the organization, does every level receive the same detail of information? [ATTENUATION]

   6a. What kinds of information are left out?

   6b. Why is information left out?

7. How is strategic information communicated through the organization? How does the IPT-level receive information about the technology strategy? [SOURCE, TERMINUS]

3.3.3.3 Round 3 Interview Guide

Confirmation questions on preliminary information structure assignment (for POCs):

1. My impression from our earlier conversation was that ____ [fill in according to structural type] is responsible for putting together the firm's strategic goals regarding the use of manufacturing process technology. Is that impression correct? Who else contributes to technology planning?
2. My impression is that the primary means by which engineers at the IPT level hear about which manufacturing technologies the company would like to target is through ____ [fill in according to structural type]. Is that impression correct? How else might the IPT learn about the company's technology strategy?
3. Do engineers from the R&D group ever serve as full-time IPT members? If so, what is their role in new technology introduction? (Use to verify uniqueness of information structure for management chain and network organizations.)
4. Can you recommend some contacts at other levels of the organization that I could speak to about their perspectives on these issues? (e.g., a team leader, a team member representing manufacturing engineer, and an engineer from the R&D department)

Questions to determine perspectives at other organizational levels (for team leaders, team members, and R&D engineers):

5. How does the IPT-level receive information about the firm's manufacturing technology plans?
6. What format is this information in?
7. How does the R&D group interact with the project teams for the introduction of new manufacturing technology?

Follow-up question for case selection (for POCs):

8. Are there any examples of recent decisions to about a new manufacturing technology in an IPT that you can think of that might be good areas for an LAI case study? I am looking for two different IPTs in the organization that have recently (within the last few years) had to make a decision about incorporating a new manufacturing process technology in their product design. The teams should be fairly similar (same size, membership, complexity of task, etc.), and the technologies should be fairly similar (same scope of implementation, same technical complexity, etc.).

3.4 Phase II: Field Study

Phase II of the research project examined technology strategy and decision making at three major United States defense aerospace firms, based on a series of case studies (site visits, interviews, and archival data collection). As Yin [1994] comments, case study research is an especially valuable technique for investigating "a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident," allowing the researcher to cope with "the technically distinctive situation in which there will be many more variables of interest than data points" (p. 13). The case study phase of the research, therefore, serves both to situate the research questions within a broader context of complex technology decision making within the manufacturing sector and to focus attention on the organizational structures most promising for improved product development. Firms were selected as a result of the analysis of the Phase I data (see Sections 3.3.2 and 4.3.3). This section describes the research design, the type of data collected, and the anticipated results for the four case studies.

3.4.1 Case Study Methodology

The goal of the field study was to document real-world examples of IPT involvement in a technology transition initiative, focusing on the distribution, use, and impact of strategic information during the decision making process. Research trips to the firms were conducted to permit intensive on-site data collection. Interviews with technology development personnel, concentrating on those individuals involved with the transition (team members, team leaders, R&D engineers, and technology management executives), were employed as the primary means of obtaining a historical account of the process behind each stage of the technology transition and an assessment of the firm's technology strategy (formulation, distribution, and implementation) in general. A basic list of interview questions is contained in Section 3.4.2. The organizational structure (comprised of authority, information, and decision structures) of the firm and of the IPT group(s) involved in the transition process were recorded, providing more detail to the firm's Phase I information structure diagram. Interviews with engineering personnel were also conducted to develop a technical understanding of each process technology. Archival data documenting the transition process and the company technology strategy were also collected where available.

Completion of the case studies required several visits and/or telephone conference calls with each firm, including a kick-off meeting, data collection period, and review meeting. Depending on the scope of the technology, approximately one to two weeks in residence were required at each firm for on-site activity, with the bulk of analysis accomplished at M.I.T. Interviews were conducted with as many people involved with the technology transition process as possible, in the range of 20 to 30 employees depending on the size of the IPT. Interviews typically consisted of one-hour sessions with each individual, with the potential for later follow-up via telephone. Approximately 150 hours of interview time was accumulated over the course of the project. Correspondence with site personnel continued through the duration of the research effort, with particular emphasis placed on confirming observations and verifying technical information. Feedback obtained from the firm was used to refine the analysis and conclusions. Confidentiality agreements were developed jointly between the researcher and the individual firms, with most of the interaction falling within the pre-established guidelines for research within the LAI consortium. Company-specific information considered important to the study was coded to guard the identity of the particular firm. Each firm received a written report on their site and a copy of the completed doctoral dissertation.

3.4.2 Data Requirements

Specific data required to assemble the historical record of the technology transition initiative, to develop an understanding of how strategic information was used by the IPT at each participating research site, and to support the hypotheses are described below.

3.4.2.1 Questions Regarding the Technology Transition Process

Producing the historical record of the technology transition process required answers to questions such as the following.

Technical Elements:

- When was the technology first available?
- What was the source of development? (e.g., internal R&D, external development, military spill-over, etc.)
- What technical assessment of the technology was made prior to the decision to transition the technology to the production program?
- How much of a leap is this new technology in regard to the required design and manufacturing capabilities?
- What technical risk was associated with early adoption of the technology? How is this risk measured?
- What changes were made to technology development plans as a result of the decision?
- If the technology was acquired from an external source, what types of additional development were needed to make the technology suitable for use in the product?
- How did suppliers' technical capability affect the decision?
- How does the firm view itself with regards to technology leadership in this area?
- What patent protection does the firm hold in this area?

Economic Elements:

- What economic assessment of the technology was made prior to the decision to transition the technology to the production program?
- What economic risk was associated with early adoption of the technology? How is this risk measured?
- If the technology was developed internally, how much did it cost (in engineering effort, if quantitative data is unavailable and/or proprietary)?
- If the technology was acquired from an external source, what was the purchase price and format of agreement? (e.g., sale, license, etc.)

Organizational Elements:

- Who are the members of the IPT? Which functional disciplines are represented? What support organizations are represented or routinely consulted? (e.g, human resources, accounting, legal, etc.)
- Who is the team leader? What is the team leader's background (functional discipline and management level)?
- Who provided input for the technology transition process? Where do those individuals fit in the organizational hierarchy?
- What were the major steps in the process?
- How long did the technology development take?
- What kinds of difficulties did the team encounter in the process?
- What management approval was required to make the decisions to proceed to each stage of the development?
- How did the various members of the organization react to the outcome of those decisions?
- What role did suppliers or subcontractors play in the transition of the technology? How involved were suppliers in the development?

Strategic Elements:

- What is the firm's technology strategy with regard to this technology?
- What is the position of the competition with regard to this technology?
- What competitive advantage did the firm through the adoption of this technology? How is this measured?
- For which other product lines does the firm intend to use this technology?
- What market assessment of the technology was made prior to the decision to transition the technology to the production program?
- How does the market reward technology leadership in this area?
- How can the market response to the technology transition be measured?
- How can the customer perception of value be quantified in economic terms?
- What influence did the customer have in the transition process?

- How did the decision to adopt or bypass this technology fit into the firm's make/buy strategy?

Regulatory Elements:

- How did regulation or government oversight affect the cost of adopting or bypassing the technology?
- How did the need for or cost of quality certification for the new technology influence the technology transition?

3.4.2.2 Questions Regarding the Distribution of Strategic Information

The following questions were intended to provide information along the structuring dimensions described in Section 3.2.1.2. Note that the questions are very similar to those posed during the Phase I telephone interviews, although the aim for the case study project was to gather significantly more detail on the particular operation and perspectives of a single IPT. Note also that the analysis of detailed team decisions permitted by case study research allowed the addition of a seventh construct, use, describing how strategic information was implemented in IPT activities. In addition to providing the basis for construction of the firm information structures, the qualitative nature of the interview approach was used to examine the issues surrounding the research questions in greater depth. The interviews also examined how the same question was answered at different levels of the organization, for example, by asking managers how they communicate strategic information to their subordinates and then asking those same employees how strategic information is communicated to them. This technique was used to assess not just how information is sent but also how well it is received.

Existence:

- Does the firm have a strategy for the adoption of manufacturing process technologies?

Origin:

- Who develops the firm's strategic goals regarding the use of manufacturing process technology?

Content:

- What types of information are included in the technology strategy? (e.g., specific technologies to be pursued or ignored, long term vision of markets and products, R&D funding allocations, specific project directives, etc.)

Format:

- How is the firm's technology strategy communicated to you? (e.g., written memo, formal presentation, informal discussions, etc.)
- How do you communicate the technology strategy to those below you?
- How frequently does this communication take place?

- How intensively does this communication take place?

Attenuation:

- When technology strategy is communicated to you, do you ever think that certain information is being left out? What kinds of information? Why?
- When communicating the technology strategy to those below you, do you ever leave out certain information? What kinds of information? Why?
- What are the advantages to limiting the distribution of strategic information to team leaders and/or team members?
- What are the disadvantages to limiting the distribution of strategic information to team leaders and/or team members?

Source:

- Who informs IPT leaders and members of the technology strategy?

Terminus:

- Are IPT members informed directly of corporate strategic goals?

Use:

- How is strategic information used at your level? (e.g., as a general guideline for long-term goals, to set priorities across projects, to make decisions for specific projects, etc.)
- How are you directed to use the technology strategy in your work?
- How do you direct those below you to use the technology strategy in their work?
- How do you rate the level of strategic information you are provided with? Would you prefer to receive more or less?
- Has lack of strategic information ever been a problem for decision-making at your level?
- Have decisions at your level ever been overruled by management for strategic reasons?
- How would you rate the need for strategic information at the IPT level?

3.5 Analysis and Anticipated Results

Each case study includes a description of how the technology works and a historical narrative of the technology transition process. A preliminary analysis of how the firm's organizational structure impacted the process is then presented, focusing on the effectiveness of the firm's IPPD implementation and the interactions between different groups in the technology transition. Areas for possible improvement are also noted. Case studies for the three selected firms are found in Chapters 5, 6, and 7. An organizational value chain was created for each case study, and the data were used to compare how the information flow paths in the technology transition matched with the information structure of the company identified during Phase I. After analyzing the different information flow paths, conclusions were drawn about how the differences in organizational structure of the three firms impacted the role of the IPTs in carrying out the firm's technology strategy.

The primary purpose of the case study analysis is to deepen understanding of how organizational structure impacts technology decision making in teams, thereby adding to the literature of strategic information distribution and aiding industry in identifying the most important dimensions of information flow in technology transition initiatives. To this end, the compilation and analysis of a small number of technology decisions will be useful for its descriptive power rather than its ability to conclusively prove structural relationships via statistical analysis of a large sample. At the same time, specific data were collected to express the impact of different information structures on (1) the process of technology transition, (2) the creation and distribution of a technology strategy, (3) the ability of IPTs to make decisions about the adoption of new manufacturing technology, and (4) the effectiveness of the company's overall product development process. These data were used to formulate qualitative observations and to analyze the hypotheses.

For hypothesis H1, the graphical models developed to represent information structures and technology transition decision making were used to compare data from Phase I and Phase II. For each case study site, the information flow paths for technology transition and the decision points represented in the value chain matrix were overlaid on the diagram for the distribution of information about the firm's technology strategy. A visual comparison was then made between the information flow paths used to distribute information about the firm's technology strategy and those paths used in the technology transition case study (see figures in Chapter 8). In this way, an analysis was performed of how the information flow paths for strategic information, as intended by upper management, compared to the actual flow paths exercised during a specific technology transition initiative. Similarities between the two information path systems would confirm the hypothesis.

For hypothesis H2, the analysis first examined the terminus and attenuation constructs as measures of information flow to the IPT. These variables proved hard to measure accurately with the case study methodology (see Section 8.2.2), so a set of alternative assessment criteria were developed. Each case was evaluated as ranking "low," "moderate," or "high" in each of the following subjective measures of information flow, considering information directed both to and *from* the team:

- IPT access to information (technical, financial, strategic, and programmatic)
- IPT participation in development, and
- IPT participation in decision making.

Based on these measures, an overall rating of "low," "moderate," or "high" was assessed for the information flow at the IPT level in each case.

The dependent variable for this hypothesis consisted of a qualitative assessment of the effectiveness of the technology transition initiative studied in Phase II. The effectiveness of the technology transition process was based on the generally accepted benefits of the IPPD and lean manufacturing management systems [Nevins and Whitney, 1989; Womack, Jones, and Roos, 1990; Wheelwright and Clark, 1992; Ulrich and Eppinger, 1995; Womack and Jones, 1996] and on the basic principles of strategy [Hax and Majluf, 1996]. Characteristics of an effective technology transition include such relative assessments as:

- time between recognition of the innovation (Stage I) and its installation as a production-level technology (Stage VI)
- ability to meet or exceed product goals for improvements in technical performance, manufacturing quality, cost, or schedule
- level of customer satisfaction with the process
- level of team member satisfaction with the process
- ability to deal effectively with organizational conflict during the transition process[14]
- strength of relationships/coordination with suppliers of complementary technologies (perhaps with shared development where appropriate), and
- formal plan for the future use of the technology on other product lines.[15]

Each of these measures was assigned a rating of "low," "moderate," or "high."[16] These ratings were then used to generate an overall assessment of each case, labeling the effectiveness of technology transition as being either "partially effective," "effective," or "highly effective."[17]

---

[14] The criteria of "dealing with organizational conflict" reflects a desire to avoid bureaucracy, miscommunication, personal tension, strained or unconstructive debate, and negative bargaining techniques in the decision making process. Scoring well on this dimension of effectiveness does not require the absence of the constructive criticism and creative tension that can be beneficial to collaborative and/or multidisciplinary design processes.

[15] This final criterion, which will be shown to be very important in the analysis phase of this research, stems from the lean principle of "doing more with less." That is, a lean manufacturer can not afford (financially or strategically) to invest in single-use technologies that do not promote the long-term competitive position of the organization. The technology strategy of a company must therefore consider not just the current uses of a technology but future ones as well. This criterion can be thought of as a necessary component of a "strategic" technology implementation, as will be discussed in Chapter 9.

[16] Note that these characteristics describe the *outcome* of the technology transition initiative. Consideration of how IPTs can positively influence the development of the technology strategy itself, such as by providing feedback as to their technology needs during the R&D investment process, is outside the scope of this research.

[17] Note that none of the cases observed in the research can be thought of as "ineffective," in that all were ranked as high on at least three or four of the characteristics (see Chapter 8).

Hypothesis 2 predicts that firms exhibiting high information flow at the IPT level will be able to achieve highly effective technology transition initiatives, while firms with low information flow will result in only partially effective technology transition. The results of the cross-case analysis are found in Chapter 8.

CHAPTER 4 PHASE I DATA AND RESULTS

In preparation for the dissertation case study work, a quick-look survey of technology strategy practices in the aerospace industry was performed, consisting of a series of telephone interviews with executive, managers, and IPT members at the M.I.T. Lean Aerospace Initiative (LAI) consortium organizations. As described in the previous chapter, the goal of Phase I of the dissertation was to assemble a catalog of information structures for the distribution of the firm's technology strategy and to gain an understanding of the variety of information structures in use in industry, their frequency, and their variation along the different theoretical dimensions. Four different primary information structures for communicating the technology strategy to the IPT level were identified, termed the management chain, focal point linkage, focal point inclusion, and network structures, with many firms exhibiting variants of these core strategies. This chapter describes the results of three rounds of telephone interviews that led up to the selection of specific structures and firms for the case study research in Phase II. Interviews were conducted according to the interview guides found in Section 3.3.3. The chapter concludes with an introductory description of the technology transition initiatives to be studied at each case study site.

4.1 Round 1 Results

A small-scale assessment of the research questions was undertaken to examine to what extent the lack of strategic information is a problem for IPTs and to discover what kinds of information structures different firms use to coordinate information flow between those who develop technology strategy and those who need to use it in decision making at the project level. The results serve as a solid starting point for Phase I, as the three different information structures for strategic communication identified in the four initial interviews with "friendly" informants ended up being validated as the primary industry forms of information distribution during in the larger telephone survey conducted in Round 2.

In Round 1, four managers from different organizations in the defense aerospace manufacturing sector were asked to discuss their experiences and thoughts regarding the proposed study. All agreed that the relationship between IPTs and corporate technology strategy had merit as a research topic, and all admitted that their organizations had struggled with the issue of managing their manufacturing technology portfolio in recent years as the declining defense aerospace market forced reductions in discretionary funding for technology development. Having come from a tradition with enough government-backed investment to pursue virtually whatever technology was "hot" at the time, the decline in R&D funding in the late 1980s and early 1990s[1] required firms to learn how to be more selective in choosing only those technologies with the most strategic promise on which to focus their money and attention. Although the decline in defense spending has leveled off and the consolidation of the industry has by now placed the surviving firms in somewhat of a growth position, the struggle with technology management is still apparent. No company in this small survey claimed to have a best practice method for technology planning and strategic implementation, and two admitted that their organizations didn't even have what could be termed a technology strategy in the academic [e.g., Hax and Majluf, 1996] sense.[2] At the same time, all did undergo an annual R&D budgeting process, the output of which determined which technologies received development funding for the upcoming year and, in some cases, which production programs would be targeted for using those technologies in the future.

All the organizations utilize the IPT authority structure extensively for product development, concentrating on its benefits in bringing together the design and manufacturing functions early in the development effort to facilitate concurrent engineering. It is important to note, however, that the respondents felt that their difficulties in communicating strategic objectives did not change with the adoption of the IPT format; the same problems were evident under the traditional functional arrangement.

Two of the organizations exhibited the anticipated reliance on filtering management directives down the reporting chain through the team leader. Firms using this "management chain" approach developed technology plans at the corporate level and then passed these down through the management hierarchy in the form of divisional, project, and team objectives to be met in the upcoming year. Based on the interview data, a management chain information structure diagram was created to identify the seven constructual elements, as shown in Figure 4-1. (See Section 3.2.1 for a description of the structural diagramming tool.) Distribution of strategic information in this case took the form of a mission statement type document, containing the annual R&D technology plan and a multi-year strategic outlook, that was distributed to upper-level managers in a division-wide meeting at which each attendee effectively signed up to meet certain portions of the firm-wide objectives. These managers then parceled out their assigned objectives to the projects and teams below them. It is unclear whether or not these management directives contained specific

---

[1] The United States defense aerospace industry has faced a considerable decline in business over the past decade, as evidenced by the order of magnitude reduction in total aircraft procurement by the Department of Defense from more than 500 planes per year in the mid-1980s to little more 50 per year in the mid-1990s.

[2] These firms did, however, show enough evidence of technology planning activity for the "existence" construct to be categorized as positive in the Round 2 interviews.

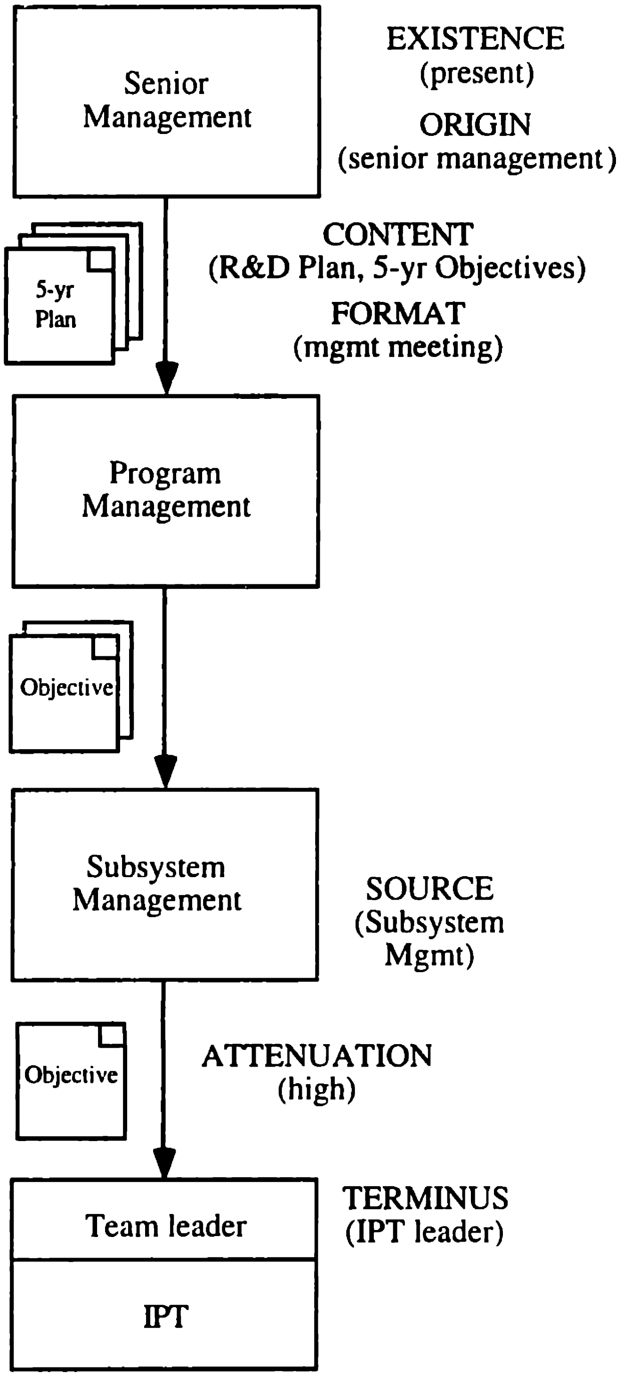

Figure 4-1. Management Chain Information Structure (from Round 1 Interviews)

information designed to help IPTs make tradeoffs in technology decision making. It does appear, however, that information attenuation is fairly high under this structure, since each organizational level received just a subset of the information available from above. The terminus of the information flow is at the team leader level, who is the final manager to accept objectives for a particular IPT.

Two different information structures were also evident. One firm, which reorganized in 1992 into an all-IPT format that eliminated all levels of management except for the president, vice presidents, team leaders, and team members, had tried using process-based teams to centralize technology adoption decisions. The process IPTs, which had responsibility for all implementation of their process technology specialty (e.g., circuit board production) across the organization, were supposed to act as a mechanism to centralize technology adoption decisions; once a new technology had been developed and adopted by one product team, the process IPT would recommend its use to subsequent projects. However, while the process IPTs were strong technically, they had no managerial authority to control or manage technology adoption across the organization. Recognizing that a more formal system was needed, last year the firm appointed an executive responsible for developing a technology road map to guide investment and a weighting system to determine the most important criteria for technology selection on individual projects. The completion of the technology road map is still in progress, but the firm in the mean time has designated a group of high performing employees across the organization (drawn from the executive level, technology process owners, and team leaders) to serve as a kind of "information elite."[3] These individuals receive regular briefings on the strategic objectives of the whole company, giving them the information they need to act as change agents in their roles. Not all team leaders are included in this group, so the information structure is not the typical management chain variety. Instead, the informed individuals are scattered throughout the organization, with the intent that their initiative as high performing employees will diffuse their knowledge of corporate technology strategy where it is needed based on their professional contacts. This information structure represents a "network" approach to the distribution of strategic information, since it relies on personal contact with the information elite members to spread knowledge of the strategy throughout the organization. The network information structure diagram is shown in Figure 4-2.

Another method of disseminating strategic information, termed the "R&D inclusion" format, is to include R&D personnel as IPT members, as shown in the information structure diagram in Figure 4-3. The firm that espouses this format begins with the typical executive level development of the R&D investment plan but then relies on an intermediary process development group to insert new manufacturing technologies into product programs. Members of this group rotate between working

---

[3] The term "information elite" was fabricated by the researcher to disguise the identity of the organization and is not the real name of the group.

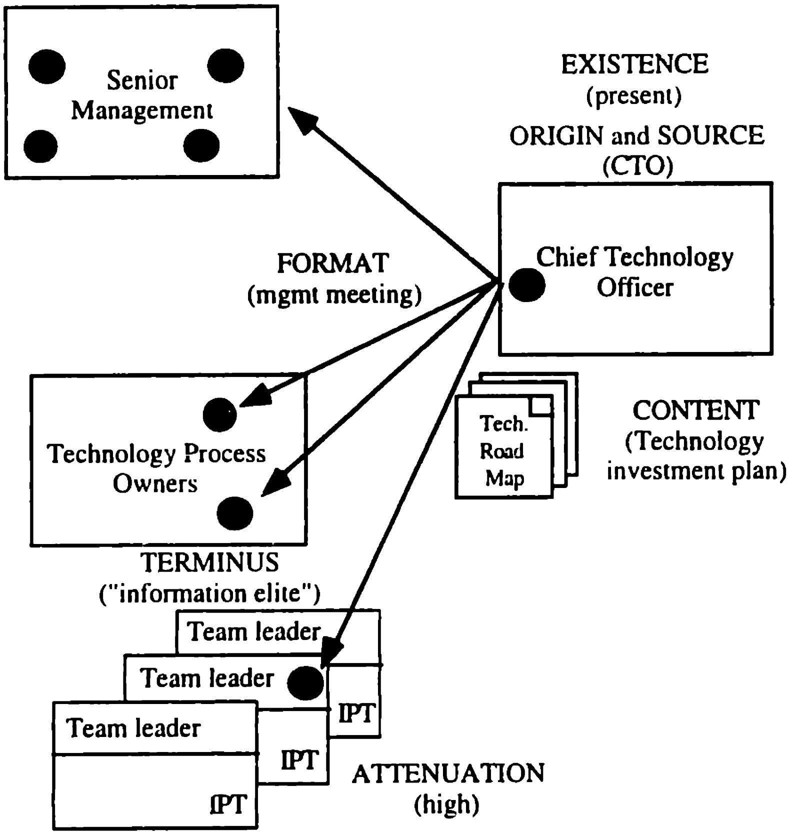

Figure 4-2. Network Information Structure (from Round 1 Interviews)

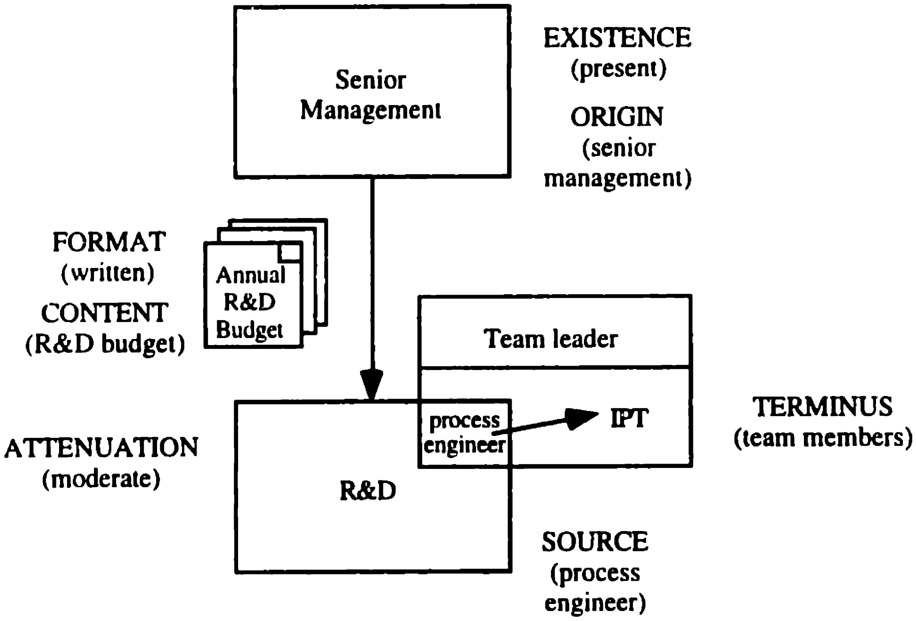

Figure 4-3. R&D Inclusion Information Structure (from Round 1 Interviews)

on in-house development activity and being assigned to IPTs. These individuals are supposedly familiar with the firm's strategic objectives through their observations of the funding profile of the R&D function. When their particular technology is needed on a product program, their reporting responsibility is transferred to that product team, so that they bring with them information on how the company prioritizes technology decision making and act as the source of information to the IPT. When the product development effort is finished, they return to the R&D area to work on new technology development and to maintain their technical specialization. In this arrangement, the terminus of information flow resides within the IPT. However, attenuation may be high, since R&D engineers may not have enough of an understanding of competitive dynamics or business requirements to communicate more than the just technical details of the strategy to the team level.

In conclusion, the Round 1 interviews showed promising evidence that the research topic has value to industry, especially in meeting their desire to learn how to maintain balance between development and production activity and how to integrate IPTs into front-end business activity like technology planning. In addition, the brief discussions identified two other structuring techniques, namely the "network" and "R&D inclusion" approaches, in addition to the anticipated "management chain" information structure, that represented alternative methods of how best to communicate strategic information to product development teams.

4.2 Round 2 Results

The Round 2 interviews consisted of a more systematic look at each of the 18 LAI member organizations that agreed to participate in telephone interviews. Discussions with the firm's LAI point of contact (POC) followed the interview guide in Section 3.3.3.2. The resulting information was compiled by the researcher in order to populate a database of constructs for each firm, as shown in Tables 4-1 to 4-6. A description of the strategic information flow path and the assigned information structure classifications are summarized in Tables 4-7 and 4-8. Company-specific information has been coded to guard the confidentiality of the firms. The results begin with a continuation of Klein and Sussman's [1995] work on an aerospace industry profile of IPT implementation. An analysis of the results for each of the seven constructs is provided below, along with a discussion of how the information structure classifications were assigned and a description of the final catalog of information structures. A brief presentation of the measures companies use to evaluate the performance of their IPTs is also included as a precursor to later evaluation of the case study teams.

4.2.1 IPT Industry Profile

The aerospace industry seems to be extremely "pro-IPT," as demonstrated by the 16 out of 18 company executives who responded that they used IPTs extensively for their new product development.[4] Of these, 7 firms claimed to use the IPT approach almost exclusively, with one firm having switched recently to a nearly all-IPT format (i.e., the only job titles are president/vice president, team leader, and team member). Companies varied as to when the IPT took over the product development project: a few teams performed both the proposal and program phases, but most were convened after another group or marketing function had performed the concept development. Overall, the results confirmed the status of the IPT organizational format as the current industry standard.

As expected, core IPT membership centered around the design and manufacturing engineering functions, with most firms citing additional input from program management and marketing/sales. About one-third of the companies had cost accounting or finance members on their teams as dedicated members, with most of the others accessing an external finance department as a support function. One firm did not rely on direct links to a financial group. Instead, an engineer on each team had been trained as a "cost account manager" and was subsequently designated to monitor cost and schedule adherence on their team as their secondary function. All teams included an IPT leader.

Respondents were quick to point out that membership on the IPT varied with both the type and complexity of the product and the stage of development. This was especially apparent in the variety of engineering subspecialties considered routine at firms with different aerospace product lines (e.g., circuit board design at the avionics companies, weight analysis at the airframe companies, heat transfer at the engine companies). Suppliers were regularly involved on the IPTs at only one of the 18 firms, indicating that this interaction mode for lean supply chain management has yet to be implemented to any extent in the industry.[5]

---

[4] As for the other two firms, one was in the process of implementing concurrent engineering and had just formed their first team. The remaining firm is a build-to-print supplier that does not do any on-site product development activity but has their manufacturing engineers participate on customers' design IPTs so that the firm can influence the development of "manufacturing-friendly" designs.

[5] Note that due to the limited questioning in the interviews and the restriction of only one respondent per site means that this assessment may not be a definitive indication of the extent of the practice in the industry. It is certainly true that manufacturing firms have become more interested in technology supply-chain management over the past few years. Perhaps the research results indicate a delay between interest in a practice at the corporate policy-setting level and its implementation on the design teams.

4.2.2 Existence

As shown in Table 4-1, fifteen of the eighteen firms in the sample were judged to have some semblance of a technology strategy for their manufacturing processes, based on evidence of technology planning activity such as the preparation of an R&D technical and/or financial evaluation. A process technology strategy was deemed absent from two firms, one that was a build-to-print facility that was not involved with new product development and the other that was still in the reorganizational throes of a buy-out (but did have plans in progress to do a process technology evaluation eventually). The interview results from the remaining firm were inconclusive: the company, which was primarily involved in the design of electronics for space satellite systems, placed very little emphasis on manufacturing technology due to its low production volume, with the interview subject stating, "You can always find a way to build something once." While the firm did invest strategic planning resources on the development of new design technology, this activity appeared to be almost exclusively devoted to product, not process, technology, and therefore was not relevant to the evaluation of the existence construct. In summary, although all of the interviews were highly informative, even in the cases where a technology strategy was absent, complete data sets and information structure classifications were composed of a total of fifteen organizations. Information gathered from the other three firms is included where it exists in the data summary tables below but is italicized to indicate that it was not used in the aggregate analyses.

4.2.3 Origin

As expected, creation of the technology strategy proved to be almost exclusively the domain of upper layers of management, with 12 of 15 respondents replying that corporate or division management was responsible for the generation of the firm's strategic planning for new manufacturing technology investment (see Table 4-2). Additional input from technical specialists was cited in the majority of these cases, such that management typically relied on feedback from the R&D group or project engineers in setting the company's technology priorities. In several cases, the development of the technology strategy included the designation or identification of "technology champions," contact personnel who were either experts in the innovative area or promoters of its application in the company. Extending this technical link in the organization, the three remaining firms seemed to perform their technology planning activities somewhat lower down the management hierarchy, with the origin of the technology strategy being cited as an engineering function performed by managers in the R&D or manufacturing engineering groups.

Table 4-1. Round 2 Interview Data: Existence Construct

Organization	Response: EXISTENCE
1.	Present
2.	Present
3.	Present
4.	Present
5.	Present
6.	Present
7.	Present
8.	Present
9.	Present
10.	Present
11.	Present
12.	Present
13.	Present
14.	Present (in progress)
15.	Present
16.	Absent (no product development done at this site (build-to-print facility))
17.	Uncertain (detailed planning may only be for design technology, not manufacturing technology)
18.	Absent (in progress)

Table 4-2. Round 2 Interview Data: Origin Construct

Organization	Response: ORIGIN	With Input From:
1.	Vice President of Engineering	Technology counsel
2.	Engineering committee	Sales
3.	Corporate level business strategy team	-
4.	Company management	Manufacturing; product programs; R&D
5.	Upper management	Technical specialists
6.	Division director	Technology planning IPTs
7.	Vice President of R&D	R&D engineers
8.	Manufacturing engineering management	Manufacturing and process engineering group
9.	Corporate management	Corporate R&D laboratories
10.	R&D group	Programs
11.	Corporate management	R&D engineers
12.	Division executive management	-
13.	Vice President of production operations and Vice President of technical operations	-
14.	Chief Technology Officer	Technology representatives
15.	Corporate management	Process technology champions
16.	*N/A*[6]	-
17.	*Division director*	*Marketing*
18.	*(will be done by) Engineering*	-

---

[6] Entries for organizations #16, 17, and 18 are italicized to indicate that the data was not used in the Phase I aggregate analysis, since those organizations were judged to have an absent or uncertain technology strategy.

4.2.4 Content

While none of the firms seemed to undertake as extensive a technology planning function as advocated by academicians like Hax and Majluf, there was evidence of a common standard of content. As shown in Table 4-3, the technology strategy was consistently described by the interview subjects as either an R&D funding plan or a technology "roadmap," in both cases involving the annual determination of which manufacturing technologies should be pursued and how much financial resources would be allocated. One respondent described how this task was co-managed at his firm by the vice president of production operations, who set discretionary R&D funding levels, and the vice president of technical operations, who prioritized the technologies. This example reinforces the impression that strategy is generated at the corporate level, as previously noted in the analysis of the origin construct.

Three of the firms also cited an analysis of the financial metrics, in terms of return on investment and profit calculations, that their business unit would be required to deliver to the corporate organization. A few firms noted the connection of their technology planning activity to their marketing requirements, describing their efforts to link development efforts with customer demand and to identify technology that would advance their search for the "needs, uses, and products of the future." Finally, one firm appeared to place more emphasis on the insertion of new applications than on analytical research, with the bulk of their technology planning devoted to the determinations of capital equipment appropriations.

4.2.5 Format

As in the case of the content construct, a definite standard format was observed, with all firms identifying the primary embodiment of the technology strategy to be a written document (see Table 4-4). This finding was as expected, since firms that receive public funds for defense R&D (as most aerospace companies do) are required to submit a written proposal to the government. In addition, two of the firms mentioned disseminating information through management briefings or meetings, and one other described an annual company-wide technology forum at which engineers could hear presentations on new process development by the R&D group. Two firms were also noted to employ more modern means of information distribution: one distributed monthly video tapes of manufacturing "success stories"; the other has set up an electronic "intranet" with "technology home pages" that engineers can access to learn about new technology development, current and future applications, and, most importantly, whom to contact for more information.

Table 4-3. Round 2 Interview Data: Content Construct

Organization	Response: CONTENT
1.	Technology roadmap and funding plan
2.	Marketing requirements survey; feasibility/concept analysis; plans for prototypes
3.	R&D funding plan: needs, uses, and products of the future
4.	R&D funding plan
5.	"Maturity path assessment": core technical competencies, next steps to maintain competitive advantage
6.	Technology wish list and budget
7.	R&D funding plan: ranking of production programs by importance; roadmaps for development time horizons
8.	R&D funding plan: projected investment, ROI, impact on federal environmental requirements
9.	Analysis of technology maturity versus customer demand over time
10.	Projected return on investment (ROI) and funding requirements
11.	R&D funding plan
12.	Appropriations requests: specific machinery, programs, and process changes
13.	Technology "roadmaps" and requirements (long-range plan of desired people, skills, and investment); corporate deliverables (profit/cash flow)
14.	Technology roadmap to guide investment
15.	R&D funding plan: specific technologies, timing, investment
16.	*N/A*[7]
17.	*R&D funding plan*
18.	*(will consist of) R&D funding plan*

---

[7] Entries for organizations #16, 17, and 18 are italicized to indicate that the data was not used in the Phase I aggregate analysis, since those organizations were judged to have an absent or uncertain technology strategy.

Table 4-4. Round 2 Interview Data: Format Construct

Organization	Response: FORMAT
1.	Written
2.	Written
3.	Written; electronic intranet technology home pages; open forum technology reviews
4.	Written
5.	Written
6.	Written; electronic intranet planned
7.	Written
8.	Written
9.	Written
10.	Written; monthly "success story" videos
11.	Written (R&D funding plan and technology "brochures")
12.	Written; briefings
13.	Written
14.	Briefings to "information elite"
15.	Written
16.	*N/A*[8]
17.	*Written*
18.	*(will be) Written*

---

[8] Entries for organizations #16, 17, and 18 are italicized to indicate that the data was not used in the Phase I aggregate analysis, since those organizations were judged to have an absent or uncertain technology strategy.

4.2.6 Attenuation

Several of the constructs were not as simple to capture through a single telephone conversation as had been anticipated during the design of the project. The attenuation construct in particular proved extremely difficult to determine through the interview methodology, since the POCs were not able to give accurate representations of what information was being received at other locations in the organizational hierarchy. In addition, interviewees are obviously incapable of determining whether information has been attenuated at a point above them in the hierarchy, although it is hoped that the extent of this circumstance was mitigated by selecting interview subjects who hold upper management positions.

As a result of these methodological difficulties, the researcher had to rely in some cases on the description of the information flow path to infer what level of attenuation (high, moderate, or low) might be present. This treatment of the attenuation construct as more of a dependent variable to the information structure obviously renders it less useful for analysis than the other constructs determined solely through the interview responses themselves. Accordingly, discussion of the attenuation variable is undertaken at this point only for informative reasons, not as any determination of next steps in the research. The case study format used in Phase II proved much more conducive to analysis of information loss at different levels in the hierarchy, due to the ability to interview people across the organization at length and to have access to the various written materials that they receive (i.e., archival evidence of what information is passed across organizational groups, levels, or positions). A more detailed assessment of the usefulness of attenuation as a measure of strategic information flow is therefore included with the case study analysis in Chapter 8.

A few of the respondents, however, were better able to convey a sense of how the upper managers in the organization regarded the dissemination of information about the technology strategy. Aside from the structural mechanism by which information flows though an organization, a wide variety of behavior was observed in terms of the *extent* to which information about technology and product plans is distributed across different levels of the company. In particular, six of the interview subjects were quite articulate on the question, with three describing organizational environments with high attenuation and three describing low attenuation. (These interview responses are marked with asterisks in Table 4-5 to distinguish them from the less reliable responses inferred from flow path descriptions.) Respondents from the high attenuation firms declared that their technology roadmaps were "very sensitive" documents, to be kept proprietary from not only competitors but also most of the individuals in the organization. At one of these companies, less than a dozen managers in the upper reaches of the organization had access to the

Table 4-5. Round 2 Interview Data: Attenuation Construct[9]

Organization	Response: ATTENUATION
1.	*High: IPT gets information only on their specific component; technology roadmap document considered highly sensitive[10]
2.	Moderate
3.	Moderate: getting information requires proactive search on the part of team members (via accessing the intranet or by going to technology forums)
4.	Moderate
5.	*Low: technology plan "shared openly" across levels
6.	*Low: access open to everyone; try to interlock project and R&D work so that "everyone knows what's going on"
7.	High: designers don't know the details of the technology plans until they reach implementation
8.	High: no formal communication of technology planning across process cells
9.	Moderate
10.	High: each level receives only a subset of the overall objectives; strategic objectives are "transparent" to team
11.	*High: teams "have a very narrow look through the system"
12.	Moderate: designers get information from written documents and from program-targeted briefings
13.	*Low: "The top level isn't enough alone; you need to understand specific parts" in order for the company plan to make sense
14.	Moderate: depends on informal networking with the information elite
15.	*High: IPT members working on a single component "don't need whole picture"
16.	*N/A*[11]
17.	*Uncertain: probably very high*
18.	*Data not yet available*

---

[9] Included for informational purposes only. Due to difficulties in accurately capturing the attenuation level with a single interview, some of the data assignments have been inferred from responses to other questions. The usefulness of this variable has been explored with more detail in Phase II.

[10] Responses marked with an asterisk (*) indicate subjects who were more articulate on the question and therefore produced more reliable accounts of the level of attenuation present in their organizations.

[11] Entries for organizations #16, 17, and 18 are italicized to indicate that the data was not used in the Phase I aggregate analysis, since those organizations were judged to have an absent or uncertain technology strategy.

strategic plans for market and product forecasts and new technology development. The interview subjects indicated that their primary planning material was too broad for use by lower level project engineers, declaring that there was "almost too much information for an individual" to have a direct link to the whole document and that IPT members working on a subsystem of a product "don't need the whole picture." In all three cases, the IPTs received only the subset of information from the technology plan that concerned their particular component. As one respondent stated, teams at these high attenuation organizations "have a very narrow look through the system."

A markedly different attitude was present in the other three cases of observable low attenuation. Here, the interviewees described their companies as being very open in sharing information across the organization, with the intent of motivating individuals to commit to their portion of the company plan in order to "seek ownership throughout the enterprise." Although these firms also broke down the goals of their technology plans into project, team, and individual objectives, they did so with the understanding that all information must be provided within the context of the broader organizational mission. As one interviewee remarked, "The top level isn't enough alone; you need to understand specific parts [in order for the company plan to make sense]." In this way, knowledge of the corporate goals extended further down into the organizational hierarchy, and information attenuation was judged to be lower than in the previous cases of firms who restricted access to the technology strategy to upper management.

Overall, even with the limited availability of reliable data for the attenuation construct, a top-level look at the firms examined in Phase I shows that there is most likely a wide variety of behavior in terms of the extent to which information is distributed across an organization. The three categories of high, moderate, and low attenuation were represented roughly equally, indicating that there is no single dominant practice in the industry and that the attenuation construct could prove an interesting component of structural determination. As a result of the interview research, the Phase II study was accordingly designed to provide further detail on the distribution of information across organizational levels.

4.2.7 Source and Terminus

The final two constructs were found to exhibit the most variation across different organizations, as can be seen in Table 4-6. These constructs represent the final segment in the path of information flow through the organization, determining which group is the final recipient of strategic information from the technology strategy (defined in Chapter 3 as the terminus) and from whom they receive it (the source). Managers in the R&D group were identified as the source in one-third of the organizations, suggesting that the R&D group can play a critical organizational role in the

Table 4-6. Round 2 Interview Data: Source and Terminus Constructs

Organization	Response: SOURCE	Response: TERMINUS
1.	Product managers	IPT leader
2.	R&D group	Product groups
3.	Business strategy management and R&D group	IPT members
4.	Program management	Subset of IPT engineers
5.	Project leader who implements the technology	IPT members
6.	R&D manager	IPT members (via manufacturing center representative on team)
7.	Materials and process development managers	IPT members (via R&D engineer on team)
8.	Manufacturing and process engineering group	Unclear: probably subset of manufacturing engineers
9.	Product marketing manager	IPT members (via product marketing representative on team)
10.	R&D group	Subset of IPT members who have participated on technology transition teams with the R&D group
11.	R&D group	Subset of engineers
12.	Operations functional manager	IPT members
13.	IPT leader	IPT members
14.	Chief Technology Officer	Subset of IPT leaders
15.	Department manager	IPT members (via technologist on team)
16.	*N/A*[12]	*N/A*
17.	*R&D manager*	*R&D member associated with the product line*
18.	*Data not yet available*	*Data not yet available*

---

[12] Entries for organizations #16, 17, and 18 are italicized to indicate that the data was not used in the Phase I aggregate analysis, since those organizations were judged to have an absent or uncertain technology strategy.

distribution of information about new technology to the manufacturing project community. The R&D/product development link was manifested with various degrees of formality in the surveyed companies, from the mass distribution of "brochures" describing new process applications to regular one-on-one meetings between R&D managers and project managers to discuss opportunities for new technology insertion. Apart from the R&D group, several other managerial functions were found in the source role, including those from manufacturing, the corporate level, or the product development program itself. Other departments also provided the information link to the IPT level, including marketing and business strategy.

In some cases, representatives from groups external to the IPT (such as R&D or marketing) were found to serve as actual members of the team, providing a peer reference link between their group and the IPT engineers. The terminus of strategic information in these situations was considered to be at the IPT team member level, a coding that occurred in 8 of the 15 interviews. Since the close working relationship found in the IPT arrangement promotes open sharing of knowledge among team members, those in the source group are likely to transfer information concerning new technology adoption to the rest of the team. Thus a terminus of all "IPT members" was determined to hold in cases where external group members with special knowledge of the technology strategy (emanating, for instance, from their primary affiliation in the R&D group) resided physically and organizationally within the IPT. Where team members had looser relationships with external knowledge-holding groups, such as when manufacturing engineers had participated in a technology transition initiative on a past assignment, the terminus was judged to extend to only a subset of the IPT members, since there was no direct and contemporary exchange of knowledge. This arrangement was observed at three other research sites.

In situations where the external group was linked to the IPT indirectly via management relationships or more impersonal contact (e.g., technology briefings, brochures), then the terminus was coded as residing higher in the organization, at the IPT leader or product management level. Three of these cases were seen in the interviewed companies, including one unique instance in which the terminus of direct information varied with informal contact. Described in the Round 1 interview results as the network model, this organization held regular gatherings of a subset of managers and team leaders (the "information elite"), who then were expected to disseminate information about the company strategy to the individuals and teams they worked with. Not all IPT leaders in the company were members of the information elite, so the case was coded as having a terminus of a subset of IPT leaders, with possible extension to the IPT depending on their managerial relationship to the project engineers. In the remaining organization, the terminus appeared to be at the manufacturing management level, outside the IPT, although more data are required for this assessment to be certain. The following section provides a more complete analysis of the relationships seen between IPTs and functional or managerial groups and discusses the various structural arrangements that were observed to result.

4.2.8 Information Structure Classifications

The data from the interviews were analyzed to determine the general patterns of information flow and to identify the means by which the firm's technology strategy was distributed between the corporate management, project management, the R&D group, and the IPT. The constructs for each firm were compared to search for common patterns, distribution methods, and managerial approaches across the industry. As noted earlier, three firms from the original 18 could not be classified due to a lack of available data. In the remaining firms, four distinct types of information distribution were identified and were termed the management chain, focal point linkage, focal point inclusion, and network information structures. Although many slight variations existed, all but one of the classified firms appeared to fit into a single predominant grouping. The remaining organization exhibited characteristics from two different information structures (management chain and focal point) and was therefore classified as a combination information structure. A description of the informational flow path for each firm is found in Table 4-7, along with each firm's information structure designation. Table 4-8 contains a summary of the Round 2 research, listing the number of firms assigned to each category. Figure 4-4 contains the catalog of information structure diagrams, showing the information and hierarchical links between groups.

The management chain information structure first identified in the Round 1 interviews was found to be the predominant information structure in the expanded Round 2 research, with 7 of the 15 classified firms falling into this category. As described in Section 4.1 above, firms with this information structure rely on the authority structure as the main information flow path through the various organizational levels, using supervisor-subordinate links to govern relationships between the groups involved in the various stages of product development. As described in the results from Round 1, a typical management chain information structure involves passing down information about the company's technology strategy, generated by upper management, to employees via their job instructions. Information might also be passed via the mass distribution of technology planning documents (such as R&D project updates or a technology handbook) to the employees in the organization. Another example of a management chain information structure is the case where a technical breakthrough implemented in one manufacturing cell is communicated to other product areas that utilize the same process by way of a common manager. Here, the flow path is bi-directional: engineers in the innovating group report their success to their immediate supervisor,

Table 4-7. Round 2 Interview Data: Flow Path and Information Structure Classification

Organization	Information Flow Path	Information Structure Classification
1.	Management hierarchy governs information flow; IPT engineers also come into contact with R&D engineers when lab needs current model parts or access to process equipment	Management chain
2.	Technology reviews: "R&D boys do a 'dog and pony' for the product groups"	Focal point linkage (via R&D)
3.	Informal network of resources	Management chain
4.	"Good ol' boy network" and some transfer of people from program to program	Management chain
5.	Technology planning document distributed across sector; technical breakthroughs in one product cell passed on to other cells via common manager of the cells' part family	Management chain
6.	Program managers become technology sponsors; manufacturing Centers of Excellence develop technology standards	Focal point inclusion (via manufacturing centers)
7.	R&D engineers and project engineers transition between the two areas; "affordability room" set up in R&D prototype center to demonstrate value of new technologies; production program representatives serve on R&D IPTs	Focal point inclusion (via R&D engineer)
8.	Historically new technology information conveyed via producibility function but have problems with engineers not understanding more than one process; "we need to work on this"	Focal point linkage (via manufacturing engineering)
9.	Product marketing representative on product team	Focal point inclusion (via product marketing)
10.	Published book of technology plan given to every engineer and customer; monthly videos of manufacturing success stories goes to every site for distribution	Combination of management chain and Focal point linkage (via R&D)
11.	R&D "brochures" for each technology area distributed to all engineers; informal networking between colleagues on different projects	Management chain
12.	Operations functional manager briefs IPT leaders and designers on how to incorporate new technologies	Focal point linkage (via manufacturing operations)
13.	Goals broken down by mission or functional area, then product line, then teams, then individual; "seek ownership throughout the enterprise"	Management chain

Table 4-7 (CONTINUED). Round 2 Interview Data: Flow Path and Information Structure Classification

14.	Network diffusion via informal contact with the "information elite"	Network
15.	"Bottom-up and top-down" communication between management levels	Management chain
16.	*N/A*[13]	*No classification (no technology strategy and no IPTs)*
17.	*R&D receives funding plan but no evidence of distribution outside their group*	*Not enough data to classify (firm only does design technology planning)*
18.	*Data not yet available (plan on having line workers work on multiple projects so they can transfer new technologies between products)*	*Not enough data to classify (reorganization in progress)*

Table 4-8. Information Structure Classification Summary

Information Structure	**# of Organizations**	**Subtypes**
Management chain	7	none
Focal point	6	Linkage (3): • via R&D group • via manufacturing operations • via manufacturing engineering Inclusion (3): • via R&D group • via product marketing • via manufacturing
Network	1	none
Combination (Management chain and Focal point linkage)	1	• linkage via R&D group
Not enough data to classify	3	none

---

[13] Entries for organizations #16, 17, and 18 are italicized to indicate that the data was not used in the Phase I aggregate analysis, since those organizations were judged to have an absent or uncertain technology strategy.

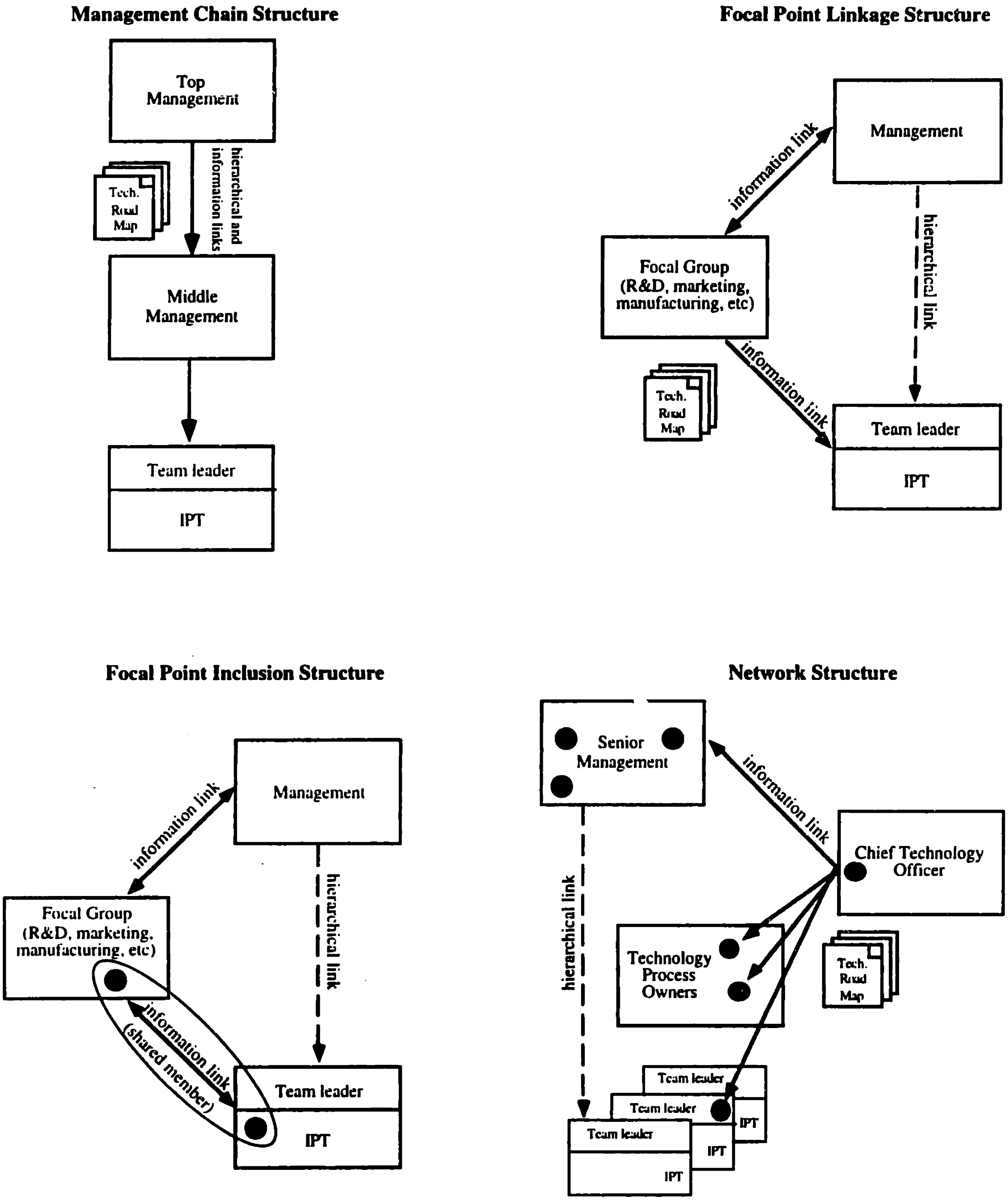

Figure 4-4. Phase I Catalog of Information Structure Diagrams
[Solid arrows show information links, dashed arrows show hierarchical links, and bold arrows show joint hierarchical and information links.]who then instructs the other product areas under his command to implement the new process in their own area.

The focal point framework proved to be the second most popular structural format, with six firms falling into this classification. Unlike the management chain information structure, firms operating under the focal point organization do not use supervisor reporting relationships as the primary information flow path. Instead, these information structures involved the transmission of information to the IPT from a group other than the supervising management level. Two subtype information structures were identified within the classification – focal point linkage and focal point inclusion. Three firms were identified as having a "linkage" relationship, such that the IPT had contact with a group external to the team, such as R&D or marketing, who provided the team members with information about the technology strategy. In the three other firms, termed "inclusion" structures, information reached the IPT via an individual who was simultaneously a member of an external group *and* a member of the IPT itself, providing a peer reference link between their group and the IPT engineers. Since the close working relationship found in the IPT arrangement promotes open sharing of knowledge among team members, those IPT members who also belonged to other groups are likely to transfer to the team information they learn from their other affiliation. Looser relationships with external knowledge-holding groups were also possible, such as when manufacturing engineers had participated in a technology transition initiative on a past assignment.

In both of these categories, as outlined in the discussion of the source construct in Section 4.2.7, it is the relationship between the IPT and some external information-holding group that forms the contact link for the transmission of information about the technology strategy. As Table 4-8 reveals, this external group varied depending on the firm. Managers in the R&D group were identified as the source of information to team members in one-third of the focal point organizations, suggesting that the R&D group can play a critical organizational role in the distribution of information about new technology to the manufacturing project community. The R&D/product development link was manifested with various degrees of formality in the surveyed companies, from the mass distribution of "brochures" describing new process applications to intranet home pages providing updates on technology development to regular one-on-one meetings between R&D managers and project managers to discuss opportunities for new technology insertion. Apart from the R&D group, several other managerial functions were found in an information sourcing role, including managers from manufacturing (either via manufacturing engineering or factory floor operations), marketing, and business strategy.[14]

---

[14] Note that the firm from Round 1 previously classified as an "R&D inclusion" information structure was deemed in the broader Round 2 survey to be merely a variant of the focal point inclusion information structure. The term "R&D inclusion" was therefore dropped in favor of the more encompassing "focal point" classification.

As for the remaining firm, the network information structure identified at one firm during Round 1 of the interviews (see section 4.1) was not found in any other organization during the subsequent Round 2 interviews. However, its organizational characteristics were deemed unique enough to warrant its designation as a distinct classification. The network firm was therefore included in the Round 3 interviews to allow for further study across the organizational levels. As described above, the distribution of information concerning the technology strategy in this company revolved around the working relationships of a group of high performing individuals here termed the "information elite." This group met regularly to be briefed on the company's technology development plan and progress, and the members were expected to then spread this information through the organization based on their individual professional contacts.

As suggested in Dougherty's [1992a] "council of elders" metaphor for strategic organization, the network information structure relies on knowledgeable and well respected individuals to consider how new product development projects contribute to the firm's strategic position. The terminus of this information structure resides with the information elite who are located at various levels but not at the IPT member level. Attenuation is unknown, but probably high, since contact between the IPT members and the information elite does not consist of the transmission of formally written information but depends instead on chance personal contact via informal conversations. This type of intentional network distribution should be distinguished from cases where the interview respondents described informal contact between people who had previously worked together, often cited as "the good ol' boy network," as a means of information distribution. Such unstructured interactions between co-workers are likely to occur in any firm and to have similar effects on communication patterns. Informal contact or the company "grapevine" was therefore not considered to be a distinguishing characteristic of an information structure, although it may indeed be a very important element in how information is diffused in the organization.

4.2.9 Measures of IPT Effectiveness

In order for managers to be convinced of the benefits of the IPT approach, they must be able to measure its effectiveness. According to Hackman and Morris [1975], group effectiveness is defined by three characteristics: group performance, satisfaction of group member needs, and the ability of the group to exist over time. Most firms tend to concentrate on the first element by tracking the IPT's performance relative to pre-established targets for cost, schedule, and quality. At the same time, more and more firms are starting to take into account the latter two characteristics when evaluating how well the integrated product development concept has been implemented in their organization. These types of measurements place more emphasis on the *process* of the IPT instead of just on the resultant product. Such an emphasis can lead to significant organizational rewards. For example, Gladstein's [1984] study of task group effectiveness showed that only market growth and organizational tenure, *not* group processes, could predict sales revenue for the company. However, the research also indicated that teams with well-established intragroup processes, sufficient training, and strong leadership tended to rate themselves higher on group effectiveness. Organizational factors thus improved the *self-reported* group effectiveness and consequently their personal satisfaction and desire to remain on the team.

The firms contacted in the telephone interviews consistently voiced their difficulties in establishing adequate methods for evaluating IPT performance. While targets can be set for cost, schedule, and performance/quality, they often change over the lifetime of the project as requirements or programmatic factors evolve, making it hard to determine how well the targets were achieved over time. Mangers can also have difficulty comparing teams, since targets might vary in how strict or challenging they are. The matrix organization itself brings with it several challenges associated with evaluating the performance of individual team members. Most of the firms studied still align their reward system along functional boundaries. Team leaders may provide input to the performance review, but often this step is divorced from the individual financial appraisals performed within each functional discipline. Since a team contains members from many different functions, a team leader would have to participate in multiple function-based review meetings in order to provide input on every worker in the project-function matrix. At the same time, since IPTs are often co-located geographically distant from the functional "home room," team members may feel that their functional supervisor has little knowledge of how well they are performing their day-to-day activities with the team.

Overall, this preliminary research effort demonstrates that the aerospace industry has not yet adequately addressed the critical question of how to evaluate team effectiveness to any sufficient extent. The best answer to date seems to be that, while one can't directly measure IPT success, "associated indicators" can be used to see how well a particular team is achieving the benefits associated with integrated product development. For example, in general, compared to a poorly-performing team or to a traditional functional organization, a team that is operating effectively should produce a design with fewer drawing changes after release, easier assembly ("parts go together better"), and fewer rejects. Apart from this abstract sense of the characteristics that should accompany good product development, most of the companies shared a similar, albeit rudimentary, strategy to deal with the challenges of evaluating team performance: teams as a unit are measured on their "output metrics," and individuals are jointly evaluated by their functional manager and their team leader. Team metrics include targets in areas such as:

- Cost: development cost, manufacturing unit cost, return on investment
- Schedule: adherence to delivery schedule, lead time reduction
- Performance/Quality: number of design changes, process capability, scrap-rework-and repair rate.

As for determining how to set these targets fairly across teams, most companies honestly admitted that they are unable to set consistent goals due to varying design complexity and technical difficulty.[15]

In most cases, rewards are individually-based; if team members demonstrate technical competence and work well on the team, then they receive individualized salary compensation. However, a few of the companies were starting to consider that, since the IPT members worked as a team, they should be rewarded as a team. In one firm, managers can grant awards of up to $1,000 per team member if the IPT has shown outstanding effort in meeting corporate business goals. More often team rewards consist of small morale-boosting recognition (rather than significant monetary bonuses) for teams that do well, such as treating the team to lunch at a local restaurant when they meet a quality goal.

One interview subject described a significantly different strategy for performance appraisals that bears mention. Although team members are still evaluated on an individual basis, that evaluation is much more comprehensive and team-oriented than those described in other firms. Here, the company has created a development grid of core competencies that the firm believes are critical for competitive success as a high-tech design house. These include program management ability, process/technology competence, industry recognition, and mentoring skills. Each individual is ranked in each competence according to very well defined criteria that indicate skill level in that area, from foundation to mastery. Financial compensation is based on the individual's position across competencies. For example, a team member who is ranked consistently above average in all competencies may be paid more than one who excels in a single technical discipline but is not contributing to team and corporate goals in the other areas. The development grid is used exclusively to set compensation levels, without any consideration of varying employment tenure.

4.3 Round 3 Results

The final round of telephone interviews consisted of follow-up calls to the most promising case study candidates to verify the main characteristics of the firm's information structure and to obtain

---

[15] On the other hand, one company stated that their proposal generation process is so rigorous that all teams start off equally with a consistent product development challenge and accurate targets, such that any variation in the ability to achieve the initial goals is due to team inefficiency. The author considers this a rather optimistic view.

more information on the distribution of the technology strategy in the organization. Six firms were chosen from the original eighteen to be first- and second-choice examples of the management chain, focal point, and network information structures.[16] These choices were based on impressions of the representativeness of the firm in exhibiting the structural characteristics and the willingness of the contact personnel to provide access for case study analyses. For each of these firms, the POC was questioned about the formulation and distribution of the firm's technology strategy in order to verify that the assigned information structure representation was correct. Additional interviews were also conducted with engineers and managers from the R&D and product program (i.e., IPT) areas to see how perceptions of information distribution varied across the organization and to assess the organizational interactions between the different groups responsible for strategy generation, technology development (R&D), and the product programs. (See interview question guide in Section 3.3.3.3.) Based on these interviews, the information structure assignments were refined (see Section 4.3.1), and the three of the first-choice firms were selected as final case study sites (see Section 4.4).[17] The researcher then worked in conjunction with the industry POC and the appropriate technical personnel at each company to identify an interesting technology adoption decision to be studied in Phase II. Results of the Round 3 interviews are given below.

4.3.1 Structure Verification and Refinement

Based on the follow-up interviews with company engineers and managers, each of the most promising firms was verified as exhibiting characteristics of the assigned information structure, but some refinements to the information structure categorizations were necessary. The four main information structure classifications identified in the earlier rounds were still deemed valid as a theoretical means to distinguish paths of information flow. However, upon more thorough examination through multiple interviews at each site, several of the Round 3 firms appeared to include characteristics of a secondary information structure. For example, one firm had initially been classified as using the management chain approach due to their practice of flowing strategic objectives down through the reporting hierarchy (as described by the vice president interviewed in Round 2). In a Round 3 interview with the head of their manufacturing technology development group, however, the firm was also found to have an established link between manufacturing R&D personnel and product development IPTs in cases where the teams needed help implementing new

---

[16] These consisted of four first-choice sites and two second-choice sites.

[17] The two second choice sites (for the management chain and focal point information structures) essentially eliminated themselves from consideration as case study candidates: one POC was unavailable for the follow-up interview during the Round 3 time period, while the public relations office at the other firm indicated that they preferred not to engage in informal interviews. The fourth first-choice site was eliminated due to a lack of case examples fitting its information structure (see Section 4.4).

process technology. The firm therefore was re-classified as primarily management chain but with some focal linkage elements. Similarly, the firm initially classified as following the network model was found to share personnel between the process technology group and the product development teams, lending them qualities of the focal point inclusion structure as well.

In light of this practical evidence that firms can exhibit characteristics of multiple information structures, the concept of strategy distribution structures was expanded to become more a continuum of organizational expression than a set of distinct practices. Figure 4-5 contains a graphic representation of the distribution of the first-choice sites across this continuum of information structures. The primary and secondary information structure affiliations are indicated for each firm, demonstrating the spread of field work across structure types.

The discovery of multiple information structures at a single company brings out the natural subsequent question of why varying results were found in interviews with different personnel in the organization. The problem of conflicting interview data is one that has dogged social researchers for years and cannot be definitively answered without deep study into the knowledge, motives, and perceptions of the interview subjects and their organizational environment. However, some simple hypotheses can be posed. In most of the cases, the interview subjects came from two different areas of the organization: upper management (vice presidents) and R&D (engineers). One explanation might be that different functions in the organization make use of different information flow paths. Another reason for the disparity might be that there is an incomplete cascade of information from the upper managerial levels down into the working levels. Either of these explanations belies the knowledge-sharing and cross-functional philosophy of the IPT. Further research into the reasons behind the apparently contradiction in information structures will be examined during the case study phase.

4.3.2 Note on the Network Information Structure Type

A final note should be made in regard to the firm which was found to exhibit a network information structure. Earlier interviews had already uncovered the fact that network interactions were a new approach for the firm, although it was not understood at that time exactly how new the information structure was to the company. During the Round 3 interviews, managers explained that they had initiated their use of the concept by bringing together a diverse group of high-performing employees for discussions of the firm's business and market plans. However, the network information structure had not yet been used to distribute information about the firm's *technology strategy*, although plans were underway for a future discussion. This meant that no

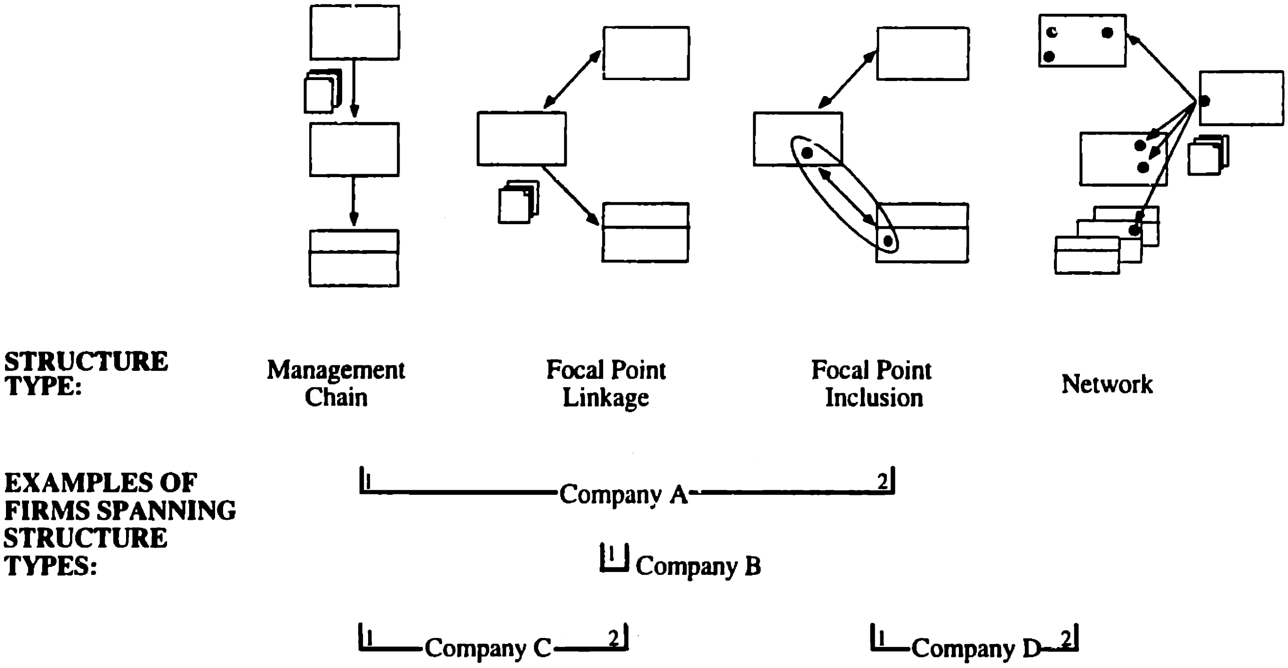

Figure 4-5. Selection of Case Study Sites
[Information structures are distributed according to the level of interaction between the strategy-generating body and the IPT-level. Primary structure affiliation is represented with a "1" and secondary structure affiliation with a "2." Information structure diagrams are as in Figure 4-4. Note that further study of the network information structure was determined to be infeasible for Phase II due to the early stage of its implementation at the firm.]

existing IPTs had yet been exposed to strategic information through a network distribution path. Although the firm can still be classified as exhibiting a network information structure (or, rather, as being in the process of implementing a network information structure), no case examples exist as of yet, and so the firm was removed from further study. The network information structure remains an interesting alternative for creating closer communication between the strategy generating body and the IPTs, and so the decision was made to include its description in information structure catalog of Phase I results.

4.4 Selection of Case Study Sites

The distribution of the Round 3 firms along the structural dimension shown in Figure 4-5 provided a strong basis for the selection of case study sites. The decision was made to examine the management chain and focal structural types, including firms with varying combinations of cross-structure forms. Three of the four first-choice sites were therefore retained as the Phase II case study firms, the network information structure being dropped due to lack of existing case examples at that firm. The three chosen firms were:

- Company A [primary classification: management chain, secondary classification: focal point inclusion]
- Company B [classification: focal point linkage]
- Company C [primary classification: management chain, secondary classification: focal point linkage]

Each firm seem to have primary influence from a single information structure, leaving the researcher confident of being able to explore the cross-firm differences between primary type without excessive convolution from the secondary types. At the same time, the simultaneous existence of two information structures within a single firm promised interesting insight into the intra-firm effects of multiple communication infrastructures. The variation in responses to interview questions among individuals in different parts of the organizations, as noted in the Round 3 identification of secondary information structure types, was especially intriguing in this regard. The information structure diagrams for the chosen firms are shown in Figures 4-6 through 4-8. The constructs for each structure are listed in tabular form in Table 4-9.

A summary of each firm's information flow characteristics is contained in Table 4-10. The technologies selected at each site for the case study analysis are also identified, having been chosen according to the criteria described in Section 3.3.2:

- decision made by an IPT regarding the adoption of a new generation of manufacturing process technology (first instance of use in the firm)
- decision made within the past five years
- decision requiring cross-functional analysis
- sophisticated technology requiring significant changes to the existing design and manufacturing process
- potential application of the technology across multiple product lines, and
- implementation process requiring interaction between multiple groups within the organization.

Results of the case studies, including a detailed description of the technologies selected for research at each site, are found in Chapters 5, 6, and 7.

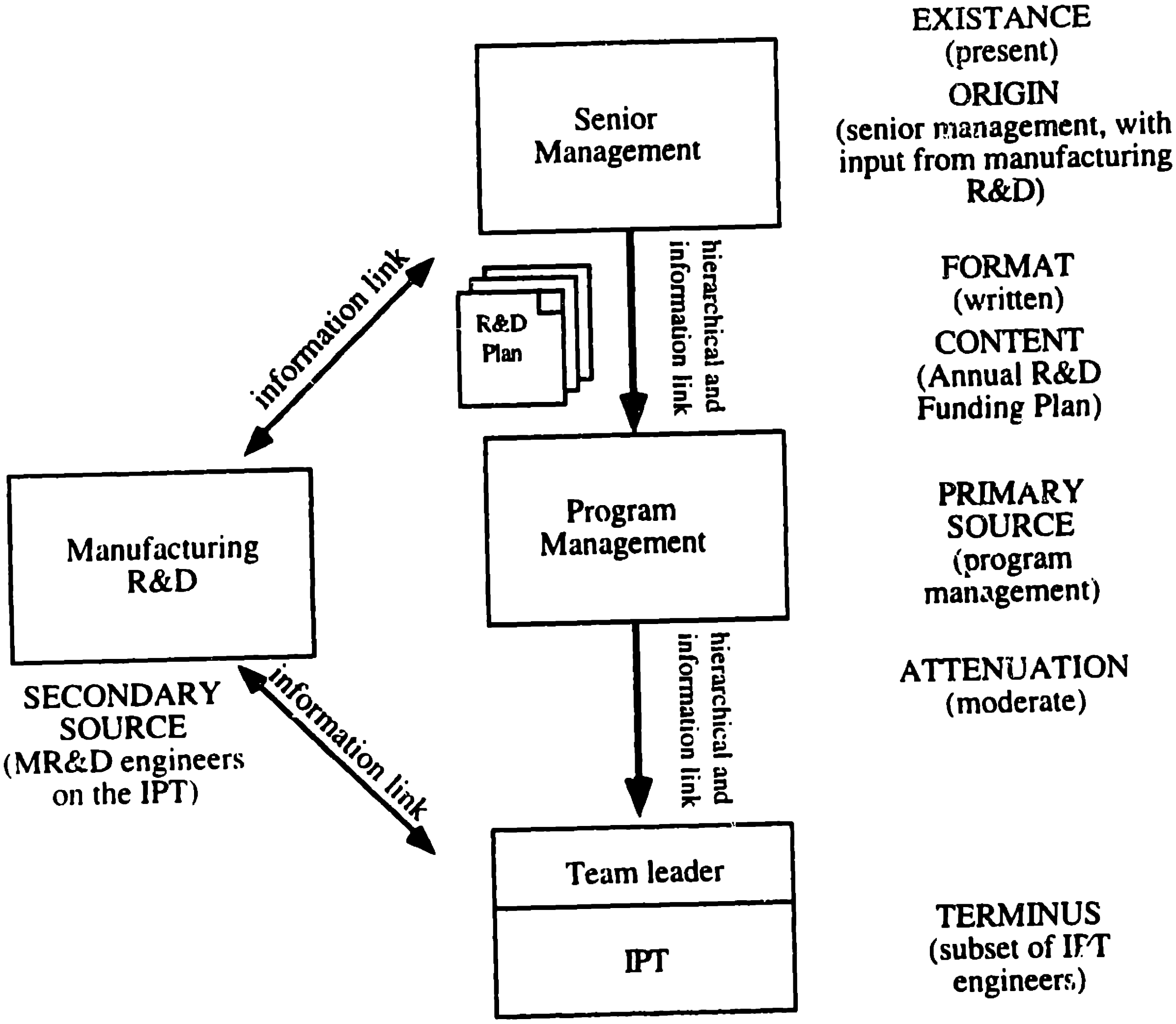

Figure 4-6. Information Structure Diagram for Company A
[primary classification: management chain, secondary classification: focal point inclusion]

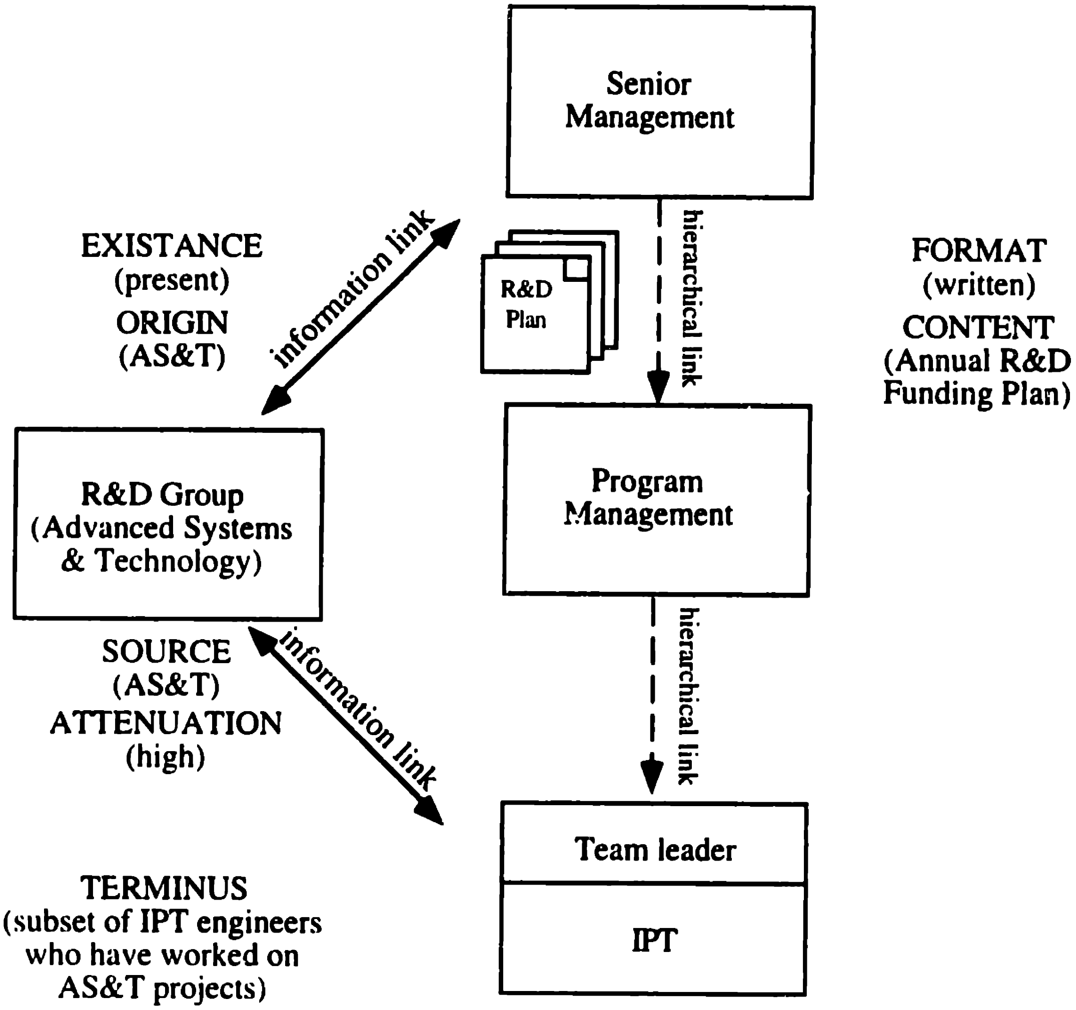

Figure 4-7. Information Structure Diagram for Company B
[classification: focal point linkage]

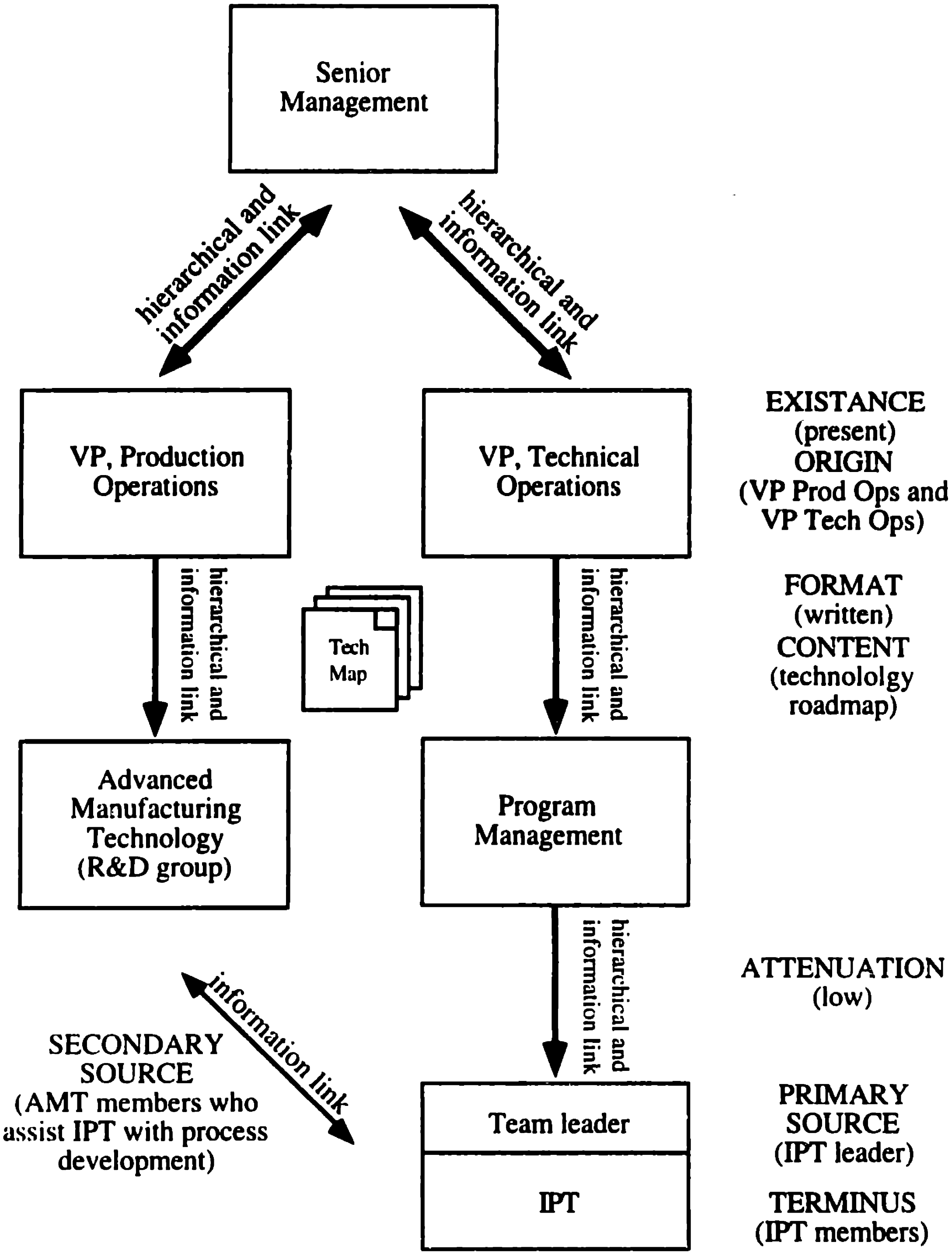

Figure 4-8. Information Structure Diagram for Company C
[primary classification: management chain, secondary classification: focal point linkage]

Table 4-9. Information Structure Constructs for Case Study Sites

Construct	Company A	Company B	Company C
Existence	yes	yes	yes
Origin	company management	VP of Advanced Systems and Technology (AS&T)	VP of production operations and VP of technical operations
Input from	manufacturing, program, R&D	AS&T engineers	
Content	annual R&D funding plan	R&D funding plan: ranking of production programs by importance; roadmaps for development time horizons	technology roadmaps and requirements; long-range plan (desired people, skills, investment); corporate deliverables (profit/cash flow)
Format	written	written	written
Flow Path	"good old boy network" and some transfer of people from program to program	R&D engineers and project engineers transition between the two areas; affordability room in AS&T prototype center; production program representatives on AS&T IPTs	goals broken down by mission/functional area, then product line, then teams, then individual; "seek ownership throughout the enterprise"
Attenuation	moderate	high - designers don't know details of technology plans until they reach implementation	low - "The top level isn't enough alone; you need to understand specific parts" for the company plan to make sense
Source	program management	AS&T	IPT leader
Terminus	subset of IPT engineers	IPT team members (engineers who have worked on AS&T IPTs)	IPT team members

Table 4-10. Summary of Case Study Sites: Information Structures, Information Flow Characteristics, and Selected Technologies

Company	Information Structure	Top-Level Information Flow Characteristics	Selected Technology & Product Program	Case Study
Company A	Primary: management chain Secondary: focal point inclusion	• strategic planning done with input from R&D, programs, and manufacturing centers, but final decision is made by upper management • IPTs instructed to look at technology opportunities by program managers • manufacturing R&D representatives included on IPTs as members	Resin transfer molding (Alpha Program: sinewave spars for aircraft wings)	Chapter 5
Company B	Primary: focal point linkage Secondary: none	• technology "strategic guidance document" developed by VP of advanced systems and technology (AS&T) • production program engineers work on AS&T IPTs for new technology demonstration • affordability room set up to act as resource of information on new manufacturing capability; program managers brought in to show them what can be done	High-speed machining (Beta Program: trailing edge parts for aircraft wings)	Chapter 6
Company C	Primary: management chain Secondary: focal point linkage	• VP of technical operations and VP of production operations create technology roadmap • IPTs learn about company strategy via information that comes from their team leader or functional manager • goals/objectives flowed down through product line hierarchy • programs can request help from manufacturing R&D group when they need more sophisticated process technology	Plating and patterning of double-curved surfaces (Gamma Program: missile radomes)	Chapter 7

CHAPTER 5

CASE A: RESIN TRANSFER MOLDING[1]

The design and construction of the wings for the Alpha Program aircraft was performed by Company A, a large military and commercial airframe manufacturer. An integrated product team (IPT) was formed to develop the wing's internal sinewave spars, the long, thin I-beams which support the wing's surface skin (see Figure 5-1). One of the most challenging aspects of the product development process for the internal spar IPT involved the selection of a composite process technology with which to manufacture the spars. The team had to decide between the traditional "pre-preg" method of fabrication and a new application of a process known as resin transfer molding (RTM). While RTM had been employed successfully for a number of years in other industries, it had never been used to make critical aircraft structural parts. Although RTM seemed to promise great cost reductions, the process also required more development effort before it would reach the quality and repeatability requirements of an airframe program. The IPT therefore had to balance the potential cost benefits with the risk of implementing a new application of the RTM technology.

The decision process to select a fabrication technology for the Alpha internal spars involved a great deal of technical analysis from each of the functional perspectives represented on the team. Since the analysis was performed while the RTM technology was still fairly immature for this application, the team was forced to find ways to reconcile tradeoffs between competing perspectives while in an environment of uncertainty. At the same time, the development was organizationally complex, with many groups involved from across Company A and its suppliers. This case study presents the history of the RTM development and implementation, exploring such organizationally important issues as the role of IPTs in program decision-making, the importance of technology "champions," and the value of risk assessment methodologies as a tool for cross-functional communication.

---

[1] Note: Data and archival materials for this case study were provided by Company A and its supplier, Omega Systems. (Company and program names have been disguised to maintain anonymity.) Information from research interviews with company employees provided the basis for the descriptions of the technologies, the development process, and the structure of the organizations. Direct quotes from employees are identified only by the individual's function or rank for privacy reasons. Representatives from the companies were able to review the descriptive portions of the case study (i.e., the description of the technology and the history of the decision in the organization) and to identify any areas that they felt required clarification. Subsequent interpretation and analysis of the data were the sole responsibility of the author.

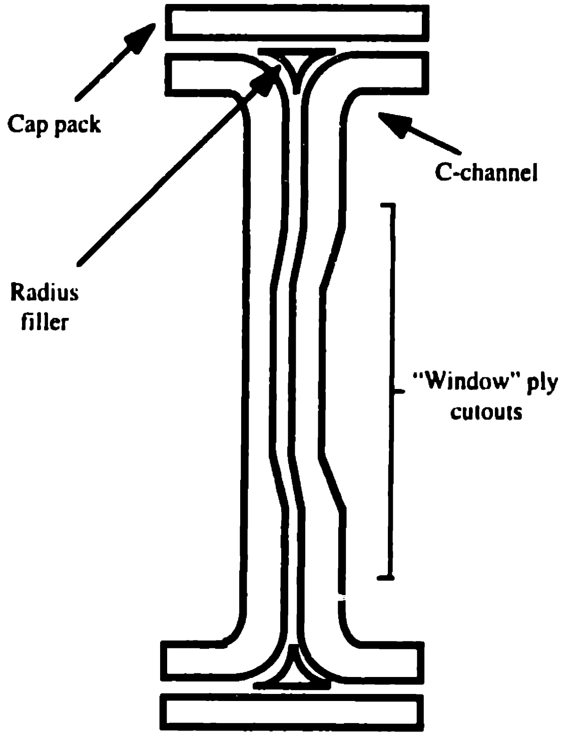

Figure 5-1. Cross-Section of a Sinewave Spar
[notional diagram; not to scale]

5.1 Overview of the Organization

The Alpha program was organized around a physical decomposition of the aircraft, resulting in a hierarchy of integrated product teams. The organizational chart in Figure 5-2 identifies the position of the internal spar IPT within the wing subsystem. The multi-functional team included engineers from the design, stress engineering, manufacturing, tooling, and materials and processing, along with representatives from quality control, testing, and procurement. A finance representative was also designated to the team to aid in cost estimation tasks. In addition, members of the Manufacturing Research and Development (MR&D) group, Company A's process R&D department, also became very involved with supporting the team. The relationships between the many individuals and groups involved in evaluating and implementing the technology are examined in greater detail in Section 5.4.

5.2 The Technology

The most common means of building parts from composite materials is the pre-impregnated or "pre-preg" technology, a method in which composite fibers (made of fiberglass and/or graphite) are woven into fabric and then saturated with resin. Layers of the resin-coated fabric are draped,

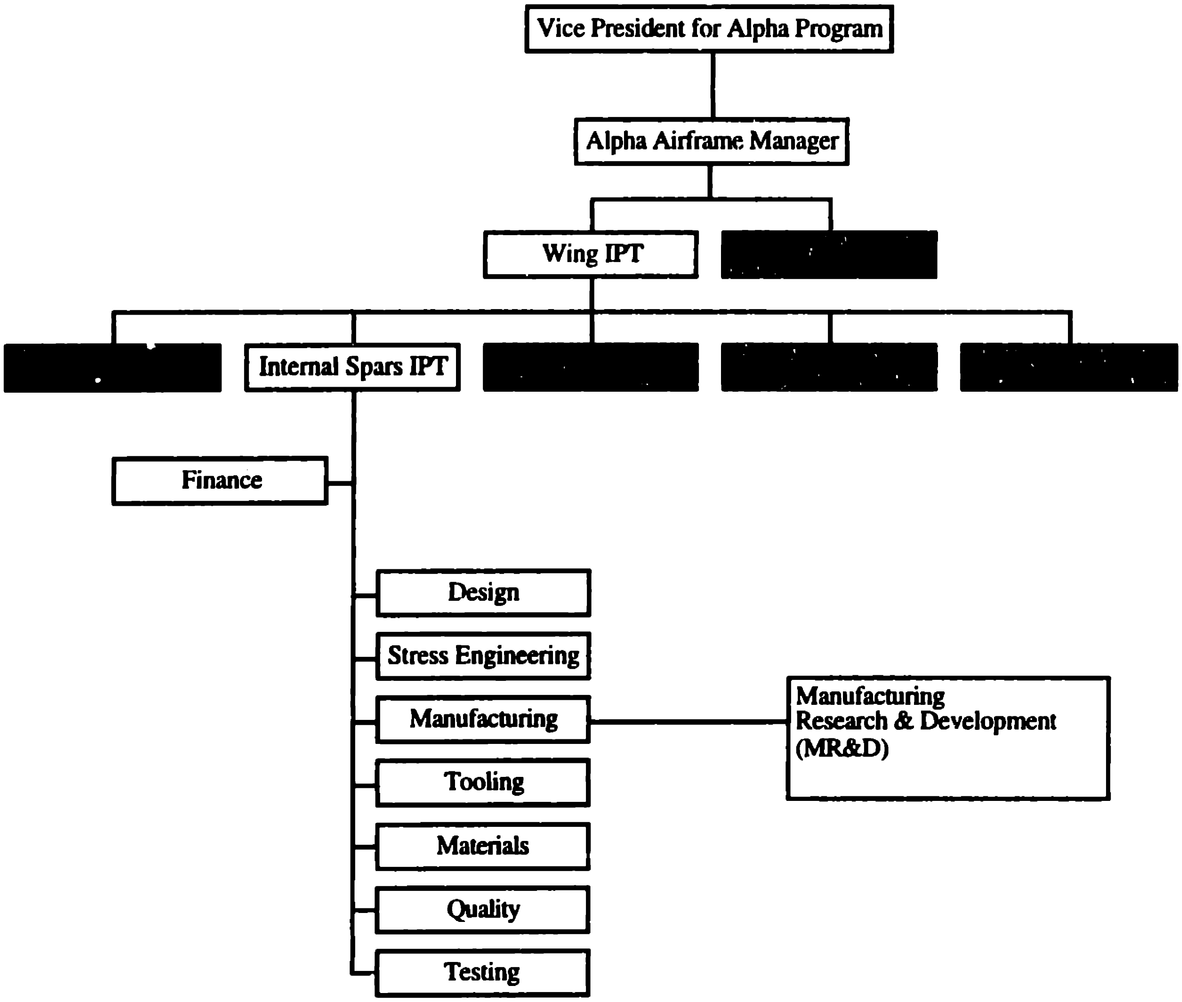

Figure 5-2. Company A Organization Chart
[focus on Alpha Internal Spars IPT]

typically by hand, onto a shaped molding tool until their thickness reaches that of the part design, a process known as "lay-up." The layers are then cured in an autoclave to form a solid part. While the pre-preg technique is a fairly well understood, the manual lay-up of fabric can be labor intensive, making the process expensive for volume production. Pre-preg designs are best suited to geometries consisting mostly of flat planes, gentle curves, and channels. Parts are typically limited to detailed shaping on one side only, since a vacuum bag is used on the other side to conform the fabric to the tool during the curing stage. The process, however, is extremely reliable, making it a good choice for parts that require high durability. In the aircraft industry, for example, the pre-preg technique is often used to make composite parts that bear high fatigue stresses in fracture critical applications, such as wing skin panels.

Resin transfer molding (RTM) is an alternative process initially developed in the mid- to late-1970s. RTM has been used the automotive industry for lightly loaded parts like body panels and in the aircraft industry for non-structural applications. Figure 5-3 presents a stylized view of the process steps. RTM involves assembling layers of dry fabric, sprinkling or "tackifying" them with a small amount of crushed resin to hold them together, and then heating them to form a "preform" structure in the desired shape. The preform is placed into the two halves of a mold. Hot pressurized resin is then injected into the mold to complete the composite matrix (Figure 5-4). Since RTM uses a three-dimensional mold, it allows the construction of complex shapes with internal cavities. This reduces unit cost compared to pre-preg since the part can be made as a single integrated structure instead of several one-sided shapes that need to be assembled with fasteners. Attachment features can also be integrated directly into the part. The technique is also well suited for the use of automated "pick and place" machinery that stacks flat fabric plys very accurately into layers of the proper thickness, which drastically reduces the per part production cost compared to a manual lay-up process. The non-recurring cost of the mold and mold die tools, however, makes RTM a more expensive investment than the pre-preg technology. (See Table 5-1 for a comparison of the two technologies along major dimensions of merit.)

In judging the relative merits of RTM and pre-preg for the Alpha, the IPT had to consider the design requirements of the sinewave spars. The Alpha wing was designed to maximize strength while minimizing weight and cost. Beneath its composite skin, the wing consists of a titanium framework braced together with a series of composite spars (see Figure 5-5). A single Alpha wing contains 22 different composite internal spars, making 44 composite spars per "ship set." As Figure 5-1 reveals, each spar consists of two C-shaped channels with a cap on either end. An additional component known as the radius filler, or "noodle," fills in the gap at each end between the two C-channels. In a pre-preg process, each of these pieces may be fabricated and then co-cured or assembled with rivets. Using RTM, the component pieces can be shaped as individual preforms and then united into a single part during the molding phase. The channel of the internal spars is sinusoidal along its length, a configuration designed to improve the strength of the spar while minimizing its weight and cost. The thickness of the web is reduced in some areas to save weight, by either using fewer plys in that area when the fabric is layered or by cutting "window" holes in the plys themselves.

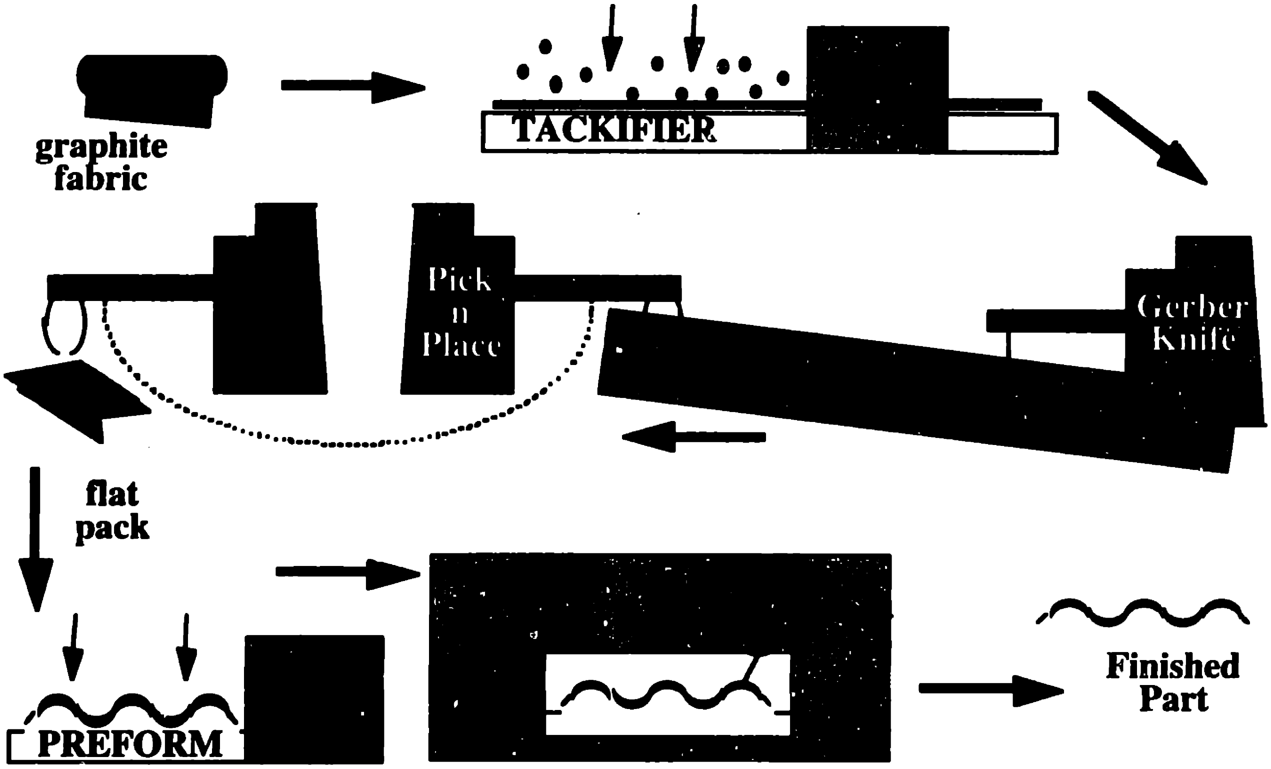

Figure 5-3. Simplified Resin Transfer Molding (RTM) Process
[notional diagram; not to scale]

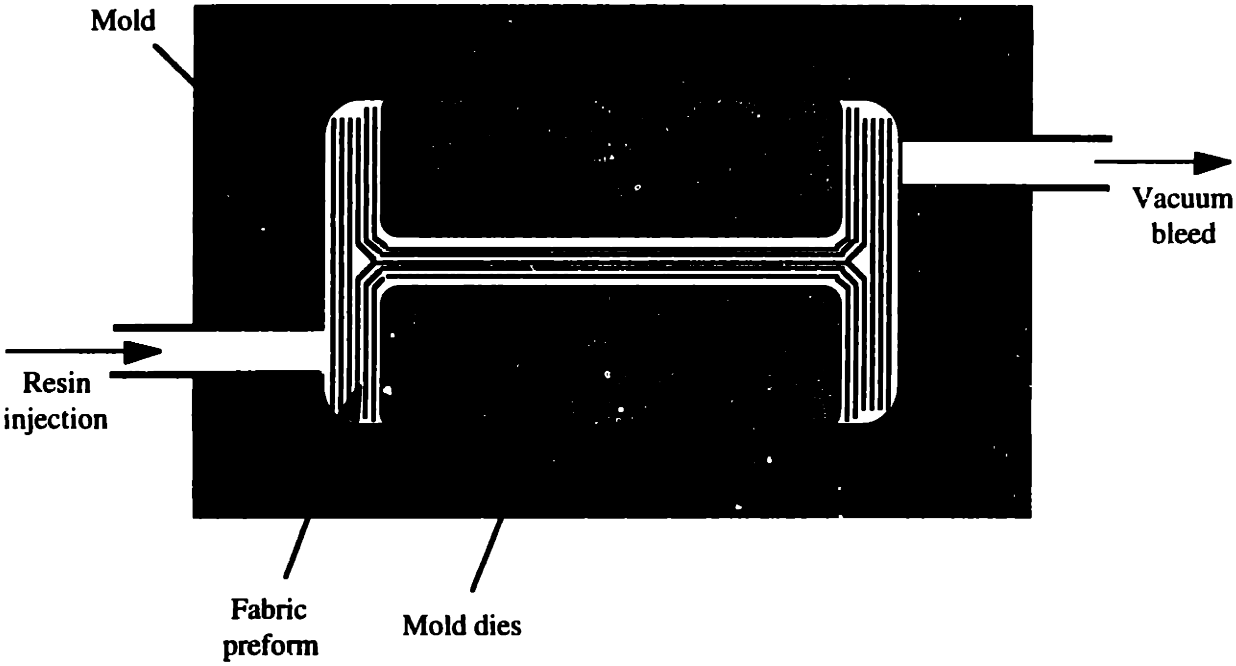

Figure 5-4. RTM Process: Injection of Resin (cross-sectional view)
[notional diagram; not to scale]

Table 5-1. Comparison of Composite Processes

	Pre-Preg	RTM
Fabric	• Pre-saturated with liquid resin	• Dry fabric that is later "tackified" with crushed resin
Ply positioning	• Manual lay-up	• Automated "pick & place"
Forming tool	• One-sided metal mold with vacuum bag on other side	• Match metal mold forming a three-dimensional part shape
Allowable geometry	• Complex two-dimensional shapes • Simple three-dimensional shapes • Primarily one-sided tooling	• Complex three-dimensional shapes • Internal cavities • Integrated metal features
Cost driver	• Recurring labor	• Capital equipment and tooling

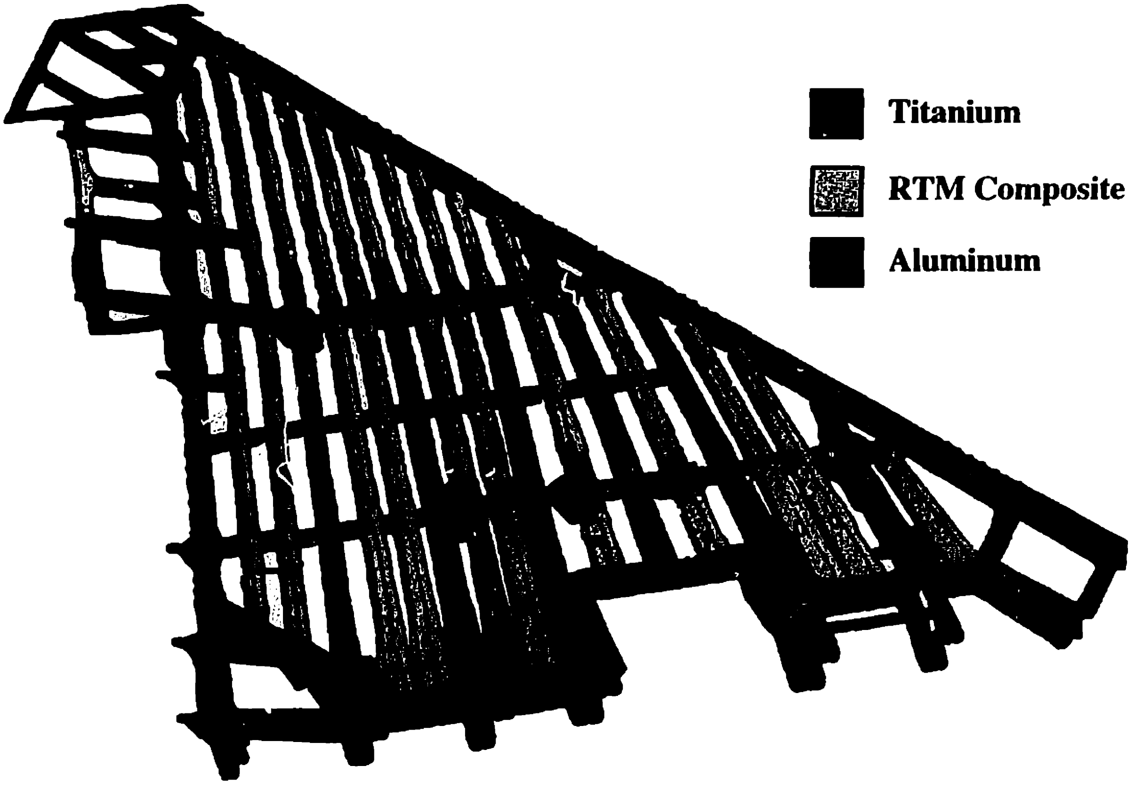

Figure 5-5. Alpha Wing Substructure

At the time of the Company A decision, the RTM process was not as mature for airframe applications as pre-preg. RTM had never been used on a primary vehicle structure, mostly due to stringent process controls required for aircraft structural parts. Without strict process control, parts can contain defects that impair their ability to withstand high stress levels. As a result, process designers were hesitant to use the technology on critical structural parts such as a wing. As the Company A engineers would discover, the technology would require a significant amount of research and development in order to meet the requirements for aircraft structural parts. Although RTM certainly had been in existence for quite a long time, process capability at Company A was not application-ready at the time the technology first came under consideration as an alternative for the Alpha spars. Company A's technology transition process therefore included laboratory-style process development along with factory implementation and production ramp-up.

5.3 The History of the Technology Transition

Prior to the Alpha program, Company A had accumulated a great deal of experience making spars for defense aircraft, having manufactured wing parts for other military aircraft programs. While their design experience was extensive, Company A's process capability for composite parts was concentrated on pre-preg, their core composite technology. The company had experimented with RTM for about ten years and had used the process to build a drain mask for a commercial airplane. RTM had never been used for a structural aircraft part, however. This section describes the steps that the internal spar IPT went through in evaluating RTM versus the pre-preg process and identifies the various analyses that were performed. Of particular interest is the relationship between the Company A team and an outside subcontractor of RTM technology, Omega Systems. A description of the technology development that was required to bring the RTM process to a reliable level of manufacturability is also included.

5.3.1 Early Development

When the Alpha wing internal spar IPT was convened, the intent was to use pre-preg to produce sinewave spars at the Company A facility. However, initial development efforts by the MR&D group at Company A ran into problems with porosity (air pockets in the matrix) and delamination (separation of the fabric plys) during attempts to scale up to production levels. In early 1992, Alpha executives became aware of work done in the RTM area by Omega Systems, a small composite manufacturing house formed specifically to develop the RTM technology for use on critical structures. The company had developed a resin transfer molding process that proposed to offer high quality, high reliability composite parts for primary structures at a low cost. As a result, the Alpha internal spar IPT was instructed to meet with Omega to discuss switching to RTM and outsourcing spar production to the supplier. In response, three RTM assessment projects were initiated: one at Omega, one by the MR&D staff at Company A, and one at another RTM supplier (who was subsequently dropped from the program).

By June of that year, the RTM development projects had shown promise for cost and quality improvements, but much work was still required to achieve a production-level process. Since the Alpha schedule was quite tight, the IPT decided to stick with its original plans for the pre-preg technology. They felt that pre-preg was more likely to produce a workable process in the short time remaining before the start of production. The RTM projects were therefore discontinued. However, several issues subsequently arose that caused this decision to be reconsidered. First, two one-year schedule slips for the entire Alpha program were announced, the result of delays associated with factors unrelated to the product development IPTs. Around the same time frame, the customer expressed a desire to reduce program expenses and instructed all suppliers, including both Company A and the Alpha Program prime contractor to seek cost reductions. The combination of these two events – the schedule delay and the pressure for cost reductions – led Company A to reinitiate the Omega development program in the fall of 1992. During the analysis period that followed, the Alpha team identified over 200 candidate parts, including the wing sinewave spars, that could be made using RTM to achieve a reduction in manufacturing and assembly costs. The in-house pre-preg effort was maintained in parallel by Company A's MR&D group to ensure that a fallback option would still be available.

5.3.2 Cross-Functional Analysis

The IPT performed extensive evaluation and comparison of the two technologies in order to make a decision as to which one would be selected for production, with each function area contributing to a variety of tests (see Table 5-2). Analyses were performed to compare RTM and pre-preg along many dimensions, including design, structural performance, manufacturing, quality, tooling, materials engineers, and finance. Neither technology succeeded in dominating in all of the test areas. This section describes the results from each functional perspective.

The simplest comparison stemmed from the design area. Although the processes of RTM and pre-preg are very different, the end result is the same: a solid part made of composite fibers enveloped in cured resin. The physical appearance of a spar made by RTM is exactly the same as one made by pre-preg. Some slight variations may exist in situations where an assembly of subcomponents can instead be made as a single unitized structure. For example, in the case of the sinewave spar, it may have been possible to integrate brackets and clips into the structure of the part. On the Alpha program, however, the assumption during the detailed design phase was that that part would be made with pre-preg. By the time RTM came under consideration, the design of the part had already

Table 5-2. Cross-Functional Evaluation of RTM vs. Pre-Preg (for the Alpha Sinewave Spar)

Functional Area	**Analysis Performed**	**Results (RTM vs. Pre-preg)**
Design	Comparison of physical design requirements	Equivalent
Structural Test	Cap pull-off, three-point bend, web shear, penetration, surface damage, military damage, environment	Equivalent
Manufacturing	Rejection rate, scrap rate, manufacturing tolerances	Uncertain
Quality	Ultrasonic testing, facility and process qualification	Uncertain
Tooling	Comparison of tooling design complexity	Pre-preg requires less design and fabrication effort
Materials	Fabric and resin specifications, injection temperatures, tackifying process requirements	Pre-preg less risky
Finance	Development cost	Pre-preg cheaper
	Unit cost	RTM cheaper

been configured according to a multiple-part assembly with brackets and clips. The Company A engineers did not consider it cost effective to re-design the spars as a unitized structure. Consequently, the two techniques were considered equivalent in terms of the design analysis.

Structurally, pre-preg and RTM are also quite similar. The test engineers on the internal spars IPT performed tests to compare the strength of parts made with the two processes. These tests evaluated such performance attributes as:

- cap pull-off (separation of the end pieces of the spar from the center web section)
- three-point bend (strength of the spar along its length)
- web shear (separation of the two center pieces of the spar from each other)
- load re-distribution
- surface damage
- military damage (resistance to weapon fire)
- environment (resistance to heat and humidity).

The tests determined that the two processes were considered equivalent from a structural perspective.[2]

In terms of manufacturability, the relative merits of RTM versus pre-preg were much less certain. Since neither process was fully operational at this point, the IPT had trouble performing a decisive analysis. The yields achieved with each of the development processes were monitored as both the in-house and Omega processes struggled to create a qualified production process. Ultrasonic testing was used to evaluate the quality of each fabricated test part, and the ability to achieve manufacturing tolerances was also studied. At the end of the analysis period, the IPT was unable to make a clear recommendation of which process should be preferred from a manufacturing point of view; both processes were still too far from being production-ready.

In the tooling and materials engineering areas, the pre-preg technology was found to have an advantage. The tooling design required for pre-preg spars was considered to represent much less effort than that required for the creation of the RTM preforms and three-dimensional molds. The materials analysis showed pre-preg to be a less risky process due to the availability of fabric and resin that was already qualified as meeting systems specifications. In addition, many of the steps in the RTM process required process control development, such as establishment of precise temperatures for the injection of the resin. The RTM tackifying process, which had not been used before at Company A, was also considered to introduce more development risk than the pre-preg technique.

Finally, in the financial analysis, results were split between the two technologies. Since Company A already had a pre-preg facility set up, the investment required to make the Alpha spars with this method would be considerably less than that involved with establishing an RTM process line. Pre-preg was therefore considered by some to be cheaper in terms of development cost. On the other hand, the labor reduction from the automation of many process steps promised significant recurring manufacturing cost savings under an RTM arrangement. The costs and benefits of outsourcing production to a supplier was also considered. The Alpha prime contractor had already decided to use RTM for some of the composite parts in their portion of the aircraft design, and they had already selected Omega as the supplier. Having the Company A components made from the same process and by the same supplier reduced the time and money the program had to spend on

---

[2] Note that the pre-preg process was at that time experiencing porosity problems which were producing weaker structures. The equivalency of the two processes was therefore on condition that those porosity problems could be eliminated.

supplier certification and oversight, allowing savings for the customer. Considering this and other aspects of the detailed financial analysis, RTM was preferred from a unit cost perspective.

5.3.3 Final Decision

The results of the evaluation did not conclusively mark either of the technologies as superior. In judging the relative risk of the two processes, the team struggled with the challenge of comparing an unproven technology that was giving good initial results (RTM) with a proven process that was for a variety of reasons generating high rejection rates at that time (pre-preg). The team felt that they could probably be successful at getting either process to work well, but it was unclear how much time and money that would require. As the IPT reviewed the results of the analyses, the Company A pre-preg process did appear to have less developmental risk at that time than Omega's unproven but promising RTM process. However, the RTM process, assuming it would continue to operate well as production volume was increased, would result in a lower production cost.

At this point, opinions among the IPT members diverge as to how the two technologies fared in their head-to-head comparison. Some of the engineers felt "out of their comfort level" with the high development risk of the RTM process, since they felt that solving the current pre-preg problems would take less time. Doubts were also expressed that Omega would be able to meet its claims for the sinewave spar production schedule. Others, forming the majority opinion, felt that the potential cost benefits of RTM were so high that the new technology should be pursued in spite of the risk. The Alpha program management appeared willing to accept the development risk and investment required to implement RTM in exchange for the promised cost reductions. They were also willing, however, to let the team's decision process continue for a bit longer. The IPT was asked to present their analysis to the program manager, with instructions to "be prepared for some hard questions." Following much discussion, and a meeting with the program manager than ran two hours over schedule, a decision to go with Omega's RTM process was announced as final.[3] At the same time, the group agreed upon a risk mitigation plan that called for the internal pre-preg development project to be maintained in parallel for approximately six more months. The IPT members then proceeded with the RTM development at full speed, with Company A engineers stationed at Omega to help improve the quality and reliability of the process so it would meet the required program specifications. Production of the first ship set of spars for evaluation and testing began in 1995, with the Alpha first flight taking place in September 1997.

---

[3] In an independent decision process, the Alpha Program prime contractor also decided to have Omega make several RTM parts (tail ribs, tail spars, and the fuel tank frame) for their portion of the Alpha airframe. Company A subsequently lead the supplier qualification for all of the Omega parts.

5.3.4 Into Production: Results of the Decision

Since the decision to adopt RTM, Company A has collected data that appears to validate their choice (Table 5-3). The RTM technology has been able to achieve much tighter manufacturing tolerances than the pre-preg process, producing dimensions to within 0.0125 inches (compared to 0.045 inches with pre-preg). The quality of the RTM parts is also considerably better than what had been achieved with the in-house pre-preg development effort at the time it was discontinued. Early development runs with the Omega process achieved a rejection rate of only 29 percent, compared to 93 percent with pre-preg. Scrap rates were similarly affected (14 percent for RTM versus 45 percent for pre-preg). In terms of cost, RTM was able to achieve an estimated cost savings of about $200,000 per plane due to reduced labor costs. While the pre-preg development had been going on for approximately four years when it was discontinued in mid-stream, the RTM development effort achieved a workable process in about half that time. The Alpha program management was understandably pleased with these improvements. The IPT members too seem satisfied overall with the results of the technology development, although some minor dissent remains over whether the pre-preg process was allowed an appropriate testing period before being terminated (see discussion in Section 5.4.2).

While the program ended up being able to enjoy the manufacturing cost and quality benefits of RTM, the IPT's prediction that RTM possessed a high degree of development risk proved to be true. Omega had more problems when applying their RTM process to the Alpha spars than were anticipated in their proposal, and the projected development time and cost were considerably extended. Company A's contribution to the RTM development effort for the Alpha, initially estimated at $5M, eventually approached $15M by the time the RTM process was ready for production (although this amount was still within their established budget, given the expected savings). In addition, Omega spent a planned $10M to facilitize their factory for producing Alpha and other RTM parts. Both companies hope to recover their investment over the lifetime of the production run due to the lower per unit cost that RTM provides.

5.4 Analysis of the Organizational Structure and Its Impact on Decision Making

Company A's experience with implementing resin transfer molding provides an interesting look into the company's approach to product development and how the organizational structure of the company affected the process of technology transition. Although RTM certainly helped to achieve the cost and schedule goals for the Alpha program, the firm can benefit from reflecting on the process of technology transition as well as the outcome. This section examines how the use of an IPT organization impacted the decisions made during the RTM project, focusing an evaluation of possible areas for improvement in the process. The relationships between the many functions and

Table 5-3. Evaluation of the Development Efforts for the Alpha Sinewave Spar

Feature	Pre-Preg	RTM
Manufacturing tolerances	- ± 0.045 inches	- ± 0.0125 inches
Quality[4]:		
- Rejection rate	- 93%	- 29%
- Scrap rate	- 45%	- 14%
Cost (per pound)	- $4110[5]	- $1340
Development time	- 4 years[6]	- 2 years

organizations that participated in the development project are examined, with attention on the special role of R&D organizations in the product development process. Finally, Company A's technology strategy with regard to RTM is discussed, followed by comments on the potential benefits of adopting a more formal risk methodology.

5.4.1 Organizational Linkages

Company A appears to have used the IPT system to their advantage for the internal spar development. Members of the IPT were drawn from functional disciplines within both the engineering and manufacturing organizations in the company, with additional part-time resources provided from the cost accounting area. Members of the MR&D group were also active participants. (See Section 5.4.2 for a more detailed analysis of the role of R&D in product development.) Establishing a cross-functional teaming arrangement early on facilitated the analysis of the two manufacturing alternatives from multiple perspectives. The team members seemed to work well together, maintaining their technical specialization while learning to communicate with individuals from other functional disciplines. While there was a clear distinction between who had performed each different technical and cost evaluation (e.g., these analyses were not performed by the group working as a whole), all of the members appeared to understand the main results of each analysis. They were therefore able to discuss the various tradeoffs in cost, performance, and manufacturability together and to make a team decision based on a synthesis of the individual

---

[4] The quality rates shown here were measured during development. Subsequent measurements of the RTM process capability taken during early Alpha production runs show even greater improvements in yield.

[5] Represents approximately $200,000 more per wing ship set than RTM.

[6] Until effort abandoned in favor of RTM development.

results. This style of teamwork, leveraging individual experience while maintaining a systems focus, reflects an effective IPT format and is a credit to the integrative skills of the team's leader.

In addition to bringing together many functional groups from within Company A, the development of the sinewave spar involved many outside suppliers. Some of the supplier involvement is due to a desire for multiple sourcing. For example, two weavers were selected to each produce half of the required amount of composite fabric. Similarly, part of the tooling fabrication for the RTM molds was outsourced to an external machine shop when Company A's own Machine Center became too busy with other work to have capacity for the full job. Other supplier relationships are more complex. For example, the Alpha prime contractor asked Omega to form a "mentor-protege relationship" with a small composite vendor as part of their corporate initiative to transfer technology to small disadvantaged businesses. This vendor, with help from Omega, will fabricate some of the simpler Alpha RTM parts. In general, Company A did a good job of managing their supplier network. Company A's support included not only sending engineers from the IPT to the Omega facility to help implement and qualify the RTM process, but also ensuring that material from second-tier subcontractors was delivered on schedule. Omega was able to contract with resin and fabric suppliers who were already qualified by Company A, which saved time in process certification and material acceptance. Managers at Omega appreciated the weight that the Company A and prime contractor names gave them in dealing with suppliers, noting that their connections to the prime contractors gave them an advantage in price negotiations.

5.4.2 R&D Involvement in Product Development

The relationship between R&D and product development groups in a company is very important in cases of new technology transition. Having engineers from the MR&D group participate as IPT members was highly beneficial to the internal spars development effort. Their experience in implementing new process technology was called upon many times, both in relation to the early research on the pre-preg technology and to the evaluation of Omega's RTM process. In some ways, the selection of a manufacturing process for the internal spars resembled more of an R&D project than a product development one, in that the amount of process development required during the detailed design phase of the Alpha program was indeed significant. Neither process was fully application-ready when the IPT started work, and it became obvious to the team very early on that they would need help in getting a process to work in time to meet the Alpha production schedule. The MR&D team members were brought in to fulfill this need. As it turned out, they ended up providing considerable assistance in both the Company A process development and the Omega effort. Even after the decision to select Omega's RTM process, Company A's MR&D engineers worked on site at the Omega facility to help resolve process issues, including supporting the development of the preform process.

While the IPT system worked very well in achieving the Alpha program's goals to reduce cost, development time, and manufacturing time, some conflicts did arise over the course of the internal spar decision process. Perhaps feeling more aware of the technical risk associated with an unproven process, some of the MR&D engineers fell in the dissenting opinion when it came time to select the Omega process for production. One team member commented,

> Some felt that, with the exception of a production-type facility that was in place, Omega didn't have a real technical advantage over Company A. ...To meet the needs of the program, Omega needed to invest in their facility. If the spars stayed in-house, Company A would have to do the same.

The tradeoffs between the pre-preg and RTM technologies were not at all clear-cut at this point in the decision process, and, naturally, differences of opinion existed. From an organizational standpoint, the MR&D group may have had more at stake in keeping the spar manufacturing process within tighter Company A control, since their group would be expected to ensure that the final process would work, regardless of whether a subcontractor was used. "If a lot of support was required, they would rather support closer to home," explained a team member.

The MR&D engineers' organizational position as matrixed support to the Alpha program might also have had an impact on their ability to influence the decision process. Although they were still part of the MR&D organization, the engineers were primarily responsible to the Alpha program. The intensity of the Alpha development may have isolated them somewhat from the rest of the R&D community. Budgetary restrictions and the fact that Company A was going through a company-wide personnel reduction at the time meant that only limited attention was available from R&D management for Company A's RTM and pre-preg development projects. One MR&D member expressed how the lack of management-level support for the RTM effort at Company A made their case a much more difficult one to make in the IPT meetings:

> It was not...experience that was lacking at Company A, but rather a technology 'champion' that could be dedicated to making certain that the pieces fell into place to bring the RTM technology to a production process. This person wouldn't necessarily be the one doing the development work, but rather the person taking care of the road blocks which would slow things down, such as facility requirements, specification requirements, and simply selling the technology to the higher-ups. Omega on the other hand had an entire facility which was primarily dedicated to the RTM process, and they were looking for work. It was not as hard of a sell at Omega.

The same rationale can be used in part to explain the decision not to select the Company A pre-preg process. While Company A had an existing pre-preg production facility, work still remained to get the internal spar process operating at a high-quality production level. Without a champion to support this effort, the IPT had a hard time convincing themselves and the Alpha management that their process would be ready. Omega therefore appeared to be a superior option. While the resolution of the differences in opinion were resolved amicably within the team, team members reflect on the process as a challenging one. The organizational dynamics exhibited here demonstrate the need for team members to recognize the conflict that members from support organizations (such as R&D) can face when the priorities or experiences of the two groups conflict. In turn, the long-recognized importance of the "champion" role in new technology development is confirmed [Roberts, 1988 *et al*].

5.4.3 The Role of IPTs in Technology Adoption Decisions

"There were what seemed like endless meetings on the subject of RTM," one IPT member recalled. Many meetings are indeed required for IPPD-style development of a complex product, probably more than in a traditional management system where working-level employees have much less input into decision making. The expected benefit however is a superior product that causes fewer problems in production. During an intense decision process such as that for the internal spar, frequent meetings are one of the best ways of keeping all of the IPT members current in their knowledge. Direct contact with other team members therefore facilitates the decision process and allows important information from different functional perspectives to be heard. According to Company A's IPPD managerial philosophy, decisions are made "by consensus building at the lowest possible level." IPTs therefore use an "all in the room method" when making decisions, such that all the members of the multifunctional team are present to voice the results of their particular disciplinary analysis and to consider trade-offs between conflicting factors. The internal spar IPT used this method to consider various issues of the RTM versus pre-preg decision, including technical issues (design requirements, structural performance, manufacturing producibilty, etc.), cost issues (development cost and unit cost), and quality issues (scrap rates, rework rates, etc.). The feasibility of outsourcing a technology requiring on-site process oversight and tight configuration control was also debated.

In implementing IPPD, it was important for the company that the first programs to use the new organizational system go well. The Alpha program appears to have established a good basis of support and credibility for future projects in this style. Still, the case provides a good opportunity to look how the teams operated, especially as to resolving disputes or conflicting requirements. While the vast majority of the internal spar IPT members seemed satisfied with how the IPPD format worked, some discomfort was expressed regarding a few incidents that took place during the decision process. For example, in mid-1993, the IPT members considered issuing an internal memorandum to stop work on the RTM tool development until the Omega process showed improvement. This memo was never distributed through the Company A hierarchy. The different levels of concern expressed over this situation reflect the complexity of the decision process. In a situation where many different individuals represent many different functional perspectives, problems in resolving conflicting information are bound to arise. Based on the information available in their decision making "room," that is, the information resulting from evaluations in the represented functional areas, some of the engineers interviewed during the case study felt that the pre-preg process developed by Company A was the more favorable technology given their understanding of program requirements. However, this sentiment was not echoed by the rest of the team or by Company A management, and the company ended up doing exactly the opposite on two dimensions, first in selecting the RTM process instead of pre-preg and then in choosing Omega as the supplier instead of having the parts made at Company A. While this incident ended up being only a minor stumbling block in the decision process as a whole, it points to the creative tension that is inherent in a cross-functional teaming arrangement. Allowing the team sufficient time to discuss each decision fully and training them in diversity and communication issues will help make such exchanges a positive part of the product development process.

5.4.4 Influence of Technology Strategy on Team Decision Making

Another aspect of the decision to adopt RTM is its impact on the strategic position of the Company A and Omega companies. In interviews with the IPT members, none of them recalled considering the long-term role of RTM in the organization as being an important factor in the decision to adopt the new technology. Pressure to reduce costs for the Alpha program and to meet the near-term production schedule seem to have dominated the decision process. Interpretation of the strategic importance of the technology is therefore difficult. Based on the outcome of the internal spar case, several observations regarding Company A's strategic intent for the RTM technology can be made. While the engineers were considering what was best for the Alpha internal spar, Company A management may have been considering the future of composite materials technology at the company as a whole.[7] Since Omega is one of the only firms with any experience using RTM on primary aircraft structures, Company A may need access to their expertise to stay at the forefront of the technology. For a company heavily involved in the fabrication of aircraft structures, RTM certainly would appear to be a critical technology for the creation of low-cost, high-quality parts.

Contradictory evidence exists, though, that calls into question the likelihood of Company A management's motivations being based on the search for a strategic foothold in composite

---

[7] This statement reflects some conjecture on the part of the author, since the senior managers involved in the Alpha program were not available for interviews during the time of the case study.

technology. Company A initially enacted a memorandum of agreement with Omega for the transfer of RTM technology: Company A would be allowed to use the Omega process to make Alpha parts in Company A facilities, in exchange for giving the supplier greater visibility within the company (both military and commercial divisions) as a reliable RTM source. Although the agreement was signed (and Company A did provide the in-house visibility), Company A was never able to follow through fully on the plan due to a lack of program funding for in-house RTM development. The team leader describes the state of the relationship between Company A and Omega Systems as "an open door," with both partners still accepting of the possibility for future opportunities, although the agreement is considered to be "dormant." Meanwhile, Omega's contract specifically forbids any transfer of their RTM technology expertise outside of the Alpha program. This includes the personal knowledge of Company A manufacturing engineers who worked with Omega to develop the Alpha process (i.e., they may not use what they learned at Omega to assist other R&D efforts at Company A). It is unclear at this point to what extent this contract clause restricts Company A's strategic utilization of the technology. As of the time of the case study research, MR&D was considering an independent multi-million dollar investment for the development of RTM technology (to be used on non-Alpha programs), which may indicate that Company A is serious about being an RTM player in the future regardless of the decision made for the Alpha spars.

5.4.5 Potential Value of Formal Risk Assessment

The effort that the Company A IPT put into the internal spar development was considerable. In the words of one team member:

> I have never seen a situation where Company A has off-loaded work that required more oversight than the spar process at Omega. ...In my estimation, there were probably on average two Company A people on site at Omega for close to two years, and I doubt that we will ever know what the true overall cost of this support was.

As this comment shows, it is extremely difficult to judge the overall cost of a technology development program, especially during the early stages at which decisions must be made to proceed along a certain path. One aid to making these judgments is the use of a formal risk assessment methodology. Such tools attempt to capture the relative risk of different options so that they can be compared on a quantitative or at least qualitative basis. Assessments may include analyses of how much such factors as cost, development schedule, technical performance, or manufacturing quality may vary depending on the outcome of uncertain parameters. Formal risk assessment is especially important for a cross-functional body of decision makers, since a risk analysis gives them a more concrete means to compare results from different functional perspectives. A formal language for assessing risk can also help to span differences in the backgrounds of the participants, most notably in bridging the gap between technical and non-technical team members.

In the case of the internal spar IPT, the team's analysis touched on questions about the accuracy of their data, but this was the closest they got to a true risk assessment. A "high-medium-low" assessment of the developmental risk for RTM versus pre-preg was performed at the program management level as part of the initial decision to start the RTM development project. However, conversations with personnel involved in the Alpha project seem to indicate that sometimes the level of risk that senior management finds acceptable can be greater than the level of risk *perceived* to be acceptable by IPT members. These differences can complicate the analysis of the costs and benefits associated with implementing new technologies. Several of the Alpha team members expressed their dissatisfaction with the lack of established risk methodologies within Company A. Without a recognized and universal tool for measuring developmental risk, they explained, team members are unable to talk about risk issues, and, consequently, they *don't* talk about them. One engineer commented that the development and implementation of risk assessment tools should be the responsibility of the Company A company as a whole, not as a task for their particular IPT. This certainly appears to be a reasonable request of the company, since such a tool could be used by many programs.

5.5 Case A Summary

The RTM technology transition ended up fitting neatly into the two-year slip in the overall Alpha program schedule, providing an interesting example of how external environmental effects can stimulate the adoption of new technology. During this period, the internal spar IPT was able to meet the considerable challenge of learning about, analyzing, and developing a new manufacturing process for the company. By leveraging the cross-functional format, the team was able to combine their expertise to take into account many different variables in the adoption decision, including cost, manufacturability, and technical performance. Their decision to select the Omega RTM process for the Alpha production was not made simpler by Omega's position as an outside vendor. If anything, deciding to outsource the process increased the level of oversight and development assistance that the IPT was required to give. In exchange, the program is able to enjoy considerably lower unit manufacturing costs, one of the primary customer requirements. Company A's experience with having IPTs make decisions about new technology adoption therefore appears to have been a positive one overall.

In looking at the decision process for the internal spar, the organizational implications of the IPT format quickly become apparent. The ability to communicate to others with varying backgrounds, to assimilate and synthesize unfamiliar information, and to make decisions that optimize a design to satisfy a set of complex and conflicting requirements were all important elements of the team members' responsibilities. While they may have encountered minor stumbling blocks along the path to a final decision, mostly in the form of differences of opinion and opposing functional perspectives, the team as a whole was able to develop the RTM technology to a point where it provided significant cost and quality benefits to their product. As a company, Company A should work to ensure future such achievements in product development by establishing a more formal network of organizational support for the IPT format, thereby bringing such important elements as strategic planning, risk assessment, and technology championing into the product development process.

CHAPTER 6

CASE B: HIGH-SPEED MACHINING[1]

Company B, a large military and commercial airframe and systems integrator, was responsible for the design and construction of the forward fuselage and wings on the Beta Program aircraft upgrade.[2] Although the mission profile of the plane required it to be approximately 25 percent larger than its predecessor, the Pre-Beta, in order to meet requirements for range and payload, the customer also considered weight and manufacturing cost to be major issues. Consequently, engineers at Company B put considerable effort into analyzing the design and production plan of the plane to take advantage of all possible weight and cost savings. Part of this effort included the introduction of high speed machining (HSM) fabrication into the design of parts. The decision to use this technology to replace conventional machining and sheet metal techniques on certain sections of the Beta involved people from many different groups and functions across the company and consequently brought together a diverse set of perspectives as to what characteristics of a new technology are important to the product development process. The process of technology diffusion in the organization that resulted from the HSM development has had a great impact on the outcome of the overall Beta program, both in terms of significant programmatic savings in the target areas of weight and cost, but also in insights concerning the influence manufacturing capability can have on aircraft design. This case study presents the history of the HSM development and implementation and explores such organizationally important issues as the management of process versus product technology development, the impact of individuals in a complex organization, and the role of IPTs in program decision-making.

6.1 Overview of the Organization

The development of the Beta fighter jet was accomplished through a system of IPTs, organized by a physical decomposition of the major subsystems of the aircraft, as shown in the organizational chart in Figure 6-1. Day-to-day design and manufacturing activities are the purview of the working-level engineers and technicians found at the detailed end of the product architecture,

---

[1] Note: Data and archival materials for this case study were provided by Company B. (Company and program names have been disguised to maintain anonymity). Information from research interviews with company employees provided the basis for the descriptions of the technologies, the development process, and the structure of the organizations. Except where noted, direct quotes from employees are identified only by the individual's function or rank for privacy reasons. Representatives from the company were able to review the descriptive portions of the case study (i.e., the description of the technology and the history of the decision in the organization) and to identify any areas that they felt required clarification. Subsequent interpretation and analysis of the data were the sole responsibility of the author.

[2] Another manufacturer makes the center/aft fuselage assembly and ships it to Company B for final assembly.

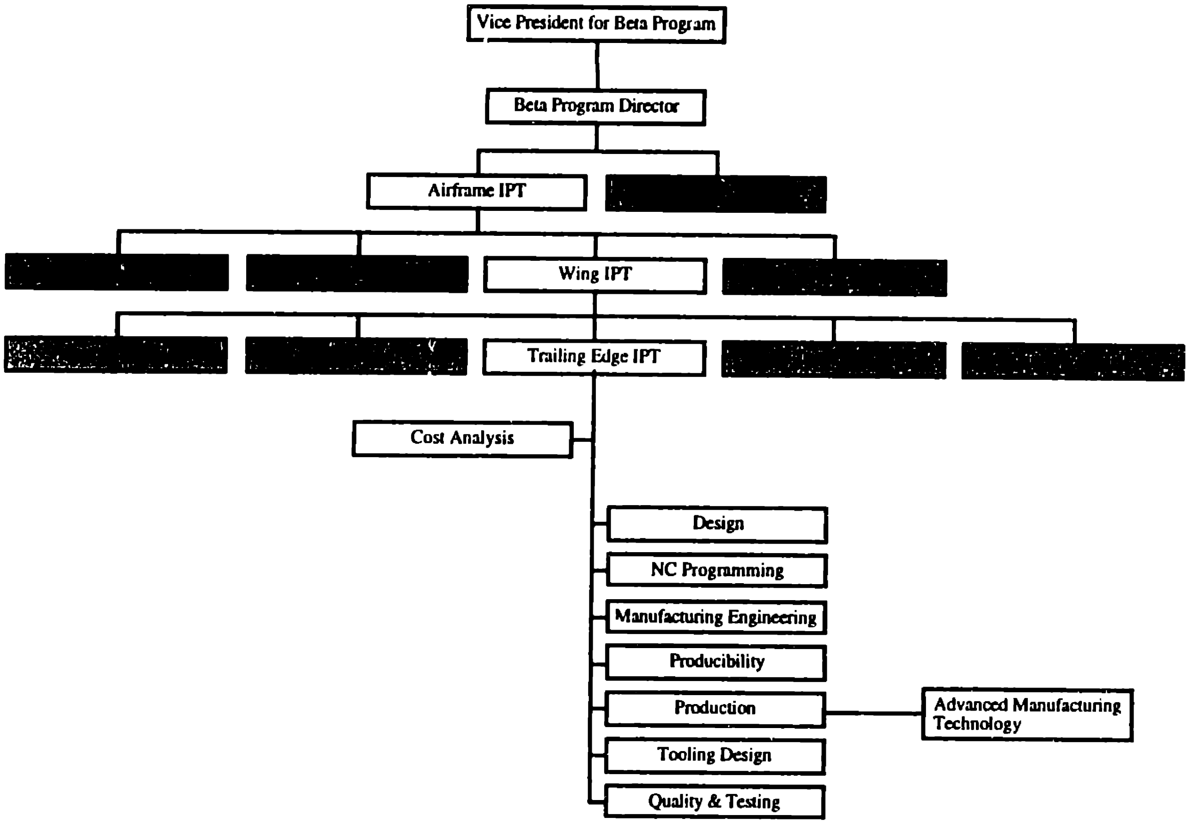

Figure 6-1. Company B Organization Chart
[focus on trailing edge IPT in the Beta Program wing subsystem]

known at Company B as "Level 5." In Figure 6-1, the inner wing, leading edge, trailing edge, inner torque box, and outer wing teams are all Level 5 IPTs. The Level 5 team leaders serve a dual role as team members on the Level 4 IPTs (here, the center fuselage, aft fuselage, wing, and forward fuselage). Responsibilities are similarly cascaded up the organizational chain to the program office (Level 1). As will be seen in subsequent sections, the decision making authority resident at different levels varies with the type of decision under consideration, although, in general, higher level approval is required for decisions that affect more than one team.

Of particular interest to this case study is the Level 5 trailing edge team within the wing subsystem, the area in which high speed machining was first applied to a real product design. This IPT contained members from the design, manufacturing engineering, and quality functions of the organization, as well as a representative from the production area. Participation from the factory floor was a relatively new inclusion on Company B's product development teams, begun in accordance with the integrated product and process development (IPPD) initiatives put into place in the early 1990s. Accounting and cost analysis people were consulted on a part-time basis as needed. In addition, an engineer from the producibility department was also intimately involved with the team's activities and figured prominently in the initial development of HSM capability (see Section 6.3). His connections with Company B's process R&D group, Advanced Manufacturing Technology (AMT), provided a link between the lab and the program. The relationships between the many individuals and groups involved in developing the technology are examined further in Section 6.4.

6.2 The Technology

The high speed machining process is not that different from a conventional machining process, except for the fact that, as the name suggests, the milling is accomplished much more rapidly. Table 6-1 compares the basic characteristics of the two processes. In general, HSM involves more revolutions per minute of the cutter, smaller cuts, and a more powerful motor. Several more precise definitions for HSM have been proposed, including:

- the spindle speed is greater than 10,000 revolutions per minute (RPM)
- the peripheral speed of the cutter is greater than 2,500 surface feet per minute, or
- the impact frequency of the tool approaches the natural frequency of the system (i.e., the part).

The notional diagram in Figure 6-2 shows the basic steps of the HSM process. Once the aluminum stock is positioned in the mill, the operator initiates a numerically controlled (NC) program running on a computer system linked to the machine. The computer program, created from the part drawing, automatically controls every aspect of the milling sequence, including the cutter speed, position, and depth of cut. A cutter made of solid carbide steel mills out all of the unwanted metal,[3] leaving the finished part shape within a "picture frame" of stock that holds it during the machining steps. This frame allows parts to be machined without the use of mill fixtures. The stock is flipped or rotated as necessary to give the cutter access to all sides of the part. Once all of the features of the part have been machined, the material is removed from the mill, and the small picture frame holding tabs are cut off manually to free the part from the stock. The part is deburred to remove any rough edges and then receives any necessary finishing treatments, such as corrosion coatings or paint.

---

[3] The metal chips removed during the milling process are sold in bulk to aluminum vendors for recycling.

Table 6-1. Comparison of Machining Processes
[Note: Values given for aluminum fabrication. Exact rates and tolerances depend greatly on the machine's quality and age and on the machine shop's process capability.]

Variable	Conventional Machining	High Speed Machining
Spindle speed	• 2,000 - 4,000 RPM	• 20,000 - 40,000 RPM
Cutting feedrate	• 20 - 40 inches per minute	• 200 - 600 inches per minute
Minimum web thickness	• ≈ 0.050 inches	• ≈ 0.010 inches
Achievable tolerance	• ≈ 0.010 inches	• ≈ 0.004 inches
Highest cost component	• set-up time	• programming time

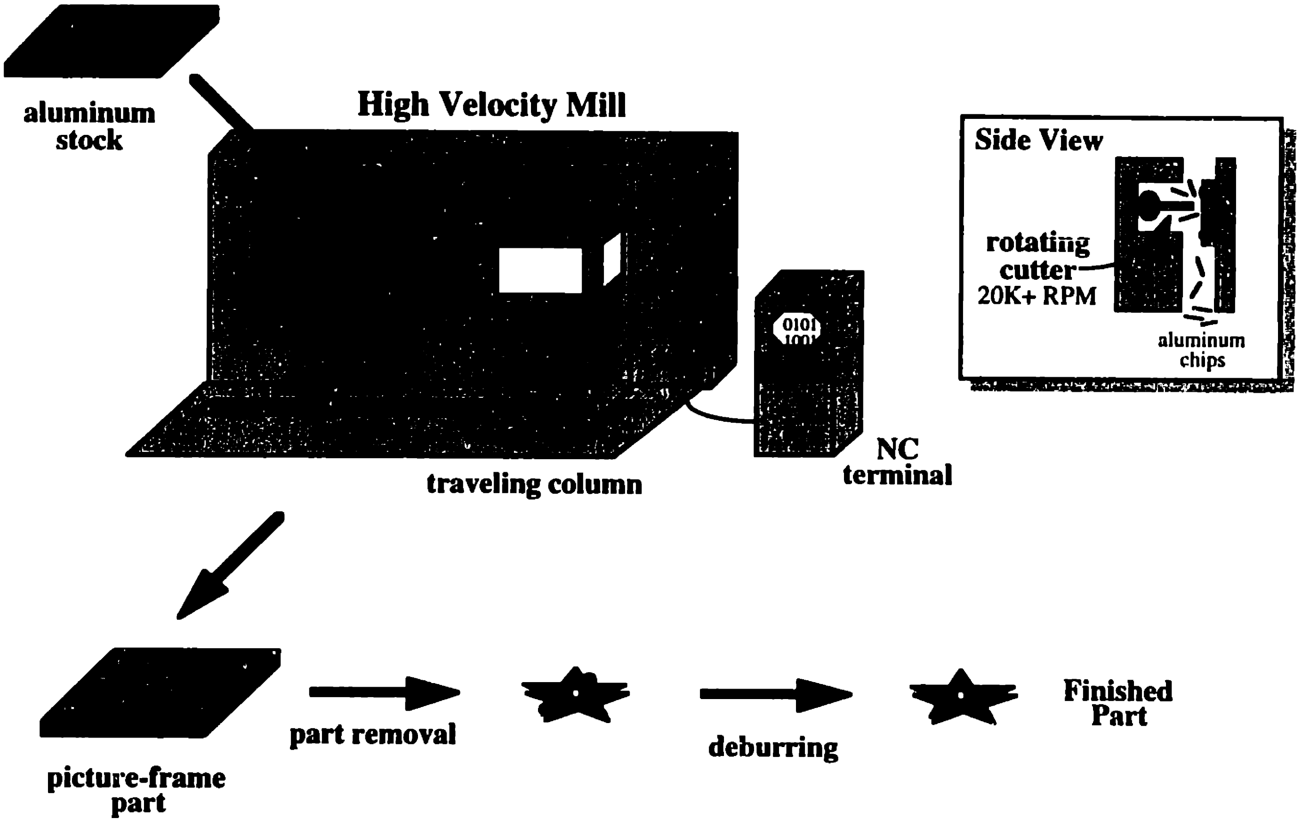

Figure 6-2. Simplified High Speed Machining (HSM) Process
[notional diagram; not to scale]

In addition to the high rotational speeds associated with HSM, engineers at Company B developed methods for optimizing the way in which cuts are made, which they have termed the "high speed step technique" (HST). Three simple process rules make up this technique:

(1) make many small cuts at a very high spindle speed

(2) maximize stiffness at the point of cut by using the uncut material to stabilize the cutting area, and

(3) once a finished surface is cut, do not cut near that surface again.

HST removes less metal with each cutting pass and therefore requires more total cuts than the conventional approach (rule 1). However, HST in turn allows thinner webs and ribs to be created since it minimizes vibration (rule 3). Taking small cuts also reduces thickness variation in the part by virtue of the lower cutting forces, which minimize the defection of the part and the cutter. Finally, high speed technique uses the uncut aluminum stock to stabilize the cutting area, which also reduces part variation (rule 2). It is important to note that using HST does not depend on having access to a high speed mill. Except for the reduction of machining time, the benefits of HST can be obtained even with a conventional, low speed machine.

The benefits of HSM can be grouped in roughly three categories: speed, quality, and design. The first, and most obvious, benefit of HSM is that parts can be made faster, which reduces manufacturing cycle time. Although more cuts are made on an HSM part than on a conventional one, the greatly increased spindle and traverse speeds result in roughly a two-thirds reduction in machining time. At the same time, the quality of HSM parts is higher than those made with conventional techniques, and the surface finish is smooth enough to require little to no post-production polishing.

High speed machining can be used as an alternative to two existing metal structure technologies. The first is the obvious substitution of HSM on machined parts made with traditional low speed methods. In addition to being able to make the same parts better and faster, however, HSM offers some unique opportunities to influence the design of a part. The ability to machine very thin webs allows sheet metal assemblies to be replaced with single machined parts, often with an overall weight savings. As will be discussed in subsequent sections, HSM came to be understood as a new way of making aircraft, not just a new way of making parts. Its primary benefit in this regard is its ability to create a more unitized design.[4] A subassembly that previously had been made of several sheet metal components riveted together can be replaced with a single machined part. This

---

[4] "Unitized design" refers to the concept of replacing an assembly of individual parts with one single part. This term began being used at Company B in mid-1993, as the HSM process began to be applied to design changes for the Beta.

can dramatically reduce the total part count in a complex assembly. For example, the detailed part count for the aircraft was cut from approximately 14,000 parts in the Pre-Beta model to approximately 8,000 in the Beta version, in part due to the merging of sheet metal parts into HSM units (and in spite of the Beta plane being 25 percent larger than its predecessor).[5] HSM can also lower the weight of a part, since the overlaps inherent in sheet metal splices are eliminated when parts are combined. Parts themselves can also be smaller, since the smaller cutter diameter and chip size used with HSM allow smaller corner radii to be created. Fasteners can therefore be placed more tightly into corners, which permits the design of the part to be more compact.

The reduction in part count brings with it associated benefits of cost, manufacturing time, and quality. There are fewer parts that fit together better, which reduces assembly time and increases the accuracy of fit-up. From a materials handling point of view, there are also fewer tools to make, store, repair, and keep track of, especially with the picture framing technique that allows most of the part-holding function to be incorporated into the digital data of the part design. HSM parts also require far fewer fasteners than sheet metal parts, an important consideration in a large product, since, in large quantities, fasteners add weight, assembly time, and inventory control burden.[6] Making fewer parts also translates to less deburring time, since this step can be done on the whole subassembly at one time instead of on each smaller sheet metal component. Inspection time and documentation are reduced for the same reason. Finally, parts can be made with less dimensional error, since the high rate at which metal chips are removed serves to transfer heat away from the part and limit heat distortion. The reduction in the number of manual set-up changes also acts to reduce dimensional error.[7]

The technical requirements for implementing an HSM system go far beyond just possessing the ability to mill out metal at a faster rate. Achieving high quality output with any degree of repeatability and cost effectiveness subject to such extremely high spindle speeds and feedrates raises many technical issues. Successful implementation of HSM requires innovation in complementary technologies to answer such questions as:

---

[5] As will be shown in Section 6.3, this result is somewhat convolved with the effects of other product improvement process (PIP) initiatives undertaken at the same time, such as variation simulation analysis, identification of key characteristics, design for manufacture and assembly (DFMA) analysis, and other process capability improvements. The switch to HSM does, however, explain a significant portion of the part count reduction.

[6] For example, the C-17 aircraft, made with conventional sheet metal and low speed machining techniques, carries approximately one million fasteners!

[7] Each part re-orientation can result in a loss of as much as 0.005 inches in the tolerance chain.

- how to damp out vibrations?
- how to hold the cutting tool?
- how to make cutting tools that will not wear quickly?
- how to get the machine's electrical controllers to process NC data fast enough to machine complex curves?
- how to synchronize five-axis movement of large structures (i.e., the traveling column)?, and
- how to handle chip removal?

The expertise required to answer these questions often falls outside the capabilities of a machine shop, and HSM users are left to depend on machine tool vendors for the development of associated complementary technologies. As will be shown in the next section, the relationships that are needed to keep such a complex system in balance often require an industry-wide effort to coordinate.

6.3 The History of the Technology Transition

This section describes the early development period of HSM and the subsequent analysis that was undertaken to explore its application to the Beta airplane. Early results from the first production use of HSM are also presented, along with an assessment of the future of the technology at Company B.

6.3.1 Early Development

From all accounts, the history of the HSM implementation at Company B revolves around the initiative and technical skills of one of the firm's producibility engineers, Mr. Smith. In 1986, Smith came across a research paper co-authored by engineers from another Company B facility, describing their work on the new concept of high speed machining. The idea of milling at much higher spindle speeds had been proposed many years earlier, although it had not yet been implemented in practice. As a former machinist, Smith was intrigued by the possible benefits of reducing machining time, and he began to think about how such a system could be developed at Company B. In his work on various aircraft structures over the next few years, he noticed that thick ribs were often required for tolerance control in the manufacturing process, although the designers preferred the structural sections to be as thin as possible for performance and weight reduction reasons. As his understanding of the HSM concept matured, Smith began to consider the broader implications of the technology in terms of how it could impact part design, not merely manufacture the same parts more quickly. In 1991, Smith was assigned to the producibility department's "core" team and received a small amount of seed money from producibility's on-going process improvement budget in order to work full-time on the development of an HSM capability.

By the following year, Smith's work on the HSM concept had developed far enough for him to be able to put together an internal white paper proposing a more formal research effort. The proposal was first funded as internal research and development (IRAD). Later, contract research and development (CRAD) money from the Air Force was obtained to fund a joint project with the University of Florida, where Smith had been in contact with a faculty members who was researching high speed spindles. During this early development period, funding levels were fairly modest, on the order of $150,000 per year. This money was enough to retrofit a mill in the Advanced Manufacturing Technology (AMT) laboratory with a high speed spindle and to cover personnel charges for Smith and some part-time technicians from AMT. A series of tests were run to explore the effects of different parameters in the HSM process. The goal was to characterize the capabilities of HSM in terms of dimensional control. For example, one test attempted to determine the minimum web thickness the machine could hold over a number of feet within a certain tolerance.[8] Although the tests were run in Company B's facility, the Florida professor provided help in understanding the dynamics and vibrations of parts and spindles, in order to more effectively manufacture thin structures. The test results were used to develop the basic process rules for high speed technique described in Section 6.2. Over time, the development team was also able to determine more precise measures of process capability, such as the minimum achievable web thickness and pocket depth.

6.3.2 Application to Real Designs

By 1992. Smith and his associates in AMT had developed Company B's HSM capability to the point where they were ready to start making parts from real aircraft designs. The retrofitted machine in the AMT lab could accommodate parts with at most a three-foot diameter, so they began to look within the company to identify candidate designs. Smith heard of a colleague on the Beta program who was working on the design of a three-foot part, the aileron closure rib for the trailing edge, which had been made via sheet metal build-up in the Pre-Beta version. This designer, Mr. Jones, had previously worked with Smith on another project and was very willing to try machining his part with HSM. Using Jones' three-dimensional computer wire frame model for the rib, the two men started working closely together on its implementation in HSM. Many tests were performed to determine how thin the ribs could be and how tight the corner radii could be on a real part (as opposed to the simple mock designs that had been used during the earlier tests). Within about a month, Smith and Jones were able to fabricate a high quality aileron rib. Made of a single machined part instead of four sheet metal components and an injection-molded attachment, it

---

[8] The testing was performed according to the Taguchi method, or "design of experiments" [Phadke, 1989], which seeks to capture the greatest statistical significance within a practical number of parameter variations.

weighed approximately one-third less than its counterpart from the Pre-Beta aircraft (see Table 6-2). These results generated much interest from Jones' management in the Beta program, since the company had recently made a commitment to their customer to reduce the overall weight of the aircraft by 50 pounds. Although the aileron was a relatively small part, and the weight reduction obtained with HSM was less than a half-pound, people in program management began to realize that HSM might promise significant weight savings if its process capability were to be applied more broadly on the aircraft. Some nervous concerns were raised within management about the riskiness of adopting a relatively untested manufacturing technology in the middle of the program, but Smith's high credibility with the design community helped gain acceptance for further HSM development.[9] Consequently, Smith and Jones began applying their HSM process and design rules to other Beta parts.

One of Jones' main concerns at this point (mid-1993) was the three-foot constraint on part dimensions imposed by the size of the retrofitted mill. He felt that they were ready to begin pushing the limits of the current process capability so that greater weight savings could be achieved. After numerous conversations between the two engineers and the AMT technicians, they agreed to try machining a much larger part, a six-foot aileron spar. Since the spar could not fit on the development machine, they decided to use one of the Company B Machining Center's five-axis gantry mills. This machine tool was not capable of high speed revolutions, but the decision was made to test out production of the spar using high speed technique with a low speed spindle. This effort proceeded at a slow pace, due to the difficulties of reprogramming the NC instructions for the part according to high speed technique. New design and process parameters also had to be established in order to combine the sheet metal components into the optimum machined assembly. The development team by this time included representatives from manufacturing engineering and production, as well as designers from Jones' Level 5 trailing edge IPT. After about eighteen months of work, the team was able to produce the spar with an acceptable level of repeatability. The part count had been reduced from twelve parts to one, and the weight had been cut by over 25 percent (see Table 6-3). From this point, the HSM project received a great deal attention from both Company B engineering management and the Beta program. Designers from other IPTs in the wing and fuselage teams asked how they could use HSM on the parts in their subsystems, so Smith started making presentations on the technology in various Level 4 and Level 5 IPT meetings.

---

[9] At this time in 1992, the Beta was just entering the engineering manufacturing development (EMD) phase, in which several complete units of the aircraft were to be built.

Table 6-2. Impact of HSM on the Aileron Closure Rib

Aileron Closure Rib	Pre-Beta	Beta
Number of pieces	4	1
Number of tools	5	0
Tool design & fab (hr)	232	0
Part fabrication (hr)	2.7	1.7
Assembly (hr)	1.7	0
Weight (lb)	0.68	0.45

Table 6-3. Impact of HSM on the Aileron Spar

Aileron Spar	Pre-Beta	Beta
Number of pieces	12	1
Number of tools	15	2
Tool design & fab (hr)	158	40
Part fabrication (hr)	7.3	5.8
Assembly (hr)	5.7	0
Weight (lb)	4.7	3.48

6.3.3 Beta Decision Process

Once word of Smith's progress was out, the Beta Program Office instructed all of the design teams to look for opportunities to insert HSM as a weight-reduction tool. A cross-program analysis was performed to identify candidate parts for re-design. This analysis consisted of tradeoff studies performed from several perspectives, including cost, design, and manufacturing. (A summary of the analyses from various perspectives is shown in Table 6-4.) Smith and his development team performed or contributed data to many of the technical studies. In addition, several of the Level 5 IPTs were proactive in attempting to implement the new technology, with the trailing edge team certainly at the forefront due to Jones' prior involvement in the development effort. Support functions outside the IPTs were consulted as well, such as cost accountants and people from the Machining Center. It is important to note that, in this decision process, HSM was being compared to two alternative processes: sheet metal build-up and conventional machining. That is, HSM might

Table 6-4. Evaluation: Conventional Machined Parts vs. HSM Parts; Sheet Metal Assembly vs. HSM Parts

Issue	**Analysis Performed**	**Results (Conventional Machined Part vs. HSM Part)**	**Results (Sheet Metal Assembly vs. HSM Part)**
Design	• Computer models of sample parts	• Equivalent (some size and weight savings with HSM)	• HSM preferred (weight savings)
Manufacturing	• Sample parts made on low speed machine with high speed technique	• HSM preferred for high-labor parts (time savings)	• HSM preferred (improved tolerances; less finishing required; assembly time savings)
Quality	• Fatigue analysis of test parts • Comparison of part quality	• HSM preferred (less heat distortion)	• HSM preferred (improved tolerances; parts fit together better)
Cost	• Empirical formulae for unit cost extended parametrically to HSM environment	• Equivalent	• HSM preferred (recurring cost savings outweigh non-recurring cost of NC programming)

be selected to replace a sheet metal assembly, which would require redesign of the parts, or merely to speed up an existing conventional milling process.

One of the first studies that was performed was an analysis of the costs associated with HSM versus those with conventional machining and sheet metal. From a development cost point of view, bringing Company B's HSM capability from the laboratory to the production floor would require a great deal more money, since the company already had in place well-established conventional machining and sheet metal facilities. The comparison of unit costs for the three processes was not as clear. Existing empirical formulae for the cost of machined parts were used to generate a base line unit manufacturing cost for conventionally made parts. These parametric methods considered the cost impact of various part features, such as the size of the part, the number of sides, the number of flanges, the depth of pockets, and the number of required tool changes. Since moving from a conventional machining process to HSM would not require re-design of the part itself but only of the NC programming and set-up sequence, the resultant conventional base line cost was used to establish a relative HSM manufacturing cost. Tests in the development lab showed that HSM could make a part in roughly one-third the time of the conventional process. For the initial HSM cost estimate, the faster cycle time, higher quality, and fewer tool changes of HSM were balanced against the Machining Center's limited high speed capacity. Since a high speed machine would only have one active spindle, where as a conventional gantry mill had three (i.e., three identical parts could be manufactured simultaneously), the cost accountants' conservative initial estimate was that unit cost of the two processes would be approximately equal.[10] Similar analyses were performed to compare HSM to sheet metal assembly, based on the costs of sample parts done with sheet metal for the Pre-Beta production model. Although actual costs for machined parts were known to depend a great deal on the expertise of the NC programmer, these empirical formulae were considered a reasonable first estimate. Therefore, from a cost perspective, there was no disadvantage to proceeding with the adoption of the HSM technology.[11]

From a design perspective, Jones and his colleagues on other IPTs were concerned with identifying weight reduction opportunities via part combination. Three-dimensional computer models were used for the analysis, allowing the engineers to transmit design drawings around the plant electronically for quick review. Manufacturing engineers and NC programmers were consulted for their input on what types of parts would be most appropriate for machining instead of sheet metal assembly. Smith also continued to present the growing collection of HSM process rules and dimensional control information to IPTs on the program so that the designers could incorporate HSM capability into their evolving designs. Convincing the designers to accept HSM was not entirely without difficulty, however, since they were being asked to commit to designing thinner part features even though the Machining Center at Company B did not yet have the capacity to meet production rates with HSM machines. Therefore, from a design standpoint, acceptance of HSM was mixed.

NC programmers in the Machining Center also worked on trade studies to examine the costs and benefits of HSM. An experimental work package was initiated to study the production methods that would be required to make HSM parts. This consisted of a series of tests using Smith's high speed technique on the Machining Center's low speed equipment. Each different machine type was tested with a sample part design, which was selected to be a five-axis geometry instead of the

---

[10] That is, the relative costs of the processes were found to relate almost solely to the per part cycle time. The one-third time savings with HSM was cancelled out on a per part basis by the fact that the conventional set-up could make three parts at once.

[11] Note that the required capital equipment purchases for new HSM machine tools were not included in the cost analysis at this stage of the technology evaluation. Capital expenditures are considered only at the company level, since they cannot be recovered through charges to government programs. This analysis was performed much later by Company B's Strategic Modernization Group, who handled the contracts for a new high speed machine facility.

simpler three-axis designs used in the AMT laboratory.[12] Separate analyses were performed for parts that had formerly been constructed of sheet metal and those done with conventional machining.

When evaluating sheet metal versus HSM, the key question was whether the part could be machined, that is, if the design tolerances and thicknesses fit within the HSM capabilities. If so, then from a manufacturing point of view, the part was preferred to be done in HSM, because of the time and cost savings from piece-count reduction. When considering a change from conventional to high speed machining, the choice was a bit more complicated. Given the lack of experience with HSM in the Machine Shop, low speed manufacture was preferred for parts that required a high degree of accuracy. The new availability of high speed technique reinforced this decision. On the other hand, HSM was a better choice for high-labor parts, those that required many cuts and many set-up changes, due to HSM's faster cycle time. In both cases, the cost of re-doing the NC instructions for any part transferred to the HSM system was estimated at approximately 600 hours per part, an investment that would be paid back quickly by the 6:1 time savings that the manufacturing people expected to gain from HSM versus conventional machining.[13]

Even though the quality of the HSM test parts was very high, the manufacturing people working on the evaluation predicted difficulties in transitioning to a full production environment. Since the NC programmers did not have experience with high speed technique, they needed time to experiment with writing instructions for complex five-axis parts. When the time later came to fabricate parts for the engineering manufacturing development (EMD) phase, this inexperience would be found to lead to some missed schedules. From a risk perspective, manufacturing capacity and capability would prove to be major issues in the evaluation of the HSM technology. Specifically, once a great number of parts were committed to HSM, any down time of the machine would have a large impact on production schedules. With no existing supplier base for HSM, managers at Company B needed to find a way to alleviate capacity constraints.

The final perspective that was considered in the analysis was that of the customer. Customer engineers who reviewed the HSM proposal were concerned with the potential fatigue of thinner parts and therefore required Company B's strength engineers to perform an additional fatigue

---

[12] A three-axis design requires movement of the cutter in three dimensions: x, y, and z. A five-axis part requires additional cutter rotation about the x- and y-axes to accomplish internal curvature of the part features.

[13] Note that this time savings estimated by the manufacturing people was considerably higher than the more conservative 3:1 savings estimated by the cost accountants.

analysis on the candidate HSM parts. The in-service repair of integrated structures was also an issue, since it would no longer be possible to replace subsections of the parts as could be done with the sheet metal assemblies. In the end, however, the customer's program office was most concerned with the affordability of the aircraft and therefore appreciated the ability of HSM to reduce weight and manufacturing cost.

When all of these competing viewpoints were taken into account, the Beta program office at Company B decided to go ahead with building up HSM capacity to meet the EMD, low rate initial production (LRIP), and full series production demand. As Smith had realized during the development studies, the deciding factor was not the cost savings that faster machining would bring, but instead the promise of improved quality and reduced weight (from thinner flanges, unsupported webs, etc.) that would together improve the performance capability of the aircraft.

6.3.4 Into Production

In 1994, the first production items for the EMD phase were fabricated with high speed technique, using retrofitted machines in the Machine Center running at 12,000 RPM (slightly higher than conventional low speed). This strategy allowed the team to demonstrate the incorporation of thin section, integral machinings into the design without risking their ability to produce the parts if the HSM capacity did not come on line as quickly as expected. A total of 162 parts for the Beta aircraft were assigned to be made with the HST process. These parts were selected by a committee led by the IPPD production representative. Parts considered good candidates included those with such part features as:

- J-flanges (a part feature which can be hard to access with a large conventional cutter[14])
- thin floors and webs, and
- large parts with high set-up costs.

As the EMD phase continued, managers at Company B began to plan the capital investment required to increase their capacity for high speed machining in the subsequent production phase. The Machining Center worked with Ingersoll, a machine tool vendor, to design a high speed mill specifically for the Company B facility and the Beta production load. In 1996 (after the conclusion of the EMD phase), the mill was installed, consisting of a 4 foot by 40 foot milling surface that could accommodate larger aircraft parts.

---

[14] A typical conventional cutter ranges between two and three inches in diameter, while the maximum diameter of an HSM cutter is 0.75 inch.

Still concerned with capacity issues as they began to ramp up production on the new mill, and faced with increasing demands from other programs that wanted to convert to the HSM technology, the leadership of Company B placed another order with Ingersoll for the construction of a one-of-a-kind high velocity profiler, to be fully operational by early 1999. This machine, designed with two independent cutting heads operating at 20,000 RPM, will be used in conjunction with the high speed mill to meet Beta production rates. The two machines together represent approximately $50M in new capital equipment. At the same time, engineering managers at Company B decided to mitigate their risk by conducting a vendor workshop on the HSM technology, in order to build up the HSM supplier base in case they needed to off-load parts in the future.[15] At the same, Company B formed an HSM consortium with several other aerospace manufacturers in order to approach machine tool builders "as a single voice." The hope was that the increased market power of the consortium would be an incentive for tooling vendors to devote more resources to the development of HSM-compatible cutters, motors, and other auxiliary technologies.

In late 1997, the Beta entered its first low rate initial production stage (LRIP-1), with the goal of making parts on the new high speed mill using high speed technique. Parts for the Beta are starting to be produced, along with cargo doors and speed brakes for other aircraft built by Company B. However, the mill was running at only 40 percent up-time, and manufacturing people were still working out problems with the operation of the fifth axis. Although the LRIP schedules appear to be achievable, a more complete implementation of the HSM technology will definitely be required for the company to meet the requirements of the subsequent full series production phase.[16]

6.3.5 Results of the Decision

After the redesign effort to incorporate HSM, the Beta version was found to have 42 percent fewer parts than the Pre-Beta version, even though the new plane is 25 percent larger. Sizeable reductions in weight were achieved in nearly all subsystems of the aircraft structure, along with a substantial shift towards a unitized design. (For example, Figure 6-3 shows how one assembly, the nose barrel bulkhead, was dramatically reduced from 90 pieces to just one single HSM part.) These results are somewhat convolved with effects of other product improvement process (PIP) initiatives that were undertaken during the break between the EMD and LRIP phases, such as

---

[15] As a result, the number of vendor that are capable of making four-axis HSM parts has increased, although Company B remains the only manufacturer with five-axis capability.

[16] Note that this is a cost issue rather than a capacity issue. The Company B facility has enough capacity to meet the Beta production demand by making parts with conventional low speed machining. In order to take advantage of the cost benefits that HSM provides, however, they will need to achieve a better up-time rate on their high speed mills.

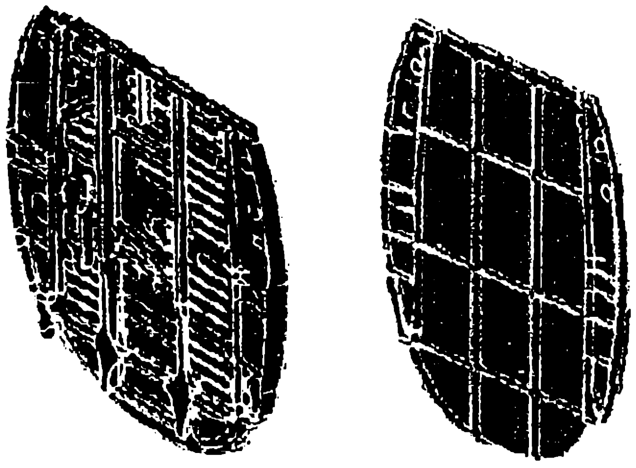
Pre-Beta model
Beta model

Figure 6-3. Impact of Unitized Design on the Nose Barrel Bulkhead
[In the Pre-Beta model aircraft (left), the nose barrel bulkhead consisted of an assembly of 90 sheet metal pieces. In the Beta model (right), the same part was designed as a single machined piece.]

variation simulation analysis, identification of key characteristics, design for manufacture and assembly (DFMA) analysis, and other process capability improvements. Notwithstanding the contributions of these other efforts, the introduction of HSM certainly played a major role in enabling the change to a more unitized design. Reactions to the technology implementation are generally positive, with individuals all across the facility sharing the realization that HSM can save weight as well as decrease cycle time. Some dissenting views are present, however, mainly consisting of concerns that full production capacity is not yet available. Given the unanticipated length of time needed to get the high speed mill fully operation, some manufacturing people feel that too many parts have been assigned to HSM, ones that perhaps do not need to be since they do not require five-axis capability.

6.3.6 Next Steps at Company B

Today, engineers at Company B have implemented the HSM technology to a greater extent than any other firm in the aerospace industry, and the firm is probably is the only one in any industry that has both the technical capability and the capacity to make large aluminum parts with HSM. The near-term goal at Company B is to continue to improve the HSM process in order to make higher quality parts at a cost comparable to conventional machining and considerably less than conventional sheet metal assembly. As discussed earlier, the most pressing issue seems to be increasing the up-time of the new high speed mill, as well as preparing for the installation and implementation of the high velocity profiler so that the plant can meet the Beta production schedules.

From a technical standpoint, two extensions of the HSM concept have emerged as challenges for future innovation. The first is high speed machining of titanium. As a tough yet light material, titanium is an attractive material for aircraft design. However, it is also expensive and time-consuming to work with. Currently, using conventional machining technology, titanium parts take approximately ten times longer than aluminum ones to fabricate. If comparable percentages of cycle time reduction could be achieved with titanium as have been with the aluminum Beta parts, the absolute time savings would be considerable due to the shorter machining time alone, let alone the ability to manufacture thinner webs or to replace sheet metal assemblies. Initial research into this application will focus on the development of new cutters, since the toughness of titanium and its tendency to become highly reactive at a low temperature preclude the use of a carbide cutter.[17] Another potentially fruitful research avenue is the construction of machined honeycomb, which would replace the current corrosion-prone aluminum honeycomb with a grid structure of finely machined, interlocking ridges and grooves. Managers at Company B are currently in contact with a small start-up firm that is looking to commercialize this application.

Apart from research into new applications, a natural next step for Company B is to extend the use of HSM across the company. Although HSM is not destined to replace all other airplane manufacturing processes, the cost and cycle time benefits gained on the Beta will certainly make HSM an attractive structural technology for other programs. Company B engineers have begun working with other manufacturing locations in their corporate enterprise to implement HSM on existing and future product lines.

6.4 Analysis of the Organizational Structure and Its Impact on Decision Making

Company B's experience with implementing high speed machining provides an interesting look into the company's approach to product development and how the organizational frameworks of the company, both formal and informal, affected the process of technology transition. As Jones commented, "It [the HSM implementation period] was a painful two years....People tend to forget all the trouble they went through to get things right." The technical development of the process was intertwined with "selling" it to Company B management, the Beta program, and the Machining Center in the middle of the aircraft's detailed design phase. Although the technology seems to have gained a firm position in the company's range of structural manufacturing processes, the firm can benefit from reflecting on the process of technology transition as well as the outcome. This section examines how the complex interactions between individuals, functional departments, and product development programs within an organization impacted the success of the HSM technology

---

[17] Titanium begins to weld to other materials (such as the carbide steel in the cutter) at only 500°F.

introduction project. The use of organizational linkages to promote technology transition is analyzed, along with the importance of cross-functional experience and individual motivation. Company B's technology strategy with regard to HSM is also discussed, followed by an evaluation of possible areas for improvement in the process.

6.4.1 Organizational Linkages

Without a doubt, the successful attempt to reduce weight on the Beta was enabled by the introduction of HSM. Looking deeper, the fact that members of the program IPTs were allowed to participate in the technology development, using their design and manufacturing knowledge to apply the process to real production part designs, led HSM to be more widely implemented and therefore to have a broader impact than if development had been restricted to the laboratory. Described by one engineer as a "grass-roots activity" within the company, the HSM development was aided by bringing together people across the organization with different perspectives. Both informal and formal organizational linkages were employed to spread awareness of the technology and how it could be used to improve both design and manufacturing operations.

The company "grapevine" and the "old boy network" have long been known to be effective transmission paths for up-to-date information, albeit and informal one. Personal relationships can not be underestimated as a means of communication and action within a large organization, and, at Company B and many other large companies, the transfer of personnel between projects is one of the main ways in which people develop information networks. For example, Smith's prior contact with Jones, and his friendly knowledge of what the designer had been working on since then, predisposed him to propose their working together on the aileron rib as a test part for HSM. Similarly, the relationships he fostered with the AMT engineers he came into contact with while working on his IRAD project made him an effective conduit of information between their development lab and people in the Beta program. The AMT engineers were never members of the Beta IPTs, but Smith's connection to both groups provided the intermediary step that led to a much quicker iteration of requirements between the two. Consequently, the maturation of the technology from laboratory to application was hastened. The relationship is a bilateral one; Smith was able to develop manufacturing process rules to give to the designers, and the designers were able to push for the extension of the technology into those areas with most benefit to their program (e.g., the ability to make larger parts).

In terms of formal organizational linkages, the IPPD approach can be considered one of the main contributors to the spread of information in the HSM development project after the initial contact had been made between Smith and Jones. Considering just the trailing edge IPT for a moment, the fact that a cross-functional team already existed facilitated the gathering of input from manufacturing engineers and NC programmers once Smith and Jones had started working on transferring the aileron rib design to HSM. Their autonomy in the product development process allowed the IPT the freedom to get involved with the technology that was coming out of the AMT laboratory and to experiment with using HSM in their subsystem. Over the course of the EMD phase, Smith attended trailing edge IPT meetings, and the designers paid visits to the AMT shop to observe the machining process in action. From both the development side and the program side, the group felt like they were working together to make something happen, as evidenced by comments from the trailing edge team leader, who explained, "We had a real teaming arrangement. Everyone who needed to be involved was involved." This participation included the unionized shop workers, who were encouraged to provide their perspective as the process was introduced to the factory floor. The Beta program was one of the first at Company B to include a shop floor person as an IPPD representative to a program, running counter to the traditional Machining Center philosophy of "a part is a part." While it is still clear that the aileron rib, for instance, is just one of the more than 3,000 part numbers that the Center deals with each year, their representation on the program team heralds the beginning of improved communication between the design and manufacturing groups in the organization. The use of IPTs certainly facilitated this change, as has the recognition that today's highly competitive defense aerospace market leaves no room for in-house rivalry.[18]

In addition to aiding in the operation of individual IPTs, the IPPD process also provided a larger communication system for the distribution of information about the HSM project. At a management level, the trailing edge IPT was able to cross-fertilize HSM to the fuselage IPT through the reports made at the Level 4 IPT meetings by the trailing edge team leader. Once the benefits of the technology had been explored by one team, others who heard of their success became interested in seeing what it could do for them. The built-in format of weekly IPT meetings gave Smith a forum to present the HSM process directly to the people who would accomplish the detailed part design.

The HSM implementation was not completely without organizational problems, however. As has been seen in many companies that have tried to implement the IPPD concept, not all functional areas come out feeling that they have been treated as equal team members. As one engineering manager stated, "Acceptance [of HSM by the Machining Center] is not as complete as some people

---

[18] Many of the people involved with the Beta development had been working on a different program at the time it was cancelled in the late 1980s, which gave them added incentive to make their next program a success for the company.

like to think....They have used those [conventional] machines for twenty-five years, and they want to use them for another twenty-five." Some sentiments were expressed that the manufacturing and tooling design members of the Beta IPTs were forced to accept HSM because the designers were already designing parts that required it. In addition, the recent problems with getting the high speed mill operational have called into question the wisdom of increasing reliance on HSM so quickly. The mill is "down more than it is up," one production worker commented, and "there are some people who don't think we should be in this business" because there have been so many problems with getting the mill to work. At least in the LRIP-1 phase, the time savings that HSM was supposed to provide have been partially subsumed by the poor up-time record of the machines.

6.4.2 Benefits of Cross-Functional Experience

In addition to the IPT authority structure, which promoted cross-functional interaction between individuals, the diverse backgrounds that several key individuals brought to the program were also of great benefit. Diversity of experience has been shown to contribute to an individual's ability to innovate, as well as to recognize the impact of their work on others, therefore resulting in the development of more creative and integrated solutions [Van de Ven, 1986]. At the same time, exposure to multiple disciplines leads to better appreciation of others' work and increases an individual's "absorptive capacity" to recognize the relevance of externally-produced ideas [Cohen and Levinthal, 1990]. At the center of this issue is, of course, Smith, whose early career as a machinist led him to the initial interest in the HSM concept. Other examples include Jones, who had spent two years as a shop foreman and therefore had an appreciation of the need for communication between the design and the manufacturing sides of the business, and the shop floor representative on the Beta program, whose cross-training in NC programming provided him with both the "language" and the personal contacts to interact effectively with the design community.

To a larger degree, the producibility department, of which Smith was a core member, can be considered Company B's attempt to institutionalize the development of cross-functional competence within individuals. This group straddled the boundary of design and manufacturing, prior to the introduction of integrated product and process development, and stressed the creation, as their name suggests, of producible designs. Accustomed to gathering information from many perspectives, producibility engineers were skilled at communicating with both the engineering department and the shop floor. A number of key people came through the producibility and liaison engineering functions on their way to contributing to the HSM implementation, including several managers on the Beta design and production teams. Their ability to look at the problem from both a manufacturing and a design perspective hastened the recognition of HSM as an architectural technology instead of one that merely impacted cycle time. Being part of the producibility function also gave Smith the organizational flexibility to serve as a link between AMT and the program IPTs. As talented engineers, the producibility people enjoyed "high credibility with the design community," which helped overcome the traditional hesitancy to accept an unproven technology on a production program.

Given the importance of this role, it is interesting to note that the producibility function is now "dispersed" at Company B. That is, while the department has not been officially eliminated, the engineers formerly in the department have left or been promoted into other positions, and no new people have been assigned to take their place. One manager explained that the IPPD concept was intended to incorporate the producibility role into day-to-day program operations, such that designers and manufacturing engineers are now supposed to be concerned with the manufacturability of the design themselves instead of having producibility engineers to do this task for them. It remains to be seen whether this shift in responsibility will be adequate for future technology implementations. The absence of dedicated people in the producibility role may remove organizational linkages between AMT and the programs, and between the programs and production operations, that have not yet been replicated in the IPPD organizational design.

6.4.3 Impact of the Individual: A Personality-Driven Process?

As can be seen from the description of the HSM history, producibility engineer Smith had a tremendous impact on the development and adoption of the technology at Company B. His initiative in obtaining funds for the initial IRAD period was almost solely responsible for the introduction of the technology at the company, and his efforts to apply the process to Beta test parts were crucial in spreading awareness that a viable and valuable alternative to sheet metal assembly existed. In addition, his interaction with machine tool vendors, necessary to get the capability of complementary technologies up to the level HSM required, spread his influence beyond company walls in terms of making Company B an industry-wide leader in this process area. When considering his impact, one manager flatly stated, "Smith is the catalyst for HSM as we know it for the entire world."

Clearly, HSM would not exist at Company B if Smith had not been there, or, at the very least, the implementation of the process would have been considerably delayed and most likely not available in time for the Beta production schedule. The HSM technology adoption can therefore be described as a highly "personality-driven" process, as opposed to one formulated through rigorous corporate assessment, decision-making, and company-wide execution. This leads to the question of how the introduction of HSM fit with Company B's strategic technology planning. In terms of formal company R&D expenditures, HSM was not initially included as a targeted technology development project nor funded through the AMT organization (in charge of the development of most other new manufacturing technology). It emerged instead from core funding through the producibility department.[19] The strategy of using HSM wherever possible on Beta structural parts, that is, the managerial dictate that kicked off the analysis of HSM's applicability for a production program, came out of Smith's demonstrated success with the aileron test parts. In other words, it was Smith's personal initiative that led to test parts being created and to the ensuing emergence of a post facto strategy encouraging the use of HSM.

Managers associated with manufacturing technology planning at Company B admit that the selection of new technologies for application in product development is "a lot driven by personality." In other words, the technologies brought forward by engineers who have both good ideas *and* the ability to put them in motion are the ones that get implemented. As another manager explained, "We have a technology transition process, but we don't do it with strategic intent." The company seems to rely instead upon good technical ideas bubbling to the surface through the effort of its engineers, a form of R&D management somewhat akin to an internal "technology push" concept. These types of personality-driven processes are not necessarily a poor choice for R&D management, as they certainly can yield great successes. Indeed, a new technology initiative almost always requires a "champion" of sorts to maintain momentum during the implementation and make sure that all the steps are accomplished in a thorough manner. At the same time, relying solely on the initiative of individuals may not be an ideal choice to ensure that the company maintains a competitive position in their manufacturing capability. This is mostly due to the questionable repeatability of the process. What about the engineers who have good ideas but lack the enthusiasm, communication skills, or network of contacts through which to promote them? As far as measuring the rate of successful technology adoption in the organization, their inabilities to spur innovation in the organization are not counted as failures of technology investment planning because they most likely were never recognized as attempts in the first place. The company therefore has only a loose grasp of what ideas and innovations are available and what their effectiveness is in bringing these ideas from the laboratory to the factory floor.

While Company B may have been slow to make HSM part of its formal strategic planning system, managers on the Beta program did appear to have the ability to recognize HSM as what can be termed a "strategic" technology (in this case, one that had the ability to reduce weight and cost through a shift to unitized design). This appreciation of the technology as more than a time saving

---

[19] In the later years of development, the AMT group did contribute resources to the project, consisting mainly of one AMT engineer, machine time on the laboratory mill, and technicians to make the test parts.

incremental improvement was evidenced by the approval necessary to begin the IRAD program, allocate funding for retrofitting the AMT machines, start manufacturing test parts, and perform the adoption analysis on the Beta program. Without this managerial recognition, Smith's efforts may have foundered. This provides evidence that the ability to recognize strategic technologies may be an extremely important component of a firm's technology planning process (see Section 9.2). In light of the earlier discussion regarding the uncertain repeatability of a personality-driven process, this ability can be termed a necessary but not sufficient condition of an effective technology transition process.[20]

6.4.4 Areas for Improvement: Information Flow and Communications

While the weight, part count, and estimated production cost reductions seen in the application of HSM to the Beta program are indicators of the success of the project, several observations can be made regarding potential improvements in the implementation process. One consideration that could help future projects go more smoothly is increased attention to information flow and communication issues. While the team approach seemed to work well during the development period, problems emerged in extending the process beyond the trailing edge IPT and into production. People in the Machining Center who were supposed to use the new process to make parts did not always have enough training to do so on their own. For example, at one point late in the EMD phase, many of the structural designers on the forward fuselage IPTs were sent to California to assist another contractor with their design of the center fuselage. During their several month absence, the NC programmers and floor operators responsible for making EMD parts did not have anyone to watch over their work or to respond quickly to problems as they struggled with the new high speed technique. In order to meet deadlines, the decision was made to return to conventional programming and machining techniques on many of the parts. Without complete training in the new process, in the words of one absent designer, "parts were programmed randomly or by individual choice." Consequently, some of the NC programming will have to be redone for the LRIP-1 phase. While this particular problem is most likely the result of unavoidable external conditions, it points to the importance of a complete transfer of information between those who develop a process and those who are to use it. Firms should be aware of the need to hold the

---

[20] In what might be another sign of a good transition process, many of the individuals interviewed spoke in confidential tones about their "unique" understanding of HSM. Although they all gave considerable credit to Smith's efforts in developing the technology, people all across the organization claimed that they were among the first to realize the design benefits of the technology (that is, that it could enable weight reduction through part combination, not just speed up the machining process). Smith's reaction to these statements is one of bemusement. He doesn't mind other people taking credit for the success of the project; he is just glad they go the point of what he was trying to accomplish. He feels that their enthusiasm for the benefits of the HSM process is a sign that the technology transition has been successful culturally as well as technically.

IPT together well into the ramp-up of production, so that the team members' knowledge, both explicit and tacit, can be used to educate the production work force. In addition, the use of more sophisticated information technology systems, such as rule-based design tools, should be explored as a way to minimize the disruptions that accompany process changes and to increase autonomy in the learning process.

The same issues arise when considering another information link upstream in the product development process: R&D to product engineering. Many engineers at Company B cited the need for more interaction between these two groups, especially in more clearly communicating the product needs that new technology fills. As one manager explained, during a program detailed design phase, "people don't have time to think about new technology and don't recognize it when they see it. For example, a designer reading an R&D brochure sees 'HSM' and thinks, 'That's a manufacturing technology. *I* need to reduce weight!'" The benefits of the technology therefore go unrealized. Several engineers on the program side of the business expressed their sense of a disconnect between R&D and product development in the organization, with a definite lack of communication between the two. "The [R&D] guys really don't know how what they're working on relates to what is in production....[As for] what's going on over there, we have no idea."

The company seems to need a clearer plan for technology transition between the three stages of the technology lifecycle– R&D, product development, and production – so that all sides can exchange ideas on what can be done to improve today's manufacturing problems and what should be done in the future.[21] The role of the IPT in this process is extremely important, since IPT members, being in the "middle" of the lifecycle, potentially have the most comprehensive view of the company's product needs. One designer summarized this need, saying, "Flowdown is key, and information needs to get to the bottom of the hourglass. These [IPT members] are the people who can give you the best data quickly." The IPT members also expressed their desire to be allowed more input into the technology development process, commenting that their experience with real part design and manufacture puts them in an excellent position to help push the development of a new technology in the most beneficial direction. For example, even though the trailing edge IPT played a sizeable role in the making of the aileron test parts, once the technology became accepted on the program, their opportunities to contribute to the process were greatly reduced. Instead of being able to continue the interactive process that had worked so well in applying the technology on bigger parts

---

[21] It is only fair to note that Company B is currently in the process of reviewing and reorganizing their technology transition process for some of the very reasons outlined here. The results of their internal analysis were not available at the time this case study was performed.

like the aileron spar, they felt they were just being handed process rules that their designs must fit, without any chance for experimentation or feedback. As was discussed above, the involvement of IPTs might well be extended in both directions of the technology development lifecycle.

6.5 Case B Summary

As was clearly pointed out in the research interviews, the value of HSM is not that it can "move chips," in Company B parlance, but that it enables design changes that reduce weight and improve assembly time and quality. Only by bringing together people who understand the strategic potential of new technology can a company institutionalize the process of communication and cooperation that goes into a successful technology implementation. This is especially crucial for integration technologies – ones that have applicability across different physically dispersed systems of the airplane and involve changes to operations in multiple functions. These types of processes require cooperation between R&D, design, and manufacturing to fully realize the benefits of the technology, thus affecting the organizational architecture of the product development process. Communication and cross-functional expertise therefore become critical aspects of strategic new technology introduction.

One means for achieving these integrative communication links which the engineers and managers at Company B employed very effectively to their benefit was the use of current *real* production part designs for testing the HSM process. It is not enough to just target a particular program for application in the future without making contact during the development phase. Certainly this will require additional overhead for meetings and to bring IPT members into the laboratory, but the investment should pay off in improved connection between the technology and real-life problems and in the identification of ways in which the technology can influence design. The construction of test parts based on real designs can also serve as a communication tool between R&D and product development. In the HSM technology transition, the first aileron spars made with the high speed process were used by Smith and Jones as demonstration tools in their discussions with engineers and managers on the Beta program. The physical presence of a real part, through which the fine tolerances and thin features of the process could easily be seen, helped to dispel the stereotype of machined parts being thick and heavy. Although the construction of test parts from real designs can be more time consuming for the development engineers than the making of traditional simple test shapes, the cognitive impact of the technology is much stronger when it is conveyed through a real, complex production part. Today, these HSM test spars can be seen in offices throughout the company as souvenirs of a successful technology transition, demonstrating how the technology was embraced across the many levels and functions of the organization.

In summary, this case study showcases both the power of the individual within a large organization and the complex communication paths that must be triggered in order for a new manufacturing process to be successfully transitioned from the laboratory to the factory floor. In the words of one engineer who found the HSM development a rewarding experience both personally and professionally, "Success depends on people going out and having fun." While the initiative to go in search of this fun may vary between individuals, a company that creates an effective organizational structure for the recognition of strategic technologies and their application to production programs can influence the fraction of technology development projects that end up in success.

CHAPTER 7

CASE C AND CASE D: RADOME MANUFACTURING PROCESSES[1]

Company C, a large defense electronic manufacturer, was responsible for the design and construction of the radome for the Gamma Program missile development. One of the main elements of their portion of the design was the radome, a protective covering at the nose of the missile that shields the antenna system (see diagram in Figure 7-1).[2] According to the concept development work performed in the very early phases of the contract, the radome was to consist of a plastic substrate coated with metal and patterned to provide a frequency-selective surface (i.e., one that would allow only certain frequencies of radio signals to pass to and from the antenna). Company C had considerable experience in the fabrication of frequency-selective surfaces for flat panels, a process very similar to the creation of circuit boards. However, they had never before made such a surface on a dome-shaped substrate. In addition, the material determined to be the only suitable substrate for the dome was a plastic that was not designed to accept a metal coating. The technical challenges facing the Gamma integrated product team as they entered the full scale development (FSD) phase were therefore two-fold: to develop a plating process to metalize the substrate (Case C), and to develop a means of patterning the resulting surface in three dimensions (Case D).

A major portion of the Gamma development consisted of experimental projects and analyses of the technical alternatives to these problems. The decision to implement relatively unproven technological solutions, including electroless plating and a proprietary patterning process, involved personnel from many different functions across the company. Consequently, the project brought together a diverse set of perspectives and skills. This case study presents the history of the development and implementation of the radome process, exploring such organizationally important

---

[1] Note: Data and archival materials for this case study were provided by Company C. (Company and program names have been disguised to maintain anonymity.) Information from research interviews with company employees provided the basis for the descriptions of the technologies, the development process, and the structure of the organizations. Direct quotes from employees are identified only by the individual's function or rank for privacy reasons. Representatives from the company were able to review the descriptive portions of the case study (i.e., the description of the technology and the history of the decision in the organization) and to identify any areas that they felt required clarification. Subsequent interpretation and analysis of the data were the sole responsibility of the author.

[2] The Gamma program represents a joint venture between Company C and another electronics manufacturer. The partners have split the design and production activities for the missile's three major sections, as shown in the diagram of the missile (Figure 7-1) and the organizational chart (Figure 7-2). The radome is part of the sensor group and is designed and manufactured by Company C. The guidance group of the missile is contributed by the other manufacturer. The design of the final section, the missile bus, is borrowed from an existing missile system produced by Company C.

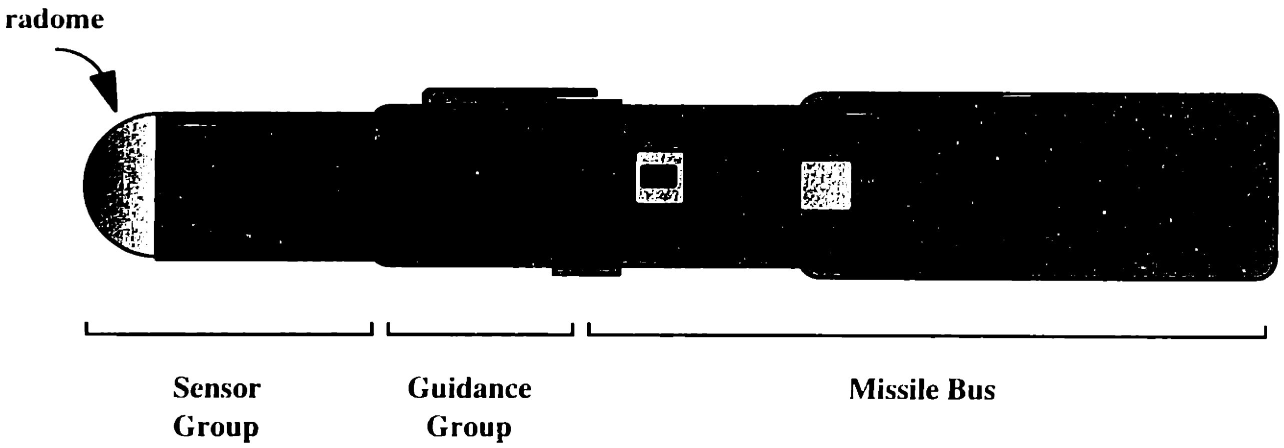

Figure 7-1. Gamma Missile Subassemblies
[notional diagram; not to scale]

issues as the coordination of R&D and product development, the implementation of a team-based product development organization, and information flow in the lifecycle of a technology transition.

7.1 Overview of the Organization

The development of the Gamma missile was accomplished through a system of integrated product teams (IPTs), organized by a functional decomposition of the major product development tasks (as shown in the organizational chart in Figure 7-2). This arrangement differs from the usual physical decomposition of the product that organizes most IPT-based development projects according to the major subassemblies of the product.[3] The decision to select a functional decomposition was a conscious choice on the part of the Gamma program management, based on the small size of the missile and the existing organizational structure in the company (see Section 7.4 for further discussion). In the Company C model, design activities were performed by the systems engineering IPT, which consisted mainly of individuals from the Technical Operations side of the company. Manufacturing activities were the responsibility of the production IPT, with its members drawn from Production Operations. The two teams worked together to coordinate the product development process, with manufacturing engineers serving on both teams as the prime link for integrated product and process development (IPPD). Other functions represented on the IPTs included design, materials engineering, and prototyping on the systems engineering team and tool design, testing, and manufacturing on the production IPT. The production planning and industrial engineering department also served on the production IPT to perform financial and planning

---

[3] In the case of the Gamma missile, a physical decomposition would be one in which there was a sensor IPT, a guidance IPT, and missile bus IPT (see Figure 7-1).

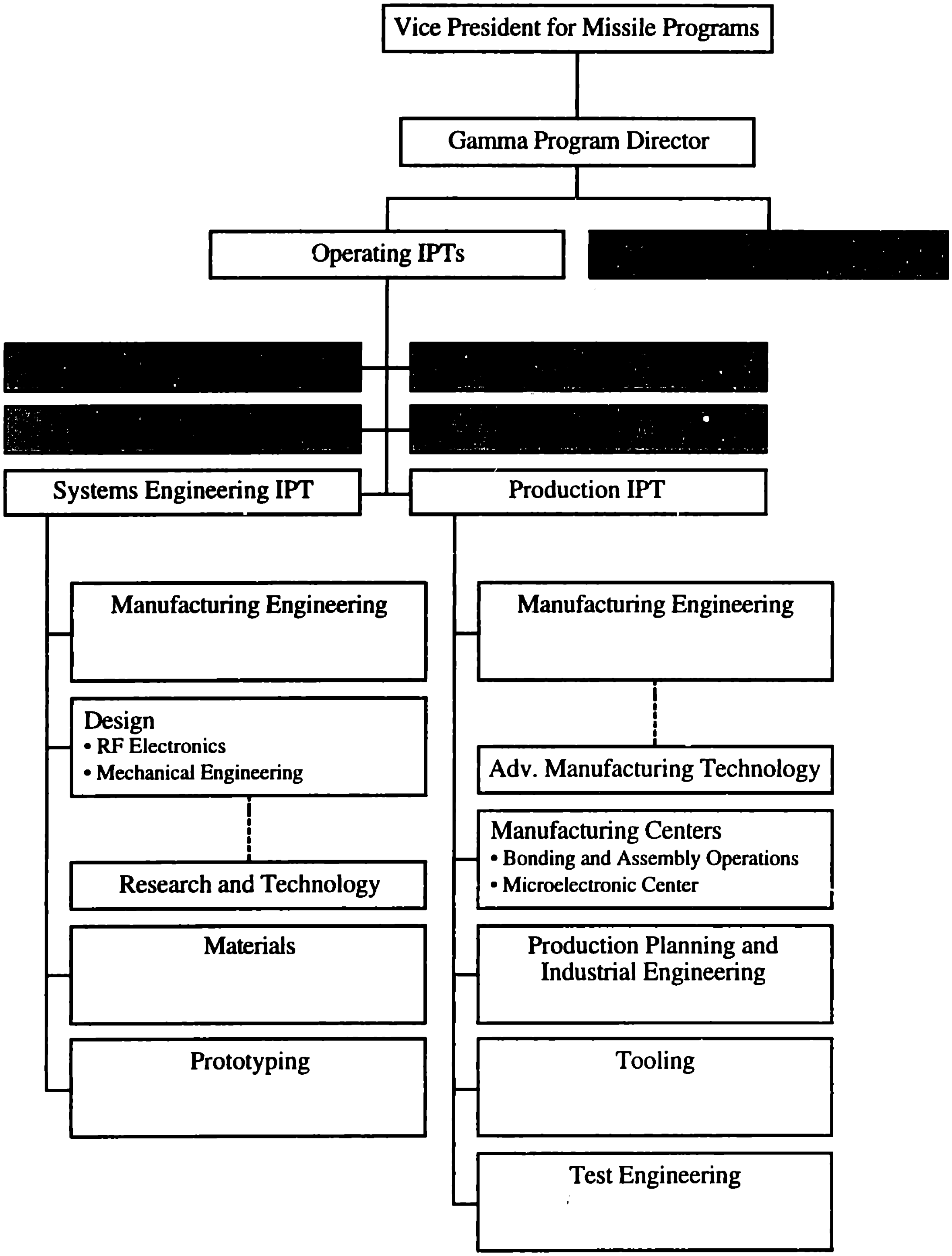

Figure 7-2. Company C Organizational Chart
[focus on Gamma IPTs]

analyses. A set of senior staff were also assembled to perform supporting functions across the operating IPTs in areas such as quality assurance, configuration management, contracts, and logistics.

Two links to R&D-type organizations were also present, although the R&D engineers were not necessarily considered to be full IPT members. Members of the Research and Technology (R&T) group, responsible for long-term product R&D, interacted primarily with the designers on the systems engineering IPT during the earliest phases of the program. Members of the Advanced Manufacturing Technology (AMT) group helped the production IPT with process development in the areas of patterning and electrochemistry. The relationships between the many individuals and groups involved in the progression from laboratory to production floor are examined further in Section 7.4.

7.2 The Technologies

The Gamma missile radome is a thin-walled dome approximately seven inches in diameter. A plastic substrate forms the core of the dome and is covered with a layer of copper plating. The inner and outer surfaces of the dome are patterned with thousands of small dipole elements, each shaped like the letter "x" (see Figure 7-3). Together, the copper plating and the elements create a stratified dielectric medium that forms a band-pass filter, so that only radio waves of certain frequency can pass through the dome to reach the antenna. Innovation was required in two processes for the manufacture of the radome: plating and patterning. This section outlines the basic steps in each process and how the approach developed by Company C differs from previous technology.

As described in the introduction, the material for the plastic substrate (polyphenylene oxide (PPO)), was chosen for its dielectric constant and structural specifications, irrespective of its ability to permit the adherence of a copper coating. For the radome, uneven distribution of the copper would disrupt the electrical conductivity of the surface, so a reliable plating process was crucial to missile performance. Similar material had been successfully metalized in other circumstances (e.g., metal-coated plastic hubcaps are used in the automotive industry), but the specifications for the Gamma project required a higher grade of plastic in order to prevent degradation of the radome's electrical properties. In addition, a successful process for plating PPO substrates had not yet been achieved in a precision environment where the thickness of the coating was highly constrained. The Gamma team first considered physical vapor deposition (PVD) for the metalization of the substrate, a mechanical process in which the material is subjected to a solution of hot gases. While PVD had worked during the early experimental stages of the project, when all of the manufacturing

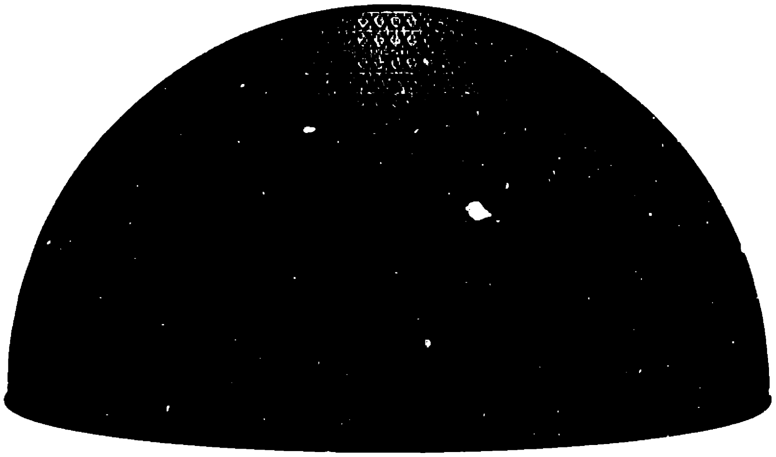

Figure 7-3. Gamma Radome
[notional diagram, exaggerated to show patterning; not to scale]

was done in the laboratory, significant problems were encountered when trying to automate the process for production. Control of the rate at which the metal deposits on the plastic is done via high-temperature power cycling of the system, which was found in the Company C tests to deform the plastic substrate. Contamination and degradation of the substrate were also significant, resulting in extremely low yield. The radome team therefore decided to research the application of another technique for metalization, electroless plating deposition.

Table 7-1 presents a comparison of the two plating processes. In the electroless approach, the substrate is submerged in a vat of aqueous copper, which adheres to the plastic at room temperature and with no required current. Both sides of the dome are plated simultaneously, and distortion of the substrate is negligible. Unlike the resistivity gradients often formed with PVD, electroless plating was found to provide uniform thickness and electrical conductivity. Although installation of an electroless deposition system would require additional process development and the acquisition of capital equipment, the higher yield of the newer process resulted in a much lower unit manufacturing cost than with PVD. After a period of analysis (see Section 7.3.2), electroless deposition was selected as the plating technology for the Gamma radome.

The other big problem facing the Gamma radome team involved the placement of dipole patterns on the inside and outside of the dome. Engineers and researchers at Company C had to develop an approach that would be able to take into account the special requirements of the inner and outer dome surfaces. As will be explained in Section 7.3, a lengthy development program resulted in the creation of a proprietary three-dimensional patterning process.

Table 7-1. Comparison of Plating Processes

	Physical Vapor Deposition	Electroless Deposition
Process environment	• Gaseous copper • High temperature • High electric current • In situ cleaning for adhesion promotion	• Aqueous copper • Room temperature • No current • Pre-cleaning for adhesion promotion
Process geometry	• Deposit applied one side at a time	• Both sides plated simultaneously
Electrical performance	• Resistivity gradients	• Uniform thickness and resistivity
Tooling requirements	• Sophisticated tooling, shielding, and fixturing required	• No shielding needed; moderate tooling and fixturing required.
Highest cost component	• Low yield results in high recurring cost • Capital investment required to meet production rate	• Capital investment in new process capacity

Figure 7-4 presents a simplified view of the process steps for the manufacture of the Gamma radome. After the PPO "as molded" substrate arrives from the vendor, it is cleaned and pretreated. The surface is roughened with a blast of sodium bicarbonate (baking soda), to promote adhesion.[4] The substrate is cleaned again in an ultrasonic bath. The final preparatory step involves dipping the dome into a series of chemical baths (acids and rinses) to prepare the surface for plating.

In the electroless plating process, the dome is agitated in an aqueous copper bath until it accumulates a metalized layer of the proper thickness. A gauge is used to measure the thickness of the accumulating copper. After being rinsed and dried, the dome is polished with a ceramic powder material that burnishes the surface, pressing out any highs or lows in the metal layer without removing material. The plating process is completed in approximately 90 minutes. The radome is next passed through the proprietary patterning process, where the dipole patterns are applied to

---

[4] The pre-treat step is currently done via a manual pumice scrub, but Company C is in the process of switching to an automated soda blast system.

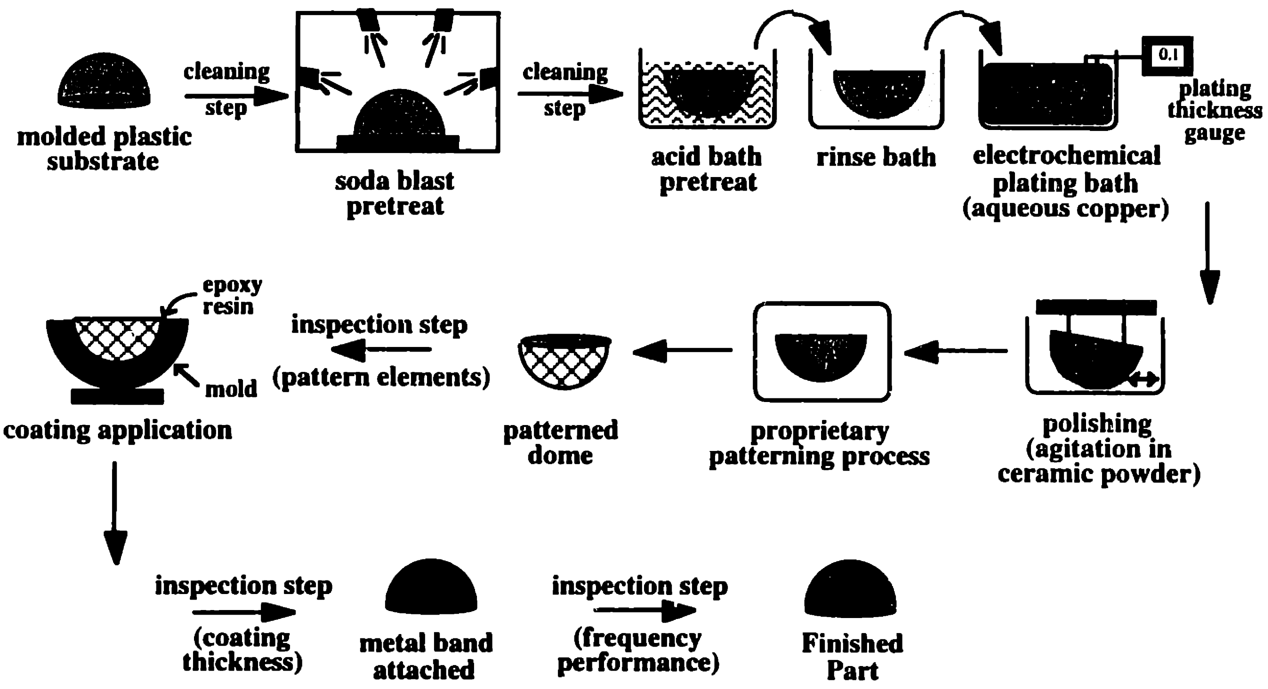

Figure 7-4. Simplified Radome Plating and Patterning Process
[notional diagram; not to scale]

both the inner and outer surfaces. Patterning the dome is accomplished in approximately 30 minutes per side.

The patterned dome is then inspected visually, since bad elements on the metal surface can be seen with the aid of a magnifying glass. Defective elements are blocked with conductive silver epoxy. Engineering specifications allow a maximum of about 150 defects among the over 20,000 elements of the radome. After inspection, the dome is placed in a mold that is mated to the inside surface. A unique, blended resin system is poured into the mold to form a one-millimeter, weather resistant coating over the conductive elements. The mold is heated and cured under pressure for twelve hours. The process is then repeated to coat the outer surface as well, after which a metal band is glued to the rim of the dome to serve as an attachment collar. Finally, the frequency properties of the completed part are tested. Domes that pass inspection are delivered to the Gamma assembly area for attachment to the rest of the sensor group.

7.3 History of the Development

The concept development the Gamma missile started out as a classified R&D program. Early work on the design of frequency-selective surfaces performed by the R&T group demonstrated the feasibility of Company C's electronic design, but only for laboratory-scale production. The processes used to make the first test parts, including the use of PVD for metalization, functioned adequately but were very expensive and not conducive to production-rate requirements. As the program entered the proof-of-principle phase in 1991, Company C's engineers had a clear challenge of making the radome process producible, repeatable, and cost effective.

7.3.1 Early Development

As the two major steps in the radome process, metallization and patterning were the main targets of the ensuing technology development. The research examining alternatives for these two processes was performed by a combination of R&T engineers, AMT engineers, and Gamma IPT members. With respect to patterning technology, Company C had funded internal research and development (IRAD) initiatives on the patterning of frequency selective surfaces since 1985. Engineers working in the AMT laboratories were able to generate patterns on single-curved surfaces, but the process was very slow and expensive. Even before the Gamma program emerged as a target application, the R&D work was focused on trying to do double-curves, including an aircraft radome as a test part. The need for three-dimensional patterning became more urgent with the advancement of the Gamma contract. The AMT engineers acted as a research resource for the program, although they did not consider themselves part of the product development IPTs. With no alternative patterning process for the hemispherical radome, the technology development became exclusively aimed at the creation of a workable process for Gamma. After much effort, the AMT engineers were able to fine-tune a proprietary process that applied the dipole pattern one element at a time, thus working around the problem of pattern distortion on the curved surface.

The development of the Gamma plating process was somewhat more involved, due to the presence of a variety of alternatives that were each too far from completion to be clearly evaluated by the IPT. As mentioned earlier, the laboratory plating technologies used during the concept development phase were thought to be too expensive for large-scale production, so the Gamma IPT started looking for an alternative metalization process. Parallel efforts were initiated to compare the existing PVD technique with the newer electroless process. After about 3 months of exploratory research by the AMT electrochemical engineers, the IPT decided to discontinue work on the electroless process due to funding constraints. Based on the currently achievable surface finish, PVD was thought to be the technique with the least development risk. However, this decision was reconsidered about six months later, when the team found they were unable to overcome serious reproducibility problems with the PVD process. A great deal of time had been spent to make just a single radome for design testing. Although they had eventually succeeded in fabricating a test part, the process was still very laborious, and the prospects of using PVD to meet production schedule deadlines were extremely bleak. In 1992, as the project entered the engineering manufacturing development (EMD) phase, a task team was formed within the IPT to address the problem.

7.3.2 Gamma Plating Analysis

Personnel from AMT, design engineering, manufacturing engineering, and the assembly shop met daily to evaluate different approaches, with the goal of improving both the plating process and the design requirements that were driving it. Table 7-2 presents some of the issues considered in the analysis from various functional perspectives. In evaluating alternative plating processes, the task team considered three technical requirements: adhesion of the metal to the substrate, consistent thickness of copper, and smooth surface finish. Their analysis showed that the design of the electronic elements had a critical impact on the accuracy required for the coating thickness. By fine-tuning the design of the elements, they were able to accommodate a thicker metal coating, which would increase the yield of the manufacturing process. Attention was also paid to determining how many elements could be defective without affecting the radome's functionality. The task team also looked at other parts of the missile system, such as the antenna, to see if the interface requirements for other subassemblies could be adjusted to give greater tolerance allowance to the radome subsystem.[5] Together, these efforts allowed the designers to increase the thickness of the adhesive layer, which allowed for more variation in elements and made the metalization process less critical. Under these conditions, the yield of the electroless process seemed to be acceptable. The end result of the analysis was to re-start the electroless plating development, and by August of that year, it was selected as the final manufacturing process for the radome and five other Gamma parts.

7.3.3 Into Production: Results of the Decision

After successfully manufacturing about 100 units during the full scale development (FSD) phase in 1994, the Gamma IPT entered the first low-rate initial production (LRIP-1) phase in 1995. With orders from the program office to undertake a major cost reduction program, the IPTs were instructed to find ways to accelerate the delivery schedule and to lower the production cost. A

---

[5] This cross-system problem solving was facilitated by the fact that the system engineering IPT leader had formerly been an radio frequency (RF) engineer working on radome design. His understanding of the requirements for the radome process enabled him to push for tradeoffs from the antenna group that would make the radome more producible.

Table 7-2. Evaluation of Alternative Plating Technologies: Physical Vapor Deposition vs. Electroless Deposition [by functional area]

Functional Area	Analysis Performed	Results
Design	• Performance tests evaluating changes in element design and copper thickness	• Electroless preferred (reduced variations in metal thickness and conductivity)
Manufacturing	• Adhesion to substrate • Surface finish • Cycle time	• Electroless preferred (good adhesion; time savings)
Quality	• Manufacturing yield	• Electroless preferred (less deformation of substrate)
Finance	• Manufacturing yield • Capital investment	• Electroless preferred (higher manufacturing yield resulted in reduced unit manufacturing cost; capital investment for installation of new plating line possibly less than what would be required to meet production rates with PVD process)

design for manufacture and assembly (DFMA) study was commenced to analyze the production process and identify areas where it could be streamlined. While DFMA can often take the form of process simplification, the greatest benefits for the radome ended up coming from further technology development to automate the plating and patterning processes. With continued support from the AMT engineers, a faster and more accurate patterning technique was developed. The new approach reduced the patterning time from 5.5 hours to less than 15 minutes per side. "Helper processes," such as the pre-treatment soda blast, were also automated to reduce cycle time and eliminate variability between operators. All in all, the DFMA study resulted in nearly a 20 percent reduction in the unit manufacturing cost of the radome, a savings worth nearly $4M over the lifetime of the program.

7.3.4 Next Steps at Company C

As the program entered the second LRIP phase in late 1997, attention shifted to upgrading the equipment used during the development stage to a production level. The development patterning system was replaced with a more sophisticated model that was capable of achieving the short cycle times required to meet cost targets, and a new plating facility is being installed to bring all of the metalization steps under one roof. While Gamma is the only Company C product scheduled to use the full-scale plating line for the near future, it is intended to be a commodity facility, with other product lines having access to the area on the third shift as needed.

7.4 Analysis of the Organizational Structure and Its Impact on Decision Making

Company C's experiences with developing a reliable and low-cost radome process provide an interesting look into the firm's approach to product development and how the organization of the company affects the introduction of new technology. While the benefits of the new technologies seem to be apparent from their success in reducing the manufacturing cost of the radome, the firm can benefit from reflecting on the process of technology development as well as the outcome. This section examines how the complex organization interactions within Company C impacted the plating and patterning technology introduction projects, focusing on the implications of the Gamma program's rather non-standard implementation of the IPPD concept. The relationship between R&D and product development is analyzed, along with the importance of cross-functional communication. Finally, Company C's strategy with regard to the technologies is examined, followed by an evaluation of possible areas for improvement.

7.4.1 Implementation of IPPD

The Gamma missile was one of the first programs at Company C to adopt an IPPD format conscientiously, and, in doing so, generated more interaction between the design and manufacturing sides of the business than had existed previously. In fact, the program represents the earliest instance of manufacturing involvement with a product development program. This occurred when personnel from Production Operations were asked to fabricate test parts prior to the production phase, a task usually performed exclusively by technicians on the Technical Operations staff. Program management attitudes regarding closer coordination between the two divisions were highly positive. Cross-functional relationships were described as particularly critical for products whose designs required some level of innovation to manufacture. As the program manager stated, "Whenever you are dealing with technology from the lab, it's never too early to get manufacturing involved."

When organizing the team approach to the Gamma product development, the program manager admitted that he had not established a "textbook example" of IPT implementation. Early attempts at bringing together people from different functions in the company involved "more meetings and charts and metrics than progress," and the program sacrificed efficiency as it adjusted to the new method of operation. His decision to organize the IPTs by function instead of by physical decomposition was described as "a compromise on how much Company C could push the concept of IPTs in the near term." Instead of implementing a whole new system of product development at once, Company C management desired to proceed more gradually with changes to the organizational culture. The small scale of the product itself was thought to reinforce the choice of a functional organization, since a physical decomposition might have created problems with sharing resources. For example, Gamma's cost accounting tasks required only one full-time staff allocation for the whole product. Isolating these support functions on the business management IPT kept that individual from being bogged down with the time demands of being on multiple subsystem teams. The decision to separate the product development activities into a "systems engineering" team and a "production" team seems less obvious, especially since the main premise of IPPD is to use systems engineering expertise to bring production activities upstream in the development cycle. When asked how the team members were able to make use of these dispersed resources, the program manager stressed his faith in the ability of the Company C employees. He felt that they were able to create an environment for themselves that would bring together the necessary skills for the product development project, even if the organizational structure did not support formal team relationships. He concluded, "It works because the people make it work. You get to the point where you say, 'Stop fiddling with the organization, and just let the people do it.'" The impact of the above decisions is examined further in the following sections.

7.4.2 Organizational Linkages

Company C's technology development organization has been described by its participants as a "labyrinth of groups." Research support on the Gamma program came first from the R&T group in Technical Operations and later, more extensively, from the AMT group and the manufacturing engineering function in Production Operations. This dispersal of resources across organizational entities can make coordination complex, but it can also result in a more integrated and useful end product if the groups are able to find ways to combine their perspectives in a constructive manner. In terms of an IPPD-based product development project, the IPT typically has primary responsibility for the product. When considering the impact of groups from outside the design function (i.e., Technical Operations, at Company C), one essential question consists of the distinction between those that participate as a consulting resource and those that serve as actual team members on the IPT. The answer is not always a definitive one. The need for particular skills can vary over the duration of the project, and some individuals may be more motivated to participate in a team situation than others. Therefore a group's participation on an IPT may be more complicated than a simple yes or no answer would indicate. In this section, the involvement of personnel from the manufacturing and manufacturing engineering functions are examined. The role of R&D groups in product development is left to Section 7.4.3.

Looking at the Gamma case, it is clear that personnel from both the design and manufacturing engineering functions were equal partners in the product development. The core team of members met up to three times per week to discuss how the work from different disciplinary perspectives impacted other areas. Manufacturing engineering in particular was used in a coordinating role, since this function contributed members to both the systems engineering and production IPTs. It is unclear whether the coordination enabled by this dual role brought with it a burden of added tasks and responsibility. The absence of designers on the production IPT meant that manufacturing engineering was expected to take on the design engineering function in production team meetings. A more conventional application of the IPPD concept would require the participation of members of the design function themselves, under the argument that the additional time spent in meetings would be offset by the improved efficiency of having direct input from all functions contemporaneously.

Turning to the other functions, personnel from the manufacturing centers (i.e., the shop floor) did indeed serve on the production IPT but were not part of the design effort. Their primary involvement was to assist engineers from AMT and manufacturing engineering with the implementation of the new plating and patterning processes. Manufacturing workers expressed a desire for more interaction with design activities, especially regarding tooling design. In particular, manufacturing seemed to see itself as being in a good position to coordinate processes across product development programs, such as in standardizing or consolidating process plans. "Program people are usually not receptive" to factory workers having more involvement with design, explained one manufacturing center supervisor, but in their capacity as a plant-wide resource, the shop would appear to be an under-utilized source of cycle time and cost reduction opportunities. For example, the plant currently has five different methods of mixing adhesives, each prescribed by a different program. The manufacturing center workers who perform the mixing tasks have valuable experience as to which methods work best. Their input could help to create one standard process that benefits all of the programs, and in doing so, save the time and expense that comes from learning and maintaining multiple processes.

7.4.3 Technology Transition between R&D and Product Development

Many companies struggle with how best to coordinate their R&D and product development programs so that the right technology is available when it is needed. Constructing an organized process for the transition of technology between the two groups is not at all easy. As one Gamma team member described their approach, "It wasn't like it was something that was very well thought out.... It was more like hard core development." This section examines the role the AMT engineers played in the technology development for the radome. Their relationship to the Gamma product development IPTs is also discussed.

The relationship between R&D and product development for Gamma stemmed mainly from the interactions between the production IPT and the AMT group.[6] Since AMT was created to be an R&D resource for the Production Operations business, the two groups already had an established organizational link with which to guide their relationship. The majority of the development activity for the plating and patterning processes was performed by AMT engineers, assisted by personnel from the manufacturing engineering function. This style of development was different from Company C's usual approach. Ordinarily, the majority of AMT's work consists of near-term process development for current production programs. The group therefore considers itself a service organization, in that the engineers are not assigned to or funded by specific programs like their counterparts in the design world. Instead, the AMT budget comes from a variety of programs, and its personnel remain organizationally independent from the company's programs. They are encouraged to work as a team (in the traditional sense) in all of their work, but they are not officially part of the IPT authority structure for the company. For this reason, the relationship between AMT and the production IPT is shown as a dashed line in Figure 7-2.

The AMT director described his people as being team members "to some extent" on the Gamma IPTs. This equivocality echoes the differences of opinion expressed by the AMT engineers themselves, leading to the conclusion that the Gamma program represented a departure from AMT's usual role in product development. One engineer working on the development of the patterning system said that he considers himself to be an in-house consultant "who helps on a problem and then goes away" (i.e., he does not view himself as part of an IPT). The Gamma program radome was only one of several projects he was consulting with at that time. Others working on the plating process felt stronger ties to the Gamma program due to their participation on the task team that compared the PVD and electroless processes. Describing the extent of their involvement on Gamma as a special case, they felt that the fact that their technology was on the critical path for the program brought them into a more prominent role. AMT might normally act in a consulting role to the manufacturing function only as a product neared production. However, the infeasibility of the plating processes used in the concept phase of the program forced the Gamma IPT to request earlier and more extensive involvement from the electrochemical R&D engineers.

---

[6] The R&T group was also involved very early on as an R&D resource for concept development. R&T also provided laboratory space and technicians during FSD, although the bulk of what could be considered technology development at that stage was performed by personnel from AMT.

The electrochemical engineers from AMT were working on the Gamma program essentially full-time during much of the development effort. The result was a much longer term, on-going relationship between AMT and the product development side of the business.

As the Gamma program enters production, the AMT group is still participating to some extent on the product development IPTs. In fact, the implementation of a full-scale process still requires considerable effort from the AMT engineers. This can be interpreted as much as a cultural and organizational issue as a technical one. The AMT director described the current situation by saying, "The technology is there. Putting the systems and disciplines in place to use it has been a challenge." AMT seems to have by this stage returned to something closer to its usual role of process improvement consulting. Hopefully, the engineers' experience with the previous stages of the product development process and their past interaction with the IPT members will result in a smoother transition to production than if they had just been brought in after all the design decisions had been made. If the cost and cycle time reductions achieved during the DFMA analysis of the radome are any indication, earlier and closer coordination between R&D and product development has the potential to impart significant programmatic benefits. In particular, it is only through such up-stream contact that manufacturing process requirements are able to influence product design.

7.4.4 Areas for Improvement: Developing and Communicating a Technology Strategy

While the coordination of R&D and product development seemed to work well in the Gamma case, the research investigation did uncover some discrepancies regarding the extent to which information about the broader agenda for technology development is disseminated through the organization. Strategic technology planning, particularly for IRAD spending, is done on an annual basis by the R&T group. The plan includes long-range (five- and ten-year) technology strategy documents, plus an annual investment plan that outlines that year's "technology convictions." These consist of funding allocations for technology development aimed at specific upcoming program applications. Proposals for manufacturing technology development are submitted by AMT and may be included as part of the strategic plans. Given the company's focus on electronic systems technologies (electro-optics, sensors, targeting, etc.), generating interest in manufacturing technology planning in the organization is described by AMT personnel as "a bit of an uphill climb." Manufacturing issues do not seem to have as much visibility in the company as design issues, a situation which may be a permanent barrier to Technical Operations and Production Operations ever holding equal roles in the product development process. This imbalance does not necessarily result in inferior products, especially in an industry where technical performance is such a critical component of product success. At the same time, investment in manufacturing technology can often result in significant time and cost savings on multiple product lines, and many technical designs cannot be implemented without the development of new manufacturing methods. The importance of manufacturing technology to the product development process should therefore not be minimized.

Given that some manufacturing component exists in the firm's technology strategy, the question turns to making sure that people in the organization are aware of the capabilities available to them. At Company C, dissemination of information about R&D projects is done via quarterly IRAD reviews presented to managers and engineers in the various technical and business mission areas. However, not everyone is available to attend these presentations, so engineers may often not be aware of all of the manufacturing options available to them. In addition, Company C now operates a great number of research facilities, including several formerly government-run labs. These acquisitions have made it increasingly difficult to compile a comprehensive source guide to technology development in the corporation. Compounding the high volume of information is the rapid pace of innovation in the electronics industry. Together, these information hurdles make keeping up in the latest developments in manufacturing technology quite difficult for Technical Operations engineers, understandably more concerned with meeting their deadlines for new product designs.

While these barriers are understandable, design engineers' awareness of manufacturing capability is nonetheless critical to bringing new process technology into product development. Other avenues for information distribution that may be more feasible have been explored. The complete technology planning documentation for the Company C Corporation, in the form of two three-inch binders, is distributed only upon request, but the company newspaper periodically includes small articles that describe technical achievements. This publicity usually takes place only after the technology has been applied to a production program, however. Some of the AMT technical groups are in the process of setting up intranet home pages to describe their work and provide contact information, which could provide for easier information access to those who are struggling to identify the available solutions to their manufacturing problems.[7] Typical of most organizations, the majority of communication occurs by word of mouth. "Information in a company like this meanders like a river. If the people who need the information don't get it, then they don't get the benefit," commented one AMT engineer. This is true not only for IPTs who need help with

---

[7] Starting in 1998, the technology plan will be also be available at each Company C division in the form of searchable CD-ROMs stored in a central location. Tentative plans also exist to make the plan available via the company intranet.

manufacturing process improvement, but also for new business management. In the Gamma case, the firm's IRAD experience with curved-surface patterning was not taken into consideration as a selling point to win the Gamma contract. The engineer who performed the IRAD study explained, "Marketing signed up to make radomes and then went and asked engineering if they could do it." Little to no awareness of the company's capability in this area had spread beyond the laboratory. Obviously, this weakens the value of the R&D investment.

If the flow of information is limited when decisions are made about how existing technological capability affects future work, the same can be said for how proposed investments will impact the company's long-term competitive position. "We're perhaps somewhat short-sighted in thinking of future uses," one manager admitted, saying that the near-term priority of cutting Gamma costs in order to get the production contract dominated the decision to invest in the patterning and plating technology development. Consideration of future uses of the radome technologies was consequently a very small part of the analysis. Although the program does have an "advanced programs" IPT tasked with looking for new applications for the product, it is unclear whether the same is being done for new applications of the *technologies* to other products.

The AMT group is currently working on designing a better approach for the transition of technology across programs. They are also attempting to standardize manufacturing processes so that the benefits of technology investment can be shared throughout the company. This work should be extended to incorporate the contents of the manufacturing technology strategy into market planning, as well as further into the realm of product development. It is not enough for senior management alone to understand the "big picture" of the company's technology portfolio. Under the IPT philosophy of decision making at the lowest possible level, information about the firm's technology strategy is now needed at a working level far below the executive realm of strategy generation. While manufacturing engineering can play an important role in linking the R&D and product development organizations, direct contact can often be even more effective. The design changes that were accomplished on the Gamma radome, made in order to accommodate the introduction of new process technology, provide a solid case for the participation of R&D engineers in product development. While the level of interaction between the AMT group and the Gamma IPT strayed away from their usual mode of operation, the communication that accompanied the closer relationship enabled an exchange of ideas that improved both the radome design and the manufacturing technologies. Company C could use this experience to build more formal communication pathways for the transition of technology between R&D and product development in the future.

7.5 Case C/D Summary

One interesting observation from the Company C interviews involved the variety of perceptions present within the company regarding which disciplines are and are not contributing to the success of IPPD. The identity of the group thought to be most unconcerned with manufacturing issues, described derisively as "lab guys" or "mad scientists," depends on who is providing the description. Typically, the farther one gets from the factory floor, the more the lack of interest in manufacturing seems to spread. For example, some shop personnel implied AMT to be "overly scientific" in their approach to manufacturing. At the same time, some people in the AMT group consider R&T and the Technical Operations engineers to be far removed from the realities of how their designs will eventually be produced. While the majority of this discrepancy perhaps can be explained away as cultural bias inherent in a large multi-functional organization, it points to the fact that the manufacturing function is not given as much visibility as perhaps it should be. The distinction between engineering and production that was emphasized in the IPT decomposition could be one organizational blockage that is reinforcing division in the company. Allowing AMT to play more of an active role in product development certainly helped to spotlight the benefits new process technology could bring to the radome. Although the existing authority structure was not set up to accommodate direct design-manufacturing interactions, the relationship between the groups evolved in a way that not only reduced cost and cycle time, but also improved the design of the system and hastened the application of the technologies to a real-world product.

The electroless plating case study (Case C) supports the hypothesized benefits of stronger communication between manufacturing R&D and product development programs. For Company C, having accomplished a successful technology transition once, the challenge will be to institutionalize information distribution paths that can guarantee continued success in the future. The AMT group may not be the sole route to accomplish this, since the assistance they provide in their more normal mode of operations, that of short-term process improvement for production programs, remains an important function. However, the case highlights the impact that process technology can have when it is brought further forward in the product development lifecycle. While the Gamma program management definitely exhibited an awareness of the critical role that manufacturing plays in product development, the choice of organizing the IPT decomposition by function remains a controversial one under today's understanding of the intent of IPPD. Continued implementation of the IPPD concept in the organization, at a pace compatible with cultural change, will most likely help to break down the remaining cultural barriers that exist between Technical and Production Operations. More thorough communication of the firm's manufacturing technology strategy, in particular to the engineering and marketing functions, will also contribute to the smoother transition of process innovation from the laboratory to the factory floor.

CHAPTER 8 ANALYSIS

While the preceding three chapters provided a preliminary examination of the role of organizational structure in each case, more formal analysis is required to compare results across sites and provide more thorough insight into the research questions and hypotheses. This chapter begins with the application of the analysis tools to the case study data. An organizational value chain matrix is constructed for each technology transition initiative. The resulting data are overlaid on the information structure diagram of the firm to compare the information flow paths set up for the distribution of the technology strategy with the information flow paths observed in the specific case of technology transition. A series of assessments are then made regarding the fit of the case study data to the relationships posed in the research hypotheses in Chapter 2. In particular, the analysis looks at the impact of different information structures on (1) the process of technology transition, (2) the creation and distribution of a technology strategy, (3) the ability of IPTs to make decisions about the adoption of new manufacturing technology, and (4) the effectiveness of the company's overall product development process. After a qualitative discussion of the similarities and differences between the four cases, the confirmation of the hypotheses is explained in detail. Additional observations concerning other sources of variation in the organizational structures for technology transition are also presented. The chapter concludes with some reflections on the relationship between the Phase I and Phase II data and results.

8.1 Case Study Data Analysis

The following sections apply the data from Chapters 5, 6, and 7 to analyze the characteristics of each case that are relevant to the research hypotheses, namely:

- the information structures for different organizations
- the extent of information distribution to and from the IPT level, and
- the effectiveness of the technology transition.

First, an organizational value chain is generated for each case study. The participants in each stage of the technology transition are identified according to the extent of their involvement and their decision making authority. (See Section 3.2.2 for a description of the value chain analysis framework.) The data from these charts are then overlaid on the information structure diagrams that were identified in Phase I. The information flow paths found in each phase of the research are then compared. The amount of information that reached the IPT level in the case study example is also assessed, along with a discussion of the overall effectiveness of the technology transition initiative.

Data in this section is presented on a case-by-case basis. A cross-case analysis is found in Sections 8.2 and 8.3. This section focuses more on assessing the process and outcome of each case than in restating the history of the development, so references to the previous chapters are given where necessary to provide easy access to the details of the case studies. The section for Company A, being the first case in the analysis, contains more detailed information on how each hypothesis variable was measured. Since participation in the technology development for the Gamma plating and patterning processes at Company C varied somewhat, the two technology transitions are charted independently.

8.1.1 Case A Analysis

This section contains an analysis of the resin transfer molding technology transition at Company A, based on the case study data described in Chapter 5.

8.1.1.1 Case A Organizational Value Chain

Table 8-1 shows the organizational value chain for the RTM case study. The supplier, Omega Systems, is noted as a primary participant in all stages, although the firm did not hold a decision making role in the process. Decisions to proceed with the development project instead were made by a variety of groups at Company A over the course of the first five stages. Initially, Company A's corporate management was the first to become aware of Omega's emerging capability in RTM, and the decision to proceed with exploring the use of RTM on the Alpha Program was made at that level. This is indicated by the presence of the "P" (primary participant) and "D" (decision maker) notations at the corporate management level for Stage I. Some members of the Manufacturing Research and Development (MR&D) group were also familiar with Company A's own prior research initiatives into the technology; their recognition is noted through an "A" notation (auxiliary participant) in that stage. After the managers became aware of the Omega opportunity, they tasked the Alpha program management at Company A with investigating the use of the technology (Stage II). Program managers in turn instructed the internal spar IPT to begin an analysis of the technical alternatives for the manufacture of the sinewave spars (stage III). The MR&D group had primary responsibility at this point, since they were performing the bulk of the development in their laboratory.

The all-IPT analysis effort to compare the RTM and pre-preg technologies can be mapped to Stage IV, prototype development. At this point, participation was at its highest across the organization, with IPT members (from both design and manufacturing), the IPT leader, and the MR&D members (technically part of the IPT) all involved in a primary role. Since the decision to proceed with the adoption of RTM was made jointly by all of these groups, with some input from the Alpha program-level management, all are listed as decision makers for Stages IV and V. In Stage V, however, most of the continuing development work rested with the MR&D group and the

Table 8-1. Case A Value Chain
(Resin Transfer Molding Technology Transition)

STAGE ACTORS	I. Recognition of Opportunity	II. Idea Formulation	III. Problem Solving	IV. Prototype Solution	V. Commercial Development	VI. Technology Utilization (Production)
Corporate Management	P D					
Program Management		P D	D	D	D	
R&D Group (Product)						
R&D Group (Process)	A		P	P D	P D	P
IPT Leader		A	A	P D	A D	A
IPT Member (Design)		A	A	P D	A D	A
IPT Member (Mfg)		A	A	P D	P D	P
Production						
Other: Supplier	P	P	P	P	P	P

Legend: P = primary participant
A = auxiliary participant
D = decision maker

manufacturing people on the IPT, so the other groups drop to auxiliary status. The participation levels are carried into the final stage (Stage VI), in which the MR&D and manufacturing IPT members worked at the Omega facility to get the process up to a production level capability.[1]

8.1.1.2 Case A Information Flow Paths

Figure 8-1 overlays the case study data for the RTM technology transition (in black) on the information structure diagram developed for the company during the earlier analysis of how their technology strategy is communicated (in gray).[2] The decision makers for each stage of the technology transition are noted (e.g., the symbol "D_I" indicates where the decision for Stage I was made). Information flow during each stage is indicated by the arrows between groups, labelled by stage and showing the direction of the flow (either one- or two-way). In this way, the two sets of information flow paths can be compared visually. The resulting evaluation determines whether or not the company has a consistent application of information structure as a means of managing technology in the firm.

In the Company A example, the site had been previously classified as primarily following a management chain information structure, with some secondary characteristics of the focal inclusion structure (in terms of the information distribution of the technology strategy). As Figure 8-1 demonstrates, the information flow paths exhibited in the RTM technology transition are very similar to this structural characterization. The decision to begin development of the technology stemmed from senior management, as befits a management chain information structure. As the stages of technology development progress, the decision making body includes personnel at increasingly lower levels in the hierarchy. Information flows between senior management and program management and between program management and the IPT are uni-directional, with information primarily being passed downward through the organizational hierarchy. Both of these aspects of the technology transition are also consistent with a management chain approach. The relationship between the IPT and the MR&D group involves two-way information flow (i.e., cooperative technology development) in Stages III through VI and shared decision making in Stages IV and V, both of which reinforce the sense of a secondary focal inclusion element.

---

[1] Note that personnel from the production facility at Company A were never involved in the technology transition process, since the fabrication of parts was outsourced.

[2] Note that the grayed-out diagram for the technology strategy is identical to Figure 4-6, except for the fact that only information links are shown, not hierarchical links. Figures 8-1 through 8-4 can rightly be called "organizational structures" instead of just "information structures" because they also include information about the firm's decision structure. The authority structure is not shown but can be assumed to follow the hierarchical links shown in the corresponding diagrams for each company found in Chapter 4.

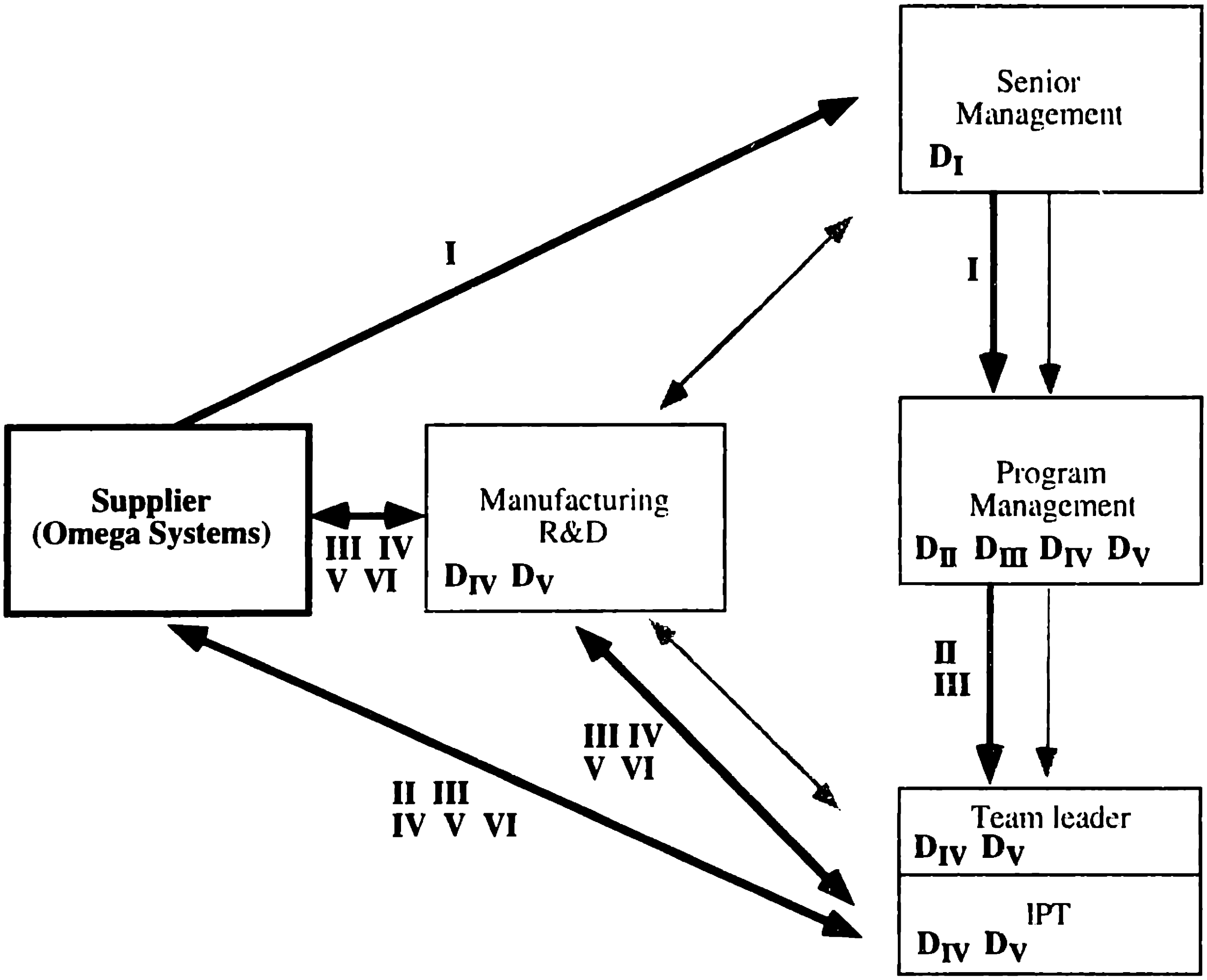

Figure 8-1. Case A Organizational Structure: Overlay of RTM Technology Transition [in bold]

The involvement of a supplier in the technology transition is the only novel aspect in the combined structure diagram. Omega provided the initial information that made senior management aware of the RTM innovation (Stage I). The Omega engineers also had a close working relationship with both the IPT and MR&D through the ensuing stages of development, although the supplier never served in a decision making capacity. In this way, they acted as somewhat of a focal linkage resource to the IPT.

The only information flow connection missing in the technology transition is the link which was present between MR&D and senior management in the generation of the technology strategy. While the MR&D personnel were aware of previous research performed at Company A into the use of RTM-like processes, they did not seem to be the ones to initiate application of the technology on the Alpha. Instead, the supplier served in this role, bringing awareness of the technology to the senior management level in Stage I. It might be possible, however, that knowledge of previous research at Company A led senior management to be more receptive to the supplier's suggestion that it be considered for the Alpha program.

8.1.1.3 Information Flow at the IPT Level in Case A

In Phase I of the research, the distribution of information about the technology strategy to the IPT level was measured according to two constructs of the information structure: (1) the terminus (the last organizational level to receive information) and (2) the attenuation (a subjective assessment of the extent of strategic information contained in the first generation technology strategy documentation that was *not* distributed to the IPT level). According to these metrics, an organizational structure that promoted the distribution of information to the IPT level would be one in which the terminus of information resided within the IPT and the attenuation construct was assessed as being "low." Referring back to the information structure diagram created for the Company A organization to describe their distribution of strategic information (see Table 5.9), the terminus construct was evaluated as residing at the IPT level, although information typically reached only a subset of the IPT engineers. The attenuation present in the organization was judged to be "moderate." These evaluations were based on a general discussion of the firm's procedures, not specific to any technology in particular. Therefore, it would be wise to also consider the level of information flow to and from the IPT level in the specific instance of the RTM technology strategy.

As Figure 8-1 shows, the IPT received information over the course of the RTM technology transition from three different sources: the Alpha program management at Company A, Omega Systems, and the MR&D group. The type of information that was received varied depending on the group. For example, information from Omega and MR&D most likely concerned the technical issues of the process, whereas information from management may have been more focused on programmatic factors like cost and schedule requirements. The IPT seems to have had a strong team-centered focus, with a high level of information sharing present between team members from different functional backgrounds. This extended to the MR&D representatives, to some extent, in terms of having them included as a members of the team. Some lapses in information flow between the IPT and the MR&D group may have been present, however, especially with regards to the different opinions held on the issue of technical risk (see Section 5.4.2).

Overall, the level of technical information flow to and from the group appears to be quite high. As Section 5.4.4 explained, however, the level of strategic information that the IPT received is uncertain. While the cost and schedule requirements for the Alpha program were well known and understood by the IPT, very little discussion seems to have taken place as to how RTM fit into Company A's broader strategic plans for the manufacture of mission critical structural components. Company A's previous R&D work in the area of composite molding was familiar to the MR&D group, but the case study did not uncover a long-term strategic plan for the use of RTM at the company. Likewise, the use of RTM on the Alpha parts made by the prime contractor seems to have been considered in isolation from the transition process at Company A. This points to an assessment of the attenuation of strategic information for this particular technology transition as being higher than previously evaluated in Phase I, perhaps better classified as "moderate" or "high," depending on how much information was considered to have been generated by upper management with regards to this technology in the first place.[3] The amount of overall information flow to and from the IPT level (considering both strategic and technical information) is assessed for this case to be "moderate."[4]

Overall, the level of involvement of the IPT in the technology transition process was fairly high. In fact, the IPT held an auxiliary or primary position in five of the six stages. Decision making power was present at the IPT level in Stages IV and V, when the decisions to adopt the RTM technology and to chose Omega as the supplier were made. The Alpha program management shared in these decision steps to some extent, through their influence in setting program requirements and their authorization of program funding for the development (see Section 5.3.3).

8.1.1.4 Effectiveness of the Technology Transition in Case A

Evaluating the "effectiveness" of a technology transition is somewhat difficult, considering that the case study approach tends to bias the research sample towards those cases with positive results.[5] Still, the companies and individuals interviewed for this research were remarkably open in their willingness to discuss not only the successful results of their projects but the challenging aspects as

---

[3] That is, one can not blame the lack of strategic information at the IPT level on a high level of attenuation if very little information content was present at the generating level to begin with.

[4] Note that the "attenuation" rating is the inverse of the assessment of "information flow to the IPT level." A firm with high attenuation has low information flow to the IPT level and vice versa. The level of information flow is the metric used in the analysis of Hypothesis 2 (see Chapter 8.2.2). In this case (Company A), a moderate attenuation translates to moderate information flow.

[5] Firms naturally tend to be more willing to allow researchers to study cases that had successful outcomes for the organization. This introduces a certain unavoidable level of selection bias into the research.

well. All of the technology transition initiatives described in Chapters 5 through 7 can be considered as successful, in terms of having produced a solution to a technical problem that resulted in manufacturing cost savings to the company, compared to previously available alternatives. However, no technology transition was completely trouble-free, and it is the analysis of the organizational and strategic issues encountered over the course of the development that are of more interest from the point of view of their power as academic and industry learning experiences. To this end, some subjective assessment can be made as to how well a particular technology transition embodied certain generally accepted characteristics of good organizational, technical, and strategic practice. Since all of the cases were considered by the companies to be successful, these assessments were demarcated as "partially effective," "effective," and "highly effective."[6]

As explained in Section 3.5, the research methodology has assumed the characteristics of an effective technology transition to be based on the benefits of the IPPD and lean manufacturing management systems, including such relative assessments as:

- time between recognition of the innovation (Stage I) and its installation as a production-level technology (Stage VI)
- ability to meet or exceed product goals for improvements in technical performance, manufacturing quality, cost, or schedule
- level of customer satisfaction with the process
- level of team member satisfaction
- ability to deal effectively with organizational conflict during the transition process
- strength of relationships/coordination with suppliers of complementary technologies (perhaps with shared development where appropriate), and
- formal plan for the future use of the technology on other product lines.

According to this definition, Company A's implementation of the RTM technology can be classified as a partially effective technology transition. On the positive side, the higher quality and reduced labor costs that the technology achieved, compared to the pre-preg process, resulted in an estimated savings of $200,000 per aircraft. Manufacturing rejection and scrap rates were reduced by approximately two-thirds, while the achievable tolerances improved by a factor of four (see Section 5.3.4). Not counting any prior R&D performed by Omega Systems, the technology transition was accomplished in about two years, which fit within the schedule specified by the Alpha program and is relatively quick for the implementation of a new process technology from laboratory to production readiness. Managers at Company A and their customer were therefore

---

[6] That is, none of the cases can be described as being "ineffective."

very pleased with the results of the project, as were the IPT members in general. Engineers at Omega also expressed their satisfaction with the development effort and with the way their company worked with the Company A team to achieve a workable process. Company A's ability to leverage the technical skills of their supplier should also be considered to be highly beneficial.

However, not all aspects of the RTM transition can be described as trouble-free. The non-recurring cost for the project turned out to be considerably higher than what had been anticipated, with over $25M being spent by Company A and Omega combined. The IPT members at Company A, especially those from MR&D, ended up spending a great deal of time at the Omega facility getting the production process to work, which was somewhat frustrating to those team members who would have preferred that the development work remain in-house at Company A. As was discussed in Section 5.4.2, the group decision process during Stages IV and V did include some organizational conflict as the team struggled with the determination of the technical and programmatic risk of the two process alternatives. While the team as a whole appeared to have functioned well, especially for a first implementation of IPPD in the organization, the analysis and decision process was still described as having been a "challenge" as the group members struggled to understand the varying functional perspectives.

Finally, the RTM transition failed to satisfy the final criterion listed above, that of including a formal plan for the future use of the technology. Company A's decision not to pursue a technology transfer with Omega for the exchange of proprietary information about the RTM process was cited as a cost-based decision (that is, Company A could not afford to invest in an in-house RTM facility at that time), but it also shows a lack of commitment for a longer-term use of RTM by the company, at least for the present. While the management of the Alpha program was highly pleased with the cost benefits that RTM provided, Company A as a whole does not currently appear to have plans to use the technology on other existing or future product lines.

8.1.2 Case B Analysis

This section contains an analysis of the high speed machining technology transition at Company B, based on the case study data described in Chapter 6.

8.1.2.1 Case B Organizational Value Chain

The organizational value chain for the HSM technology transition is shown in Table 8-2. As described in Chapter 6, both the recognition of the innovation and the initial proposal for R&D funding stemmed solely from the personal initiative of Mr. Smith, a member of the producibility

Table 8-2. Case B Value Chain
(High Speed Machining Technology Transition)

STAGE ACTORS	I. Recognition of Opportunity	II. Idea Formulation	III. Problem Solving	IV. Prototype Solution	V. Commercial Development	VI. Technology Utilization (Production)
Corporate Management						
Program Management					D	
R&D Group (Product)						
R&D Group (Process)			A	A	A	
IPT Leader				D	A	A
IPT Member (Design)				P D	P	P
IPT Member (Mfg)					P	P
Production					P	P
Other: Producibility Engineer	P D	P D[7]	P D	P D	P	P

Legend: P = primary participant
A = auxiliary participant
D = decision maker

---

[7] The decision to appropriate seed funding for Smith's initial HSM study was authorized by the head of producibility engineering department, in response to Smith's submittal of a white paper proposal.

engineering core staff. After preparing a white paper proposal (Stage II), Smith received seed money for a small research project from the head of the producibility department. The Advanced Manufacturing Technology (process R&D) group became peripherally involved in Stage III through their loan of test machinery for Smith's study. Once the technology had a reached a minimum capability for test parts, Smith brought in one of the Beta design IPT members, Mr. Jones, to help with the fabrication of parts from real designs (Stage IV). Here, it is interesting to note that the first member of the IPT to be involved came from the design function, even though the technology under consideration was a manufacturing process. This most likely was due to the fact that Smith was looking for a real design to test his process on, and Jones was able to provide the design data needed to manufacture test parts.

Jones quickly recognized the value of Smith's work and convinced his IPT leader to permit him to spend more time developing the technology for application to the trailing edge parts. More of the trailing edge IPT members were brought into the process for Stage V, especially those from the manufacturing engineering function. After observing the success achieved by the team in applying the technology to both small and large trailing edge parts, the Beta program office directed the rest of the IPTs to begin using HSM. The AMT laboratory remained connected to the Beta part manufacture via their relationship to Smith and their loan of test machines through Stage V, at which point the new high speed mill was purchased and installed in the company's production facility. The final stage consisted of continued effort by all of the Beta IPT members (both design and manufacturing) and production personnel from the Machining Center to get the technology ready for the EMD production.

8.1.2.2 Case B Information Flow Paths

The case study data for the HSM technology transition is shown in graphical form in Figure 8-2. The figure also shows the information flow paths for the communication of Company B's technology strategy (from Figure 5-7). The technology transition mimics the focal linkage information structure identified in Phase I, but the IPT's focal partner is from the producibility engineering function instead of the R&D group. The R&D group and the IPT still exchange some information in Stages IV and V, as evidenced by the visits the IPT engineers paid to the AMT development laboratory, but the primary relationship between the two groups is through Smith's coordination efforts. Smith is essentially part of the IPT by Stage V, but the AMT engineers never achieve this strong relationship.

Within the IPT, some variation of involvement between functions is also seen. Smith's first interaction with the Beta Program come through his contact with Jones in the design function of the

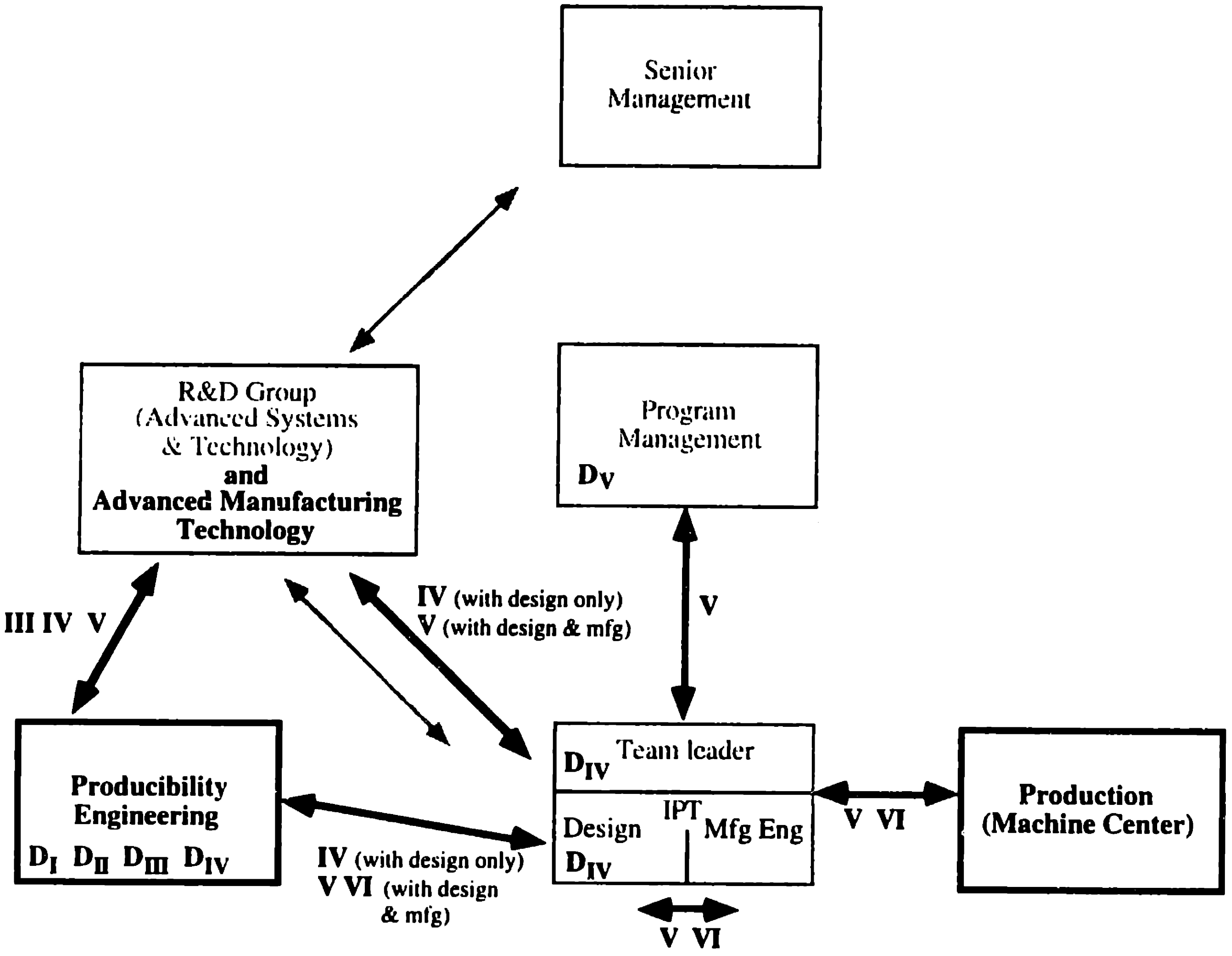

Figure 8-2. Case B Organizational Structure: Overlay of HSM Technology Transition [in bold]

trailing edge IPT during Stage IV. With the approval of Jones' IPT leader, they decided to continue working on applying HSM to the aileron test parts. As their work proceeded to the Stage V level, additional IPT members from the manufacturing engineering area became involved. The decision (Stage V) to implement the technology on parts made by other Beta IPTs was made by Company B's program management, after being informed of the successful results achieved by the trailing edge team. The technology transition portion of Figure 8-2 also shows an additional relationship to the production function, which received information from the IPT during Stages V and VI as the high speed approach was introduced on a full-scale mill. The production area was also represented in the Stage V analysis of which parts on the aircraft were best suited for HSM implementation, the first instance in the company of a shop floor person serving as an IPPD representative to a program.

The information flow paths in the HSM transition resemble a "bottom-up" process, with the knowledge of the development project reaching to the program management level only after a significant amount of R&D work and an IPT-level analysis of the specific application of the technology to the Beta trailing edge parts. HSM was not included in the company's technology strategy plans submitted through the AS&T (product R&D) group; it emerged through Smith's producibility core initiative. A link between the R&D group and senior management for the early recognition of the innovation (what would have been Stage I) is therefore missing in the history of the technology transition.

8.1.2.3 Information Flow at the IPT Level in Case B

In the Phase I evaluation of the information structure at Company B, the terminus construct was evaluated to reside at the IPT level, via engineers who had previously worked on R&D development projects. The attenuation present in the organization was judged to be "high," since designers weren't typically exposed to the details of the firm's technology plans until a particular technology reached implementation. The HSM implementation, however, seems to have followed a rather different path. Here, IPT involvement was extremely high, with Jones and the trailing edge IPT acting as a primary participant in Stages IV through VI of the initiative. The means by which HSM gained a foothold in the company can be described as a bottom up process, with both the initiative for the development and the interest in its application on a production program stemming from the engineer level (the "worker bees," in their words), as opposed to coming from a management level. Although the early stages of the project revolved solely around Smith and his IRAD work, the value chain shown in Table 8-2 belies the intensity of IPT-level activity that took place in Stages IV, V, and VI. In those later stages, the trailing edge IPT, and subsequently all of the structural IPTs for the Beta program, were highly involved in improving the HSM process, changing their designs to take advantage of the high speed capability, and installing and fine-tuning the new high speed production mills.

As the above analysis would indicate, information flow in and out of the IPT was quite high. The Beta teams worked very closely with Smith (from the producibility department) and also held technical interactions with the AMT group. After the first aileron spar test parts were machined, the trailing edge IPT became the primary communication link to the program level, with the trailing edge IPT leader providing information about the technology results at the higher level IPT integration meetings. This in turn led to the trailing edge team acting as a resource for the other

IPTs, after the program management instructed all of the teams to begin using HSM wherever possible on the aircraft. Once all of the IPTs were involved, coordination also proceeded with the Machining Center for the implementation of HSM in a production environment.

Within the IPT, strong communication links were evident between the different functions represented on the team. Although the initial entree to the IPT was through Jones, a designer, individuals from the manufacturing engineering function were quickly brought into the process (Stages V and VI) to provide input on how the process could be more broadly applied to the Beta production needs. The shop floor representative to the program was also consulted during the evaluation of candidate parts for HSM implementation, thus bringing the production function into the IPPD environment as well.

In terms of strategic information being present at the IPT level, the HSM case provides an interesting example of a technology strategy to some extent actually being formulated at a low level in the organization. Smith and the trailing edge IPT were the first ones in the organization to recognize the potential strategic benefits of the HSM technology, with respect to its ability to influence the design of the aircraft and to reduce weight. It was only after the dramatic weight and part count improvements demonstrated on the aileron spar and rib that upper levels of the management at Company B became aware of the broader implications of the technology for the organization. The recognition and insistence of the strategic benefit of the technology therefore took place at a low level in the organization, instead of at the upper management level where strategy generation typically is performed. Although the attenuation construct loses some of its meaning when applied to this situation, the understanding of the strategic importance of HSM at the IPT level certainly cannot be described as significantly less than that of upper management (the "high" evaluation of attenuation made in Phase I). Instead, if anything the attenuation seen in the case study should be estimated as "low." That translates to a "high" assessment of the information flow at the IPT level, due to the bottom up nature of the development effort.

8.1.2.4 Effectiveness of the Technology Transition in Case B

According to the characteristics defined in Section 3.4.3, HSM can be considered a highly effective technology transition for Company B. The early development period for the technology was surprisingly short: under two years of IRAD work by Smith in the AMT facility and then only about a *week* between the time he asked Jones for access to the aileron spar designs and the time that they made their first HSM part from a real design. Of course, the pace slowed down again after the manufacture of that first spar, with another year or so passing while the capability of the technology was improved for larger parts and the program authorized the use of the technology on other areas of the aircraft structure. All in all, though, the pace of the technology transition was quite rapid. The speed at which the machine tool manufactures were able to meet the demands of HSM on complementary technologies such as cutters and electrical controllers was also a tribute to the cooperation achieved with suppliers over the course of the development.

As mentioned in Section 6.3.5, the implementation of HSM produced very favorable results for the Beta program. The final design has 42 percent fewer parts than its predecessor the Pre-Beta model, even though the new aircraft is 25 percent larger. Cost benefits of the switch to HSM are proprietary, but the cycle time for the production of HSM parts is approximately one-third of the time for conventional machined parts, giving some impression of the magnitude of the cost savings of the new process. In addition, the replacement of sheet metal assemblies with HSM parts (as in the case of the nose barrel bulkhead, where 90 parts were replaced with one single HSM part) provides significant time and cost savings in the areas of touch labor, tooling design, and inventory management.

Although the introduction of HSM at the company was highly focused on the needs of the Beta aircraft, the technology was envisioned from the start as having company-wide benefits. Since Company B does so much metal fabrication, opportunities to apply HSM to parts made previously with traditional low speed machining or sheet metal assembly are numerous. The application of the technology to the aileron rib brought about the ability to machine much larger parts, in turn making the technology more useful to many other programs. Company B has wasted no time in implementing the technology across its product lines, with parts already being fabricated for their other military aircraft programs. Even as the Beta program began exploring the use of HSM on multiple subsystems of the aircraft, the company had clear goals for the future use of the technology across the company. In fact, the decision to invest in a new high speed machining facility, with the one-of-a-kind Ingersoll high velocity profiler at its cornerstone, was based not only on the production volume for the Beta but also for all of the other programs at the company that began clamoring for HSM implementation once the results of the aileron spar became public knowledge.

All of the personnel interviewed for the case study at Company B described working on the HSM development to be a highly rewarding experience, often citing it as one of their career highlights. The "grass-roots" nature of the development may have contributed to the enthusiasm that was generated for the project, with a high level of teamwork and ownership among the working-level team members. Since machining processes had been traditionally thought of in the company as being for the creation of heavy parts, some amount of organizational culture had to be overcome before the technology could be seen as capable of producing weight reduction benefits. The process of educating and essentially converting fellow employees and supervisors to the HSM philosophy thus brought personal and professional rewards to the engineers who participated in the development. The subsequent high profile that HSM has received in the organization has in turn been beneficial to their careers.

8.1.3 Case C Analysis: Electroless Plating Process

This section contains an analysis of the electroless plating technology transition at Company C, based on the case study data described in Chapter 7.

8.1.3.1 Case C Organizational Value Chain

Table 8-3 shows the value chain for the introduction of the electroless plating process at Company C. The need for an innovation in plating was recognized during the early concept phases of the program when the process being used for test parts was proving to be both expensive and unreliable (Stage I). Program managers expressed their desire for the identification of alternative technologies, leading electrochemical engineers in the Advanced Manufacturing Technology (AMT) group to begin working on the development of electroless plating as a replacement process (Stage II). During the problem solving period (Stage III), manufacturing engineers from the Gamma IPT decided that electroless plating was more technically risky than its predecessor, so development was halted. A break of about six months occurred between Stage III and Stage IV, after which time the decision was reconsidered. Stage IV was comprised of the task team effort to re-evaluate the electroless process, involving AMT engineers, design and manufacturing IPT members, and production personnel from the Company C assembly shop. Based on their analysis, the task team decided to re-start the electroless plating development. After some further development in Stage V, the Gamma program accepted the IPT's recommendation to select the process for production of several parts. In Stage VI, the AMT engineers worked with the IPT's manufacturing engineers and the assembly workers to set up a production facility for the plating process.

8.1.3.2 Case C Information Flow Paths

Figure 8-3 presents the combined data for the case study and the company's distribution of technology strategy (from Figure 5-8). The match between the two sets of information flow paths is weak. Company C had originally been classified as a management chain information structure, with secondary characteristics of a focal linkage structure. In contrast, a focal inclusion connection between the AMT group and the IPT level dominated the electroless plating technology transition effort, with the management chain falling to a secondary effect. The AMT engineers considered themselves to be part of the product development team, and strong communication occurred

Table 8-3. Case C Value Chain
(Electroless Plating Technology Transition)

STAGE ACTORS	I. Recognition of Opportunity	II. Idea Formulation	III. Problem Solving[8]	IV. Prototype Solution	V. Commercial Development	VI. Technology Utilization (Production)
Corporate Management						
Program Management	P D				D	
R&D Group (Product)						
R&D Group (Process)		P D	P	P D	P	P
IPT Leader			A D	A D	A	
IPT Member (Design)			A	A D	A	
IPT Member (Mfg)		A	A D	A D	A	P
Production				P D	P	P
Other						

Legend: P = primary participant
A = auxiliary participant
D = decision maker

---

[8] A six-month break occurred between Stages III and IV.

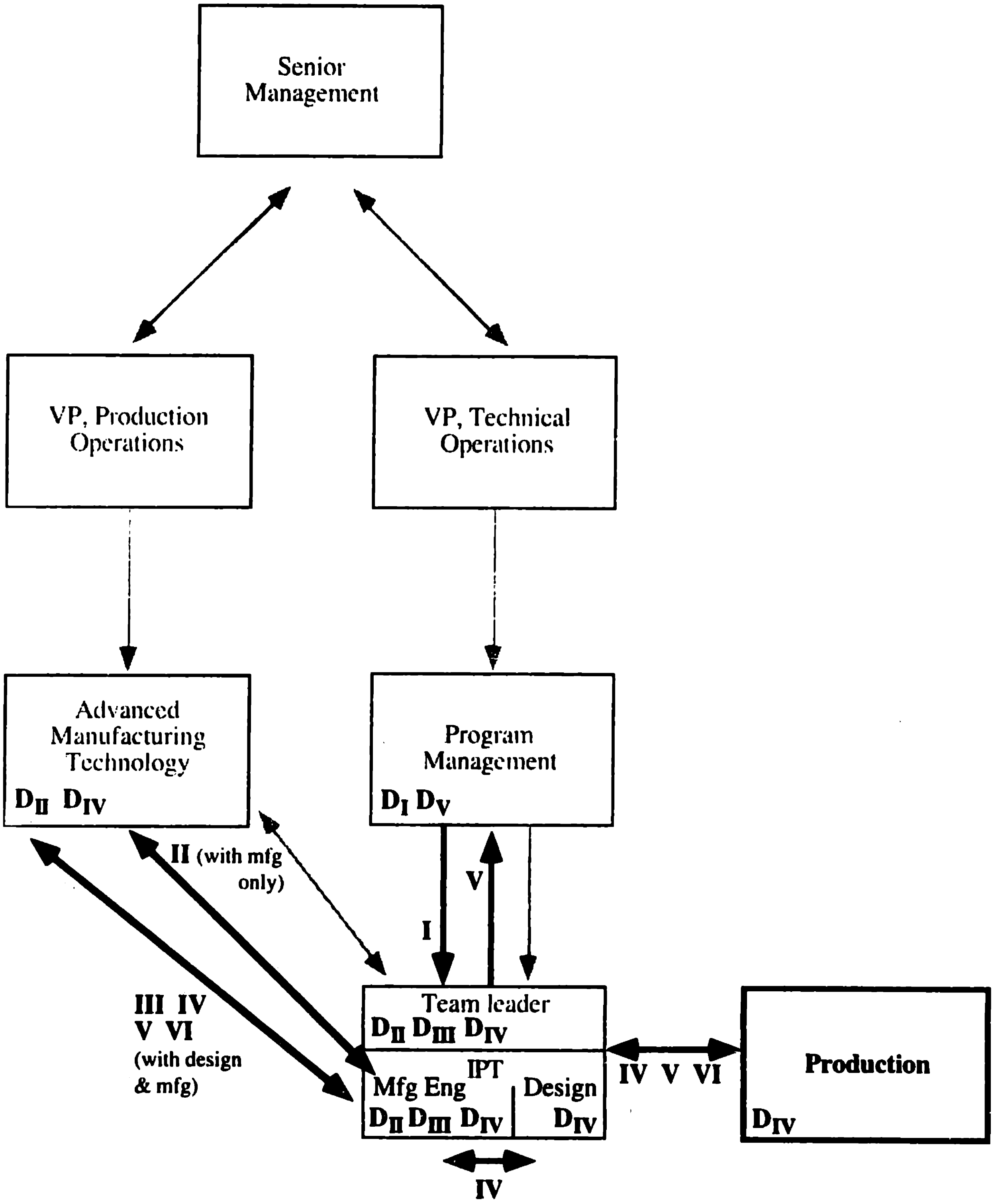

Figure 8-3. Case C Organizational Structure: Overlay of Electroless Plating Technology Transition [in bold]

between the two groups in all stages except the first. Shared decision making was also evident in Stage IV, when the task team analysis indicated that the development of the electroless process should be re-started. Interaction between the AMT group and the IPT was mostly focused on manufacturing engineering issues, although design engineers from the IPT were more involved in Stage IV as decision makers on the task team. Some aspects of a management chain flow did persist in the technology transition project, however. The Gamma program management provided the initial impetus for the search for alternative technologies when they expressed their dissatisfaction with the physical vapor deposition process (Stage I). Program management was also involved in decision making in Stage V, when the technology was approved for use in production. Therefore, while the majority of the development work was performed at relatively low levels in the organization, these actions were not without management oversight at both the IPT leader and program management levels.

8.1.3.3 Information Flow at the IPT Level in Case C

In the Phase I evaluation of the information structure at Company C, the terminus construct was evaluated to reside at the IPT level. The attenuation present in the organization was judged to be "low," since the company believed in having all members of the organization understand how their contribution impacted the company's top level goals. For the most part, these constructs seem to have held true during the electroless plating technology transition, as well. The directive to pursue an alternative plating technology was passed down through the Gamma program management to the IPT level, where the members clearly understood the need of the company to develop a lower-cost and more reliable alternative to the existing plating techniques. The IPT then decided to enlist the aid of the AMT group in the development of such a technology. Although most of the technical work was subsequently performed by the AMT engineers, they were essentially acting as members of the IPT. The original IPT members (mainly the manufacturing engineers) maintained close involvement in the decision process during Stages III and IV of the development, especially during the task team evaluation of the competing electroless and physical vapor deposition processes. Additional interaction took place between the IPT level and the production area during Stages IV through VI, as the design, construction, and implementation of a production scale plating facility took place. The overall assessment of information flow to and from the IPT level is therefore judged as "high."

8.1.3.4 Effectiveness of the Technology Transition in Case C

The electroless plating development at Company C can be considered an effective example of technology transition. Although the cost data provided by the company does not specify what fraction of the 20 percent cost reduction achieved over the course of the Gamma design for manufacture analysis (DFMA) is attributable to the plating process alone, it is clear that a significant improvement in quality and manufacturing time resulted from the development of the electroless plating capability. The radome thus achieved the cost goals set out by the Gamma management.

As the previous section explained, the plating development was indeed a team effort. With the exception of some confusion that may have resulted from the temporary cessation of the electroless technology (manifested as a six-month gap between Stages III and IV), the entire team, including the AMT members, appear to be satisfied with both the technology transition process and its outcome.

In terms of relationships with suppliers, contact with vendors during the development was limited to the procurement of specifications and test samples for materials such as the resin coating, so the supplier relationship criteria is not applicable. When questioned about the possibility of demanding finer tolerances on the outsourced substrate, which would have lessened the necessary precision for the metal coating, engineers at Company C explained that their business was of too low a volume to give them leverage with the PPO vendor. As one of the first companies to use such "non-platable" plastics in a precision environment, the company faced the challenge of appearing as a negligible niche market to the vendor, giving them little opportunity for shared development.

Finally, Company C does appear to have a formal plan for the future use of plating technologies at the company. The new plating facility, while reserved for Gamma production in the near term, was constructed with the needs and capacity demands of other programs in mind. The facility has been set up in flexible cells which can plate different substrates with different metals with only a change of the solutions in the baths.

8.1.4 Case D Analysis: Patterning Process

This section contains an analysis of the patterning technology transition at Company C, based on the case study data described in Chapter 7.

8.1.4.1 Case D Organizational Value Chain

Engineers from the AMT group also played an important role in the patterning technology transition, as charted in Table 8-4. In this case, the initial recognition of the innovation (Stage I) and preliminary research (Stage II) were conducted by AMT engineers working on an IRAD project, independent of the Gamma program. When they became aware of a need for their technology in the product development side of the company, the engineers introduced their

Table 8-4. Case D Value Chain
(Patterning Technology Transition)

STAGE ACTORS	I. Recognition of Opportunity	II. Idea Formulation	III. Problem Solving	IV. Prototype Solution	V. Commercial Development	VI. Technology Utilization (Production)
Corporate Management						
Program Management				D	D	
R&D Group (Product)						
R&D Group (Process)	P D	P D	P D	P	P	P
IPT Leader				A D	A D	
IPT Member (Design)						
IPT Member (Mfg)			A	A D	A D	P
Production						P
Other						

Legend: P = primary participant
A = auxiliary participant
D = decision maker

patterning process to manufacturing engineers on the Gamma IPT (stage III). AMT was then used as a technology development resource to the IPT, performing continued process refinements to carry the technology through Stage IV. Through the evaluation of the manufacturing engineers and the oversight of the IPT leader, the IPT made decisions to continue the application of the prototype process to the missile radome, most likely with some consultation with the Gamma program office. Stage V was very similar, consisting of further cost reduction and process improvement activities. The AMT laboratory set-up was later established as the production facility for the radome patterning (Stage VI), and specially-trained production workers were brought in to manufacture parts for the Gamma LRIP-1 contract.

8.1.4.2 Case D Information Flow Paths

Figure 8-4 compares the information flow paths for the patterning case study and for the company's technology strategy (from Figure 5-8). As noted previously, Company C was found to exhibit a management chain information structure for the distribution of strategic information, with secondary characteristics of a focal linkage arrangement. Information flow paths used during the patterning technology transition seem to fall closer to the later structure. Although the AMT engineers who performed the IRAD work in Stages I through III remained highly involved with the development work as the technology began to be applied to the Gamma missile, they did not consider themselves to be part of the IPT. Instead, the AMT engineers acted as a technical resource to the program's manufacturing engineers, leaving the decision making in Stages IV and V to the IPT level.

Within the IPT, responsibility and authority for the application of the patterning process seems to have rested primarily with the manufacturing engineering function, with little to no involvement from the design members of the team. Program management was most involved in the decision making during Stages IV and V, when they authorized the allocation of program funds for technical support from the AMT group. This role for management reinforces the presence of a management chain information structure. The production function formed the final link in the value chain, when the AMT and manufacturing engineers helped to set up process requirements for the manufacture of production parts using laboratory equipment.

8.1.4.3 Information Flow at the IPT Level in Case D

As explained in Section 8.1.3.3 above in the note on the plating process, the information structure at Company C included a terminus construct at the IPT level and an attenuation level of "low." Once again, for the case of the patterning development, this initial assessment of the attenuation level does not appear to match what took place in the technology transition. Although the IPT level

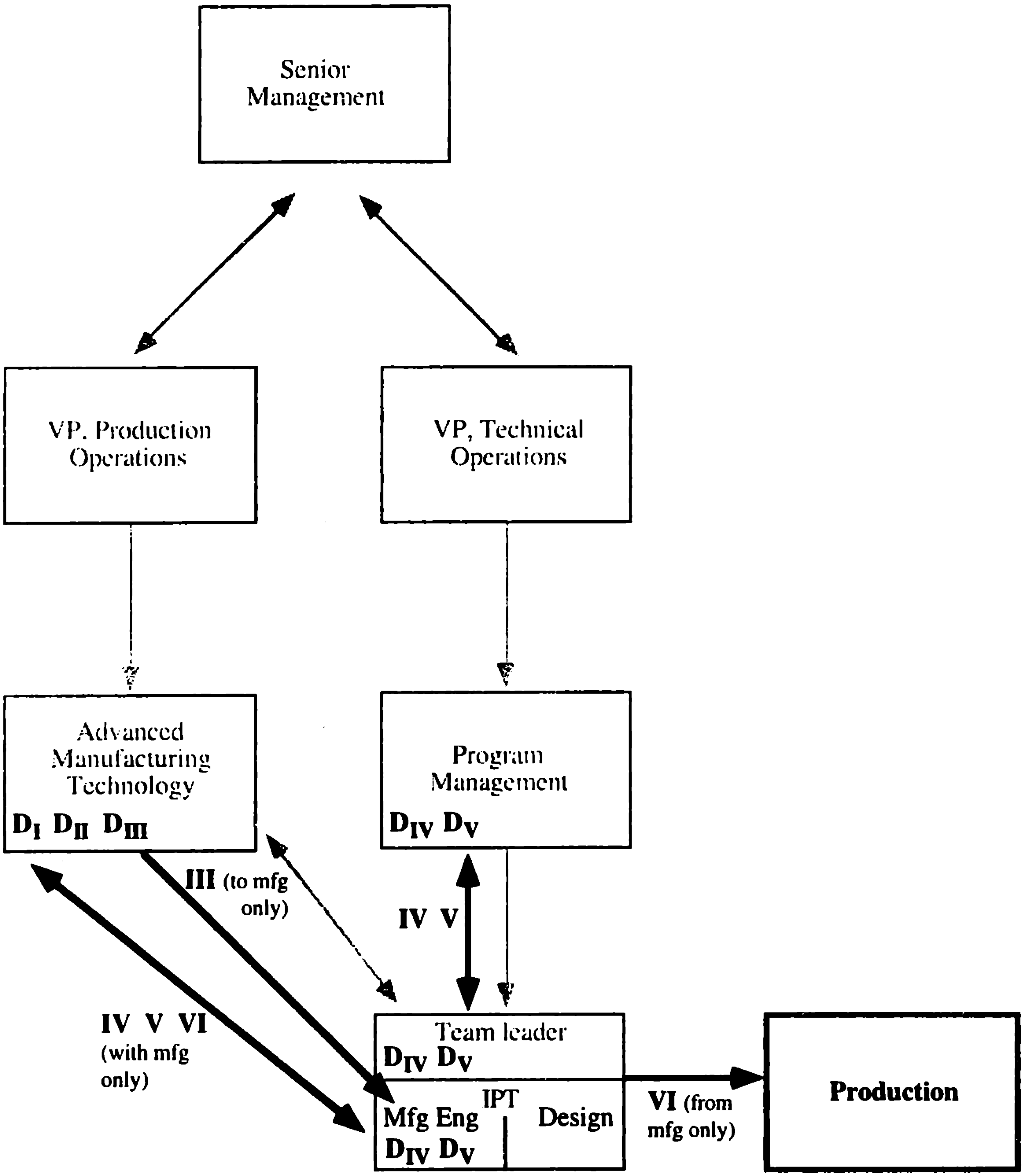

Figure 8-4. Case D Organizational Structure: Overlay of Patterning Technology Transition [in bold]

did receive information from several sources over the course of the development, including technical information from the AMT group and managerial information from the Gamma program management, the transmission of information about the firm's technology strategy appears to be quite limited. The AMT group had been working on IRAD projects involving the patterning of frequency selective surfaces for several years prior to the initiation of the Gamma program, but there is no evidence that the marketing and concept engineers who proposed the initial design of the radome during the contract bidding period were aware of this work. In fact, it was only after the development contract had been awarded, which promised the availability of a double-curved patterned surface, that the Gamma IPT came to the AMT group to ask if this technology was possible (see Section 7.4.4). Although the company clearly had included double-curved patterning in its technology strategy, as evidenced by the history of R&D funding, little to no awareness of the company's capability in this area had spread beyond the laboratory. The Gamma IPT therefore did not receive any input on the technology strategy for frequency selective patterning until after the connection with the AMT group had been made, leading to a corrected attenuation assessment of "moderate" to "high." This translates to a "low" rating for the amount of information flow at the IPT level.

Looking at the level of participation of the IPT in the technology development, the patterning case shows the least involvement at the IPT level of any of the four technology transition examples. Although the manufacturing engineers on the IPT were auxiliary participants, most of the technical work was performed by the AMT engineers working in a consulting role. Designers from the IPT do not appear to have played a role. The development project was focused solely on the creation of a workable process, since no alternative patterning process existed that could accomplish the radome patterning. Cost and schedule issues seem to have been of secondary importance to the technical demands of the project, since the performance capability of the missile was highly dependent on the quality of the patterning. After a workable process was achieved, , attention did turn towards manufacturability and cost effectiveness. The IPT became more involved in the later stages of the transition when the DFMA analysis was performed and was responsible, under the oversight of the Gamma program management, for making the decisions in Stages IV and V to proceed with AMT's work on the technology.

8.1.4.4 Effectiveness of the Technology Transition in Case D

The patterning development at Company C can be classified as an effective technology transition. The development was highly focused on the needs of the Gamma program and produced a process that is customized for its production needs. In fact, the laboratory equipment used during the development is still being used for the fabrication of Gamma production parts (since the volume is fairly low). After realizing that the patterning of a double-curved surface was not a trivial matter, the Gamma IPT leaned heavily on the technical expertise of the AMT engineers, who came through with a high-quality process. Through the addition of automation and process control, the cycle time for the patterning step was reduced more than twenty-fold, which contributed a significant cost savings for the program (see Section 7.3.3). The IPT and the Gamma program management both appear very satisfied with how the development project turned out. The relationship with the AMT group seems to have been a strong one, with few to no organizational conflicts despite the arm's-length consulting arrangement. The only aspect of the development that does not meet the effectiveness criteria lies in area of future uses for the technology. Right now, the Gamma missile is the only product design in the company that includes a radome, so there is no immediate need for the patterning technology on other product lines. It remains to be seen whether the firm will be more successful in communicating its process capability in this area that it was in the past, should the opportunity for incorporating patterning into other designs arise.

8.2 Evaluation of Hypotheses

This section evaluates the validity of the two research hypotheses in light of the data gathered during Phases I and II of the field work. The analysis focuses on the case study examples of technology transition and seeks to extend this anecdotal base of information to the broader scope of industrial product development.

8.2.1 Hypothesis 1

The first hypothesis seeks to establish a relationship between how a firm uses its technology strategy and how it accomplishes technology transition. Information flow paths in the organization and the manner in which decisions are made, that is, the organizational structure of the firm, are thought to regulate both of these activities. Restating the hypothesis from Section 2.4.3:

> H1. The flow paths for information concerning the firm's technology strategy are a key component of the information structure for technology transition.

As explained in Section 8.1 above, the graphical models developed to represent information structures and technology transition decision making were used to compare data from Phase I and Phase II. For each case study site, the information flow paths for technology transition and the decision points represented in the value chain matrix were overlaid on the diagram for the distribution of information about the firm's technology strategy. A visual comparison was then made between the information flow paths used to distribute information about the firm's technology strategy and those paths used in the technology transition case study. In this way, an analysis was performed of how the information flow paths for strategic information, as intended by upper management,[9] compared to the actual flow paths exercised during a specific technology transition initiative.

Table 8-5 presents a comparison of information flow paths for each case. As the results indicate, the information flow paths for two of the four technology transition initiatives (resin transfer molding and the patterning process) strongly resembled the flow paths found in the assessments of the firm's technology strategy distribution. The other two cases (high speed machining and electroless plating) maintained some similarity in the two assessments, but not to as strong a degree. In the high speed machining project (Case B), the relationship between the main developer of the technology (Mr. Smith) and the IPT more strongly resembled a focal inclusion situation than the earlier classification of focal linkage. However a focal linkage relationship was still evident between the IPT and the process R&D laboratory (AMT), so the overall classification was amended to consist of primarily focal inclusion, with secondary characteristics of focal linkage. The electroless plating case (Case C), where the AMT engineers were considered part of the IPT, showed the most difference between the two assessments. Here, the original classification of management chain and focal linkage was changed to a primary classification of focal inclusion, with the management chain approach exhibiting only a secondary effect. Data from the three of the four case studies are therefore relatively in agreement with the hypothesis, The research shows, however, that (1) the correct assessment of information structure requires a fairly detailed look into the organization (as opposed to the cursory interviews done in Phase I) and (2) variations can exist within a company, with different IPTs having different relationships with the other groups involved in technology transition.

Some further analysis of the plating case at Company C is required, to explore why the case results did not follow the hypothesized pattern. The Phase I analysis showed that the company followed primarily a management chain information structure for the distribution of strategic information, with secondary elements of focal linkage. In the development of the plating process, however, the principal relationship between groups was one of focal inclusion. The AMT engineers worked very

---

[9] The flow paths found in the Phase I study are assumed to be the ones "intended" by management, since senior managers were the ones providing the data as to how the distribution of strategic information was supposed to work in their organization. Thus the case study data from Phase II not only compares the distribution of the technology strategy to the process of technology transition, but also compares the intended information and decision structures of the firm to what is actually seen in practice via the case study examples. Of course, it is recognized that each case studied here represents merely one example of the many of new processes that are introduced at a company over time and therefore may not be completely representative of the firm's technology transition process as a whole. The value of the case studies lies instead in their ability to illustrate range of relationships between organizational structure and technology transition that exist in manufacturing firms.

Table 8-5. Comparison of Information Flow Paths (Data for Hypothesis 1)

Case	Information Flow Paths Technology Strategy	 Technology Transition	Support for Hypothesis 1
Case A (RTM)	1. management chain 2. focal inclusion	1. management chain 2. focal inclusion	confirms
Case B (HSM)	1. focal linkage	1. focal inclusion (to producibility engineer) 2. focal linkage (to AMT group)	partially confirms
Case C (electroless plating)	1. management chain 2. focal linkage	1. focal inclusion 2. management chain	rejects
Case D (patterning)	1. management chain 2. focal linkage	1. management chain 2. focal linkage	confirms

closely with the Gamma IPT to develop a plating technology for the radome. In their own opinion, they were part of the product development team, and their work was the primary source of information about the plating process that reached the team (thus leading to the focal inclusion classification).

At the same time, however, the AMT electrochemical engineers acknowledged that the plating technology transition was a departure from their usual mode of operation. Most of the time, as was the case for the patterning technology development, AMT acts in a "expert for hire" role, providing consulting services to various product development teams that need help with manufacturing process improvement. However, for the Gamma program, creating a reliable and cost effective plating process was essential to the overall success of the product development. This in turn affected the amount of communication that had to occur between the two groups. In the words of one AMT engineer, "The fact that plating was on the critical path for the program forced [the AMT electrochemical engineers] to be more involved with the IPT. Otherwise, we probably would not have been asked to the early meetings." The plating technology transition can therefore be seen as an exception for Company C, which at least partially explains the discrepancy between the expected information structure and the one that was observed.

8.2.2 Hypothesis 2

The second hypothesis considers how different degrees of information flow impact the overall effectiveness of the technology transition process. Restating the hypothesis from Section 2.4.3:

H2. Organizational structures which promote the distribution of information to and from the IPT level will contribute to a more effective technology transition process.

As the four case study analyses showed, the measures used in Phase I of the research to evaluate the extent of information about the technology strategy to the IPT level, namely, the terminus and attenuation constructs, were not that representative of the evidence found in the Phase II case study data. That is, the level of information that the interview subjects in Phase I (all middle or upper managers) described as in general getting transmitted to the IPT level was not related to what was actually observed in the case studies. Table 8-6 compares the attenuation constructs assigned to each company in Phase I with the assessment of information flow at the IPT level in the Phase II case study. Agreement was present in only one case (Case C, the electroless plating development). Two explanations for these discrepancies are possible:

1. What top managers think is happening in their organization may not be what is really happening.
2. The level of attenuation in an organization cannot be measured without more sophisticated data collection and analysis than was pursued in the "quick look" phase of the research.

The first explanation could be the subject of a complete dissertation in its own right. The second provides a simpler explanation for the purposes of this research. It is therefore assumed that the attenuation construct, while useful for making top-level distinctions between firms during the Phase I study, was not shown to have value as an assessment tool for case study evaluations *within* firms. As noted in Section 4.2.6, the measurement of the attenuation variable was considered uncertain even in Phase I of the study, so its absence is not thought to be critical for the case studies. Instead, alternate measures for the extent of information flow to and from the IPT level were developed.

The organizational value chains developed for each case (Tables 8-1 through 8-4) provide several indications of how information flow impacts the IPT level. IPT members who are involved either as primary or auxiliary participants over the course of the development certainly receive more information than those that do not participate. Being cited in a decision making role also indicates an exchange of information (assuming a rational decision process). The organizational structure diagrams for each case study (Figures 8-1 through 8-4) also indicate information flow paths in and out of the IPT level. The extent of interaction between the IPT and other groups, including R&D, production, and management, was described in the case studies according to the regularity of meetings between the groups, the participation of personnel from other groups as members on the IPT, and the level of technical participation of the IPT members in the development. Finally, the extent to which strategic factors were considered in the decision points of the technology transition

Table 8-6. Comparison of Information Flow at the IPT Level: Assessments from Phase I and Phase II

Case	Assessment of Attenuation Phase I	Phase II	Agreement between Phase I and Phase II?
Case A (RTM)	• moderate	• high	no
Case B (HSM)	• high	• low	no
Case C (electroless plating)	• low	• low	yes
Case D (patterning)	• low	• moderate to high	no

also provides an indication of whether or not strategic information was communicated through the organization. Based on these subjective factors, an assessment can be made for each case that considers the participation, decision making power, and knowledge present in the IPT. These elements in combination are considered to make up the assessment of the information flow to and from the IPT level, as shown in Table 8-7.

Turning to the dependent variable of technology transition effectiveness, all of the technology transition projects resulted in some degree of success (as described in Section 8.1.1). In evaluating this hypothesis, therefore, attention must be focused on the distinguishing characteristics of the four cases. A summary of the data for the four projects is found in Table 8-8. At the most basic level, all of the technologies achieved significant performance, cost, and quality gains for the companies, and all of the transition initiatives were accomplished in a relatively short time frame. Both customers and team members appeared to be relatively satisfied with the technology transition process in all cases as well. These four areas (development time, meeting goals, customer satisfaction, and team member satisfaction) can be primarily thought of as relating to factors internal to the IPT's operation, measured over the short-term course of the technology transition initiative. When looking at characteristics of effectiveness concerning the relationship of the IPT to other groups, or to longer term issues of planning and performance, however, some variations began to emerge across the cases. In particular, the four IPTs differed in their relationships with suppliers, their ability to deal with organizational conflict, and the perspective of the company regarding the longer-term implementation of the technology on other product lines. In addition, the ability of the process technology to impact the design of the product varied depending on the involvement of IPT members from the design function and the recognition of the technology as

Table 8-7. Evaluation of Information Flow at the IPT Level[10, 11]

Case	**Case A (RTM)**	**Case B (HSM)**	**Case C (plating)**	**Case D (patterning)**
IPT access to information:				
Technical	• high	• high	• high	• moderate
Financial	• high	• moderate	• moderate	• low
Strategic	• low	• high	• moderate	• low
Programmatic[12]	• high	• high	• high	• high
IPT participation in development	• moderate	• high	• high	• low
IPT participation in decision making	• moderate	• moderate	• high	• moderate
Overall evaluation of information flow	*moderate*	*high*	*high*	*low*

having "strategic" importance. This aspect of the research, which falls outside the technology transition effectiveness measurement itself, will be explored further in Chapter 9.

Putting these evaluations together, Table 8-9 shows the assessments rendered in each case study regarding the level of information flow at the IPT level and the effectiveness of the technology transition. The relationship of each data point in the support of Hypothesis 2 is also presented. In three of the four case, the hypothesis is confirmed, with an effective or highly effective technology transition being associated with a high amount of information flow to and from the IPT, and, inversely, a partially effective technology transition being associated with only moderate information flow to and from the IPT. The fourth case, the patterning development at Company C, partially rejects the hypothesis, in that that a low amount of information flow still resulted in an effective technology transition. However, the more extreme pairing of low information flow and a *highly* effective transition was not in evidence, so this result is not a complete rejection of the

---

[10] Information flow "at the IPT level" refers to information flowing both to and from the team.

[11] These data, and the rating of technology transition effectiveness in Table 8-8, are subjective and consist of the author's best judgment of the information flow and organizational interactions taking place in the firms at the time of the site visit research. In the case study tradition, the interview data and other available historical documentation have been assembled and analyzed in as complete a manner as possible. While the insights than can be gained from this approach are indeed significant, the author recognizes that additional data could be extremely useful in understanding the complexity of the case study situations and in determining how the results might be applied more broadly to other firms and other industries. Some suggested areas for further data collection are therefore outlined in Chapter 9.5.

Table 8-8. Evaluation of Technology Transition Effectiveness

Case	Case A (RTM)	Case B (HSM)	Case C (plating)	Case D (patterning)
Time between Stage I and Stage VI	• high	• high	• high	• high
Met goals:				
Performance	• high	• high	• high	• high
Quality	• high	• high	• high	• high
Cost	• moderate	• high	• high	• high
Customer satisfaction	• high	• high	• high	• high
Team member satisfaction	• high	• high	• high	• high
Deal effectively with organizational conflict	• low	• high	• moderate	• high
Supplier coordination	• high	• high	• low	• moderate
Plan for future use of the technology	• low	• high	• high	• low
Overall evaluation of effectiveness	*partially effective*	*highly effective*	*effective*	*effective*

Table 8-9. Comparison of the Level of Information Flow at the IPT Level and the Effectiveness of the Technology Transition (Data for Hypothesis 2)

Case	Information Structure[13]	Information Flow at the IPT Level	Effectiveness of the Technology Transition	Support for Hypothesis 2
Case A (RTM)	1. management chain 2. focal inclusion	• moderate	• partially effective	confirms
Case B (HSM)	1. focal inclusion 2. focal linkage	• high	• highly effective	confirms
Case C (plating)	1. focal inclusion 2. management chain	• high	• effective	confirms
Case D (patterning)	1. management chain 2. focal linkage	• low	• effective	partially rejects

---

[12] Programmatic information consists of information about the specific goals and requirements of the product development program.

[13] The information structure here refers to the revised structure classifications determined for each specific case of technology transition (as shown in the "technology transition" column in Table 8-5).

hypothesis. However, the data raises questions concerning why a firm can fail to establish close organizational structures with the IPT level and still achieve quite decent results in their technology transition initiatives. In addition, the manufacturing process in this case was never transitioned to a full production environment; the production volumes were low enough to be met using the laboratory equipment, and the workers were specially selected and trained to work in that environment. Other problems may have been encountered (presumably lowering the "effectiveness" rating) had the technology been implemented in a full production setting as occurred in the other cases.

Returning to the question of organizational structure, the data from the case studies suggests that the focal inclusion information structure, with the close relationships and exchange of information that it provides, to be the arrangement most conducive to the flow of information to and from the IPT level, and therefore to a highly effective technology transition. The two technology transitions that showed the most positive relationship between information flow and technology transition effectiveness, the HSM and electroless plating cases, were both considered to fall under the focal inclusion classification for their primary information structures. This relationship between focal inclusion information structures and more effective technology transition results may stem from the extent to which R&D engineers are able to participate in IPT decision making. R&D personnel who are treated as members of the IPT may be better able to communicate information to the team than those that act in a separate consultant role, due to their team bond, history of shared development, and familiarity with each other's functional "language." Having R&D members on the IPT may allow the product development team to see technology as a potential contributor to improving their overall product, not just how it is manufactured. This in turn allows them to enjoy greater benefits from the technology transition than those IPTs who treat new manufacturing technology as a "black box" provided by an external resource. More discussion of how the focal inclusion structure can be implemented to improve technology transition effectiveness is found in Section 9.3.

These two cases also were the only ones in which the production function was involved in the technology transition process before Stage VI (technology utilization/production). While IPT members from the manufacturing engineering function were involved at some point in each of the four cases, only the HSM and plating initiatives brought factory floor manufacturing personnel into the development before the project actually entered a production mode. The involvement of factory floor personnel, who essentially serve as the "users" of the technology, may also have contributed to the effectiveness of those two cases of technology transition. Certainly the participation of factory personnel in the development of new manufacturing technology can contribute to the quality and performance of the finished product, as demonstrated by the documented benefits of the lean manufacturing approach. The use of a focal inclusion information structure during the early stages of a technology transition may lead the IPT and other involved engineers to follow a more collaborative style of development. They familiarity with cross-functional interaction may lead them to be more inclusive of personnel in functions across the company in general, and thus more likely to extend the process of development to include the area of production operations.

Finally, the cases with the strongest instances of the focal inclusion information structure (Cases B and C) were also ones in which the generation of the firm's eventual technology strategy can be considered to take place at the IPT level. That is, in these cases, the activities and analysis performed by the IPT and the focal point engineers strongly contributed to the understanding of the strategic significance of the technology for the company. This evidence is contrary to the initial premise of the research, which assumed strategy generation to take place exclusively at the senior management level. Instead, the working level individuals in these cases acted as grass roots champions of the new process and spread awareness of its benefits upward as well as laterally through the organization. The ability of the IPT level to contribute to strategy formation is an important indicator of the benefits of information flow both to and *from* that level, since in these cases the IPT was seen to act as a synthesizing body for the gathering of information from cross-functional sources and then the reshaping of that information into a strategic map for the company's subsequent technology use. The implications of this aspect of IPT capability will be explored further in Chapter 9.

8.3 Additional Observations: Other Sources of Variation

In addition to the data gathered in relation to the research hypotheses, several other sources of variation between firms were noticed. This section examines some of the differences between cases and provides a brief assessment of how they may have contributed to the effectiveness of technology transition. For example, the types of technologies under examination in the various cases were quite different: two were construction techniques for structural aircraft parts (RTM and HSM), one was an electrochemical application process (electroless plating), and one was a patterning process for the creation of electronic circuitry. The technical maturity of each process was roughly equivalent, however, as was the scope of the development efforts (in terms of time and number of people involved). In addition, all of the cases represented the first use of the technology in the organization. The nature of the technological development does not appear to have influenced the differences observed regarding information flow at the IPT level or the effectiveness of the technology transition initiatives.

The motivation behind the search for alternative technologies that accompanied each technology transition also varied. Only the patterning development could be considered absolutely essential from a technical standpoint. In each of the other three cases, a technically feasible alternative was present, albeit at much greater cost, and the newer technologies were pursued mostly for their cost and time benefits. In the patterning case, however, no alternative technology existed for the patterning of double-curved surfaces. This may have contributed to the relatively independent nature of the development by the AMT engineer; he was the expert in that field, and the IPT members were relatively unsuited to participate in the development by virtue of their insufficient technical training in that area. This may have led the IPT to have a more hands-off approach to the development, essentially considering the proprietary patterning process to be a "black box" in the radome process steps. In the other cases, the IPT members had greater familiarity with the process in question, having, for example, worked on many other projects that required the use of composite or machined parts (in the cases of the RTM and HSM developments, respectively). Their technical ability to assist in the development may be directly related to the greater extent of information flow at the IPT level seen in those three cases.

Differences were also present regarding the source of innovation and development in each case. Both the HSM and patterning projects began as IRAD initiatives, which implies some assessment of anticipated need for those technologies prior to their application to a specific product (by virtue of the fact that some level of management authorized the investment). The impetus to investigate the use of RTM on the Alpha program, on the other hand, arose from a chance contact between a program manager and the supplier. This contact led the Alpha program management to instruct the internal spar IPT to examine the feasibility of the new technology, even though a different process had already been planned during the early design phase. In the plating case, it was also program management who initiated the development project, although in this case due to the prohibitive costs of the process tested during concept development. These differences had some affect on how the pattern of decision making for the rest of the technology transition emerged. For example, in the RTM case, program management's directive for the IPT to examine the possibility of using another technology set them up to have a supervisory role in the subsequent analysis and decision making regarding the choice of a manufacturing process for the sinewave spars. Likewise, in the HSM case, the strong personal initiative of Mr. Smith in starting the IRAD project extended the depth of his involvement through the rest of the development stages. Although his ability to influence the authority structure of the Beta program IPTs was hierarchically limited, his in-depth knowledge of the technology gave him great power in communicating the value of the technology to others and in convincing them to expand the company's process capability and capacity in that direction.

One final area of variation between the cases was the relationship the companies had to their suppliers. While suppliers played little to no role in the technology transitions for the radome process at Company C, they had significant involvement in the development processes at the other two firms. In the RTM case, Company A chose to outsource the manufacturing development and production of the Alpha sinewave spars to a relatively young and inexperienced composites vendor, Omega Systems. This choice caused some friction for some of the IPT members at Company A, since it meant that the process development going on at Company A was abandoned in favor of the Omega process. The team's response to this organizational conflict lessened the effectiveness of the technology transition, in terms of reduced satisfaction of the team members and greater time spent in the decision process resolving tradeoffs and conflicting opinions. However, the IPT and program managers felt that the cost and schedule gains promised by the supplier were worth giving up in-house oversight and proprietary control of the primary manufacturing technology for their parts. At Company B, in contrast, supplier involvement mostly revolved around the development of complementary technologies to the high speed machining process, such as the manufacture of machine tool holders, cooling systems, and machine controllers. Since Company B did not have experience in those areas themselves, they were dependent on suppliers to bring those technologies up to a level of sophistication to match the requirements of their HSM process. By joining a consortium of prime contractors interesting in HSM technology, the firm was able to create incentives for its suppliers to invest in those complementary technologies. This action proved to be crucial to the success of the Beta program. Mr. Smith and the IPT members, therefore, were required to form and maintain an information structure both inside and outside the company walls in order for the technology transition to succeed.

8.4 Reflection on Phase I Data and Results

Now that the results obtained from the case studies have been analyzed, it is appropriate to reflect on the validity and usefulness of the Phase I data. Although a wider range of companies were surveyed in Phase I (eighteen firms as compared to three in Phase II), the time spent researching each company was considerably less (30 to 45 minute telephone conversations with a single manager versus five to ten days of on site interviews with up to 25 different individuals). As a result, the Phase I data is considerably more superficial. This should not be thought of as a defect in the research design, however, since the intent of the first phase of the project was to quickly gather a broad perspective on how the industry dealt with issues surrounding the creation and communication of a manufacturing technology strategy. Given the necessarily smaller scope of the Phase I data, the question shifts to the usefulness and validity of the data that were collected.

The multiple rounds of interviews in Phase I and the in-depth data collection performed in Phase II uncovered several discrepancies between the variables measured early on in the research and what seemed to be happening in the firms upon closer examination. For example, Section 8.2.2 describes how the attenuation and terminus constructs measured in Phase I for the three companies eventually chosen as case study sites were not fully representative of the evidence found for those companies in Phase II. Similarly during Round 3 of the Phase I research, as interviews were conducted with a broader range of employees across the organization, refinements were made to the information structure classifications of the case study companies. While upon closer examination no company was found to possess completely different characteristics of information flow than initially thought, some were found to exhibit characteristics of additional structural types. Gathering data from a single perspective, as was done in the initial interviews, was not sufficient to detect the variety of communication methods and flow paths present in the overall organization. It should be expected that similar problems with the Phase I data would be detected at more of the eighteen companies upon further research at those sites. Thus it appears that the data gathered in Phase I does indeed possess some significant flaws as a result of the narrow scope of the questioning and the limited number of interview subjects at each site. The results therefore indicate that a more sophisticated research methodology is required in order to accurately measure the organizational constructs of information flow and strategy formation at a company.

At the same time, the Phase I effort had considerable value. The goal was to quickly capture the variety of approaches present in industry for dealing with strategic information and technology management. The project was designed to be a "quick look" study, and from this perspective, it did succeed in identifying the presence of differences between firms. Four distinct information structures were identified through the industry survey, which allowed firms to be catalogued as to their primary means of distributing strategic information. Closer examination of three of those structures, during the case study analysis, validated the typology. The process of gathering data from a larger sample of companies was also extremely useful for the refinement of the organizational constructs of information flow. That is, the Phase I data collection may not have been extensive enough to accurately measure all of the variables, but it did serve to identify which variables were important. The model developed for information structure over the course of Phase I benefited from the series of interviews with representatives from different companies. The work showed that it is indeed possible to inquire about information flows within organizations through an interview-based methodology, even though more extensive interviews are needed to capture the nuances of perspective and activity within a complex organization. Suggestions for future research to improve and expand these results can be found in Chapter 9.

CHAPTER 9 CONCLUSIONS

The main premise of the dissertation project has been that differences in organizational structure influence the participation and effectiveness of IPTs in the technology transition process. In approaching this topic, the research has examined the relationships between information flow paths, decision making, the formulation and dissemination of a technology strategy, and the implementation of new manufacturing processes. The research has described current industrial practice for the use of IPTs in strategic technology decision making, assessed the strengths and weaknesses of the current system, and analyzed the contribution of information structure to the effectiveness of technology transition. This chapter summarizes the results of the research and discusses its application to the theory of strategic technology transition. The implications of the research for both academia and industry are examined, focusing on the clarification of how these results can be applied to real-word technology development initiatives. The chapter concludes with a discussion of opportunities for future research.

9.1 Summary of Results

The research questions and hypotheses were addressed through a comparative analysis of case studies concerning technology transition. This research was paired with a survey-style analysis of the various distribution systems in use in industry for disseminating information about a firm's technology strategy. The main goal was the determination of how organizational structure affects the transition of new technologies from development into production within an IPPD environment. This section summarizes ten major contributions of the work. The first five provide answers to the research questions and confirmation of the hypotheses. Methodological lessons from the development and use of the analysis tools are presented. In addition, the case studies provided anecdotal evidence as to how the use of IPTs can help or hinder the technology transition process. Several of these areas are described in the last five points.

1. The first achievement of the research was *the articulation of a working definition for organizational structure composed of three subelements: the authority structure, the information structure, and the decision structure.* Traditional concepts of organizational structure have focused on the distributed reporting system by which tasks are assigned, performed, and evaluated. This definition was expanded to include the methods by which the firm communicates information concerning the development and manufacture of new products within and across the functional disciplines and managerial layers of personnel. Organizational structure regulates how decisions are made in the firm, in terms of who receives information and how it is interpreted to make choices about the firm's activities.

Thus the structure of an organization regulates not just the hierarchical arrangement of workers within the firm but also the means by which they interact with each other to complete their tasks. This definition was applied to the problem of technology transition.

2. Before the study of organizational structures for technology transition could be undertaken, methods had to be developed to capture data at each firm and present it in an analyzable format. *Two analysis tools were developed* to meet this need. The first is a diagramming method for information structure, focusing on the identification of information flow paths for the distribution of the firm's technology strategy. Seven key constructs for the process were also identified and used to make distinctions between firms. Another analysis tool was developed to capture the information flow paths exercised during a particular technology transition. Termed the organizational value chain for technology transition, the model is a matrix diagram showing which individuals or groups were involved in each stage of the technology transition. The level of participation and decision making authority for each group over time is also indicated.

3. Using these tools, a catalog of the information structures in use in industry today for the generation, distribution, and use of manufacturing technology strategies was assembled (see Figure 4-4). Interviews were conducted with middle- and upper-level managers at 18 aerospace manufacturing companies. Phase I of the research resulted in *the identification of four distinct models of information structure: management chain, focal linkage, focal inclusion, and network.* The information structure types differed in terms of where the technology strategy was generated, how information reached the IPT level, and how much information reached the IPT level. Firms were found to primarily be identified with a single information structure, although secondary characteristics of other structures might also be present.

4. In the case study phase of the research, four different examples of technology transition performed in an IPPD environment were examined in detail. The information flow paths and decision patterns exercised over the course of the technology development were analyzed to evaluate relationships between how firms communicate their technology strategy and how they accomplish technology transition. *The flow paths for information concerning a firm's technology strategy were found to be a key component of the information structure for technology transition* (Hypothesis 1). That is, the methods by which a firm communicates information about its strategic plans for the use of technology establish organizational relationships that govern how different groups in the organization

work together to implement new technologies. Organizational and cognitive boundaries exist between the different functional disciplines involved in technology transition. Thus, in order for integrated technology development to take place among the various groups, information flow paths must be established (i.e., where information flows, work can be performed). These information flow paths serve to accustom the groups to the importance of external information, to facilitate personal interaction between the groups, and to provide data for the analysis of tradeoffs between competing functional requirements.

5. The analysis of the case study data also demonstrated that, given their temporal and organizational position between R&D and production, IPTs are well suited for a pivotal role in the transition of new manufacturing technology. *Organizational structures which promote the distribution of information to and from the IPT level were found to contribute to a more effective technology transition process* (Hypothesis 2). In cases where the IPT level was highly involved in the technology development, had decision making power, and received more comprehensive information about the technical, strategic, and programmatic requirements for the technology, a better technology transition resulted. While all of the case study technologies achieved significant cost and quality gains for the companies, the ones with the highest levels of information flow to and from the IPT level enjoyed more of the benefits of IPPD and lean manufacturing, as evidenced by the ability to deal effectively with organizational conflict, to coordinate across functional groups, and to plan for the future use of the technology in the firm. The ability of the manufacturing technology to positively influence the design of the product was also shown to be related to increased information flow to and from the IPT level, as was the ability of the IPT to participation in the formation of the technology strategy for the subsequent use of the technology across the organization.

6. The relationship between the R&D and product development groups in a company is very important in cases of new technology transition, since the implementation of most new manufacturing technologies requires some level of customized development. The dispersal of participants across organizational entities can make coordination complex, but it can also result in a more integrated and useful end product if the groups are able to find ways to combine their perspectives in a constructive manner. *The positive relationship between focal inclusion information structures and more effective technology transition illustrated in two of the case studies may stem from the extent to which R&D engineers were able to participate in IPT decision making*. Having R&D members on the IPT may allow the product development team to see technology as a potential contributor to improving the

overall product, not just how it is manufactured. This in turn allows them to enjoy greater benefits from the technology transition than those IPTs that treat new manufacturing technology as a "black box" provided by an external resource. Information flow is thereby increased both to and from the IPT level.

7. As previous research has suggested, *the IPPD process is conducive to promoting information flow between diverse groups.* Establishing a cross-functional teaming arrangement in the early stages of the technology transition was shown to have facilitated the analysis of the manufacturing alternatives from multiple perspectives. This style of teamwork, leveraging individual experience while maintaining a systems focus, requires strong integrative skills from the team's leader. A nested-IPT arrangement also provides a formal communication system for cross-fertilizing technologies across teams and across programs. Gaps in communication between different programs were also seen in IPPD-style organizations, though, indicating that the focused nature of the team-based approach may also lead to greater isolation between product lines.

8. In addition to the IPT authority structure, which promotes cross-functional interaction between individuals, *the diverse backgrounds of individuals can also be of great benefit to the technology transition process.* Diversity of experience has been shown in the past to contribute to an individual's ability to innovate, as well as to recognize the impact of their work on others, therefore resulting in the development of more creative and integrated solutions. The current research contributes additional insight into how an individual's cross-functional background can help to achieve cooperation across organizational entities. For example, at Company B, the ability of several of the key players to look at the problem from both a manufacturing and a design perspective hastened their recognition of high speed machining as a weight-reduction technology instead of one that merely impacted cycle time. Their past technical relationships with individuals across the organization also contributed to their ability to bring together the diverse set of functions required to complete the technology transition.

9. In spite of all of the focus on the importance of establishing formal organizational designs, *personal relationships can not be underestimated as a means of communication and action within a large organization.* The company "grapevine" and personal relationships between individuals were cited as important contributors to information flow in all of the case studies. The HSM technology development in particular can be described as a highly "personality-driven" process, since it was essentially formulated and implemented through

the personal initiative of two individual engineers. The autonomy they had in the organization allowed them to develop close communication networks across the R&D, IPT, and production areas and to gather the information and resources needed for the development. While this type of R&D management can yield great successes, relying solely on the initiative of individuals may not be an ideal choice to ensure that the company maintains a competitive position, mostly due to the questionable repeatability of the process.

10. Finally, one area in need of improvement in all of the case study companies is *increased attention to communication issues.* Many IPT members expressed their sense of a disconnect between R&D and product development in their organization, especially in the articulation of how new technologies can address product requirements. Members of the R&D group in turn expressed frustration with the fact that their work typically received attention in the organization only after it had been applied to a production program. The companies seem to need a clearer plan for technology transition between the three organizational stages of the technology lifecycle – R&D, product development, and production – so that all sides can exchange ideas on what can be done to solve today's manufacturing problems and what should be done in the future. Some manufacturers have begun to explore the use of information technology tools, such as company intranets and on-line process handbooks, to promote communication across the organization. Increased understanding of the organizational structures at work in the firm will also help to establish information flow where it is most needed.

9.2 Discussion: Strategic Technology Transition

The research has stressed the ability of the IPT to use strategic information in its decision making processes, in order to more effectively transition new manufacturing technologies from the laboratory to the factory floor. But what exactly does strategic information consist of and how can it be used to make choices for the selection of a particular technology? What are the strategic benefits of a new technology and why should a technology transition analysis bother to include them? This section addresses these questions by analyzing the patterns of data and anecdotal evidence found the research. The concept of "strategic technology transition" emerges from this discussion and points to the future of technology insertion as a tool for providing an architectural innovation of the organization.

9.2.1 What is a Strategic Technology?

Many of the people interviewed over the course of the two phases of the research seemed to balk at the descriptor "strategic" when discussing the adoption of new manufacturing technology in the aerospace industry. Most cited desires to reduce costs and schedules as the primary motivation for process development and made a point of commenting that technology does not provide a "strategic" advantage in their business. As one of the more eloquent interview subjects stated, "The customer doesn't care if you use stone or straw." One possible interpretation for this avoidance of the term "strategic" may stem from a lingering attitude in the industry that the days of "technology for technology's sake" are over. In Cold War terms, "strategic" meant putting new technology on the airplane simply because it was new and promised performance gains, although typically at great cost. Today, defense aerospace product development takes place in a market with an uncertain military threat and a shrinking procurement budget, shifting the primary emphasis from capability to "affordability" (i.e., adequate performance at a lower cost and with a shorter development schedule).

Although this environmental change means that the market attractiveness associated with having the most modern technology is drastically diminished, a cost-conscious market does not have to mean that the ideal design incorporates no new technology or that decisions made by contracting organizations should be without a strategic component. Instead, the strategy has shifted from one that chooses technologies on the basis of their capability to increase performance to one that chooses technologies based on their capability to lower cost and shorten development times. For example, one manager interviewed in Phase I of the study mentioned the desire to identify "desk-top technologies" – small, customized processes (such as the application of a heat treatment or anti-corrosion coating) that can be applied within a product manufacturing cell. Such processes are typically performed exclusively by external suppliers due to their time-, capital-, and labor-intensiveness that demands economies of scale. The development of localized alternatives now allows firms to reduce process time by eliminating the need for batch outsourcing, while at the same time making the process affordable on a much smaller scale of operation. IPT engineers in this firm need to be aware of the company's intent to bring such process steps in-house, so that they can optimize their designs to make use of innovative desk-top technologies. As this example demonstrates, even though aerospace executives may shy away from the term, these types of technology adoptions can still be defined as "strategic" under the assumptions of this research project.

9.2.2 The Conflict between the IPT Organization and Effective Technology Transition

In the list of characteristics of an effective technology transition (see Section 3.5), the final criterion requires a formal plan for the future use of the technology on other product lines. This requirement stems from the lean principle of "doing more with less." That is, a lean manufacturer can not afford (financially or competitively) to invest in single-use technologies that do not promote the long-term competitive position of the organization. The technology strategy of a company must therefore consider not just the current uses of a technology but future ones as well. This criterion can be thought of as a necessary component of a strategic technology implementation. Although some manufacturing processes may be appropriate for use on only a single product, many could be used to replace older or less capable processes on other product lines. For example, an airframe contractor typically manufactures many structural parts with the same process, such as metal machining. A machining technology therefore could potentially be applicable to many different aircraft programs in the company.

At the same time, given the high investment required for capital equipment and process development, use of a new technology on only one part or product is extremely inefficient. If the technology provides quality or performance benefits, it could often be used to improve these aspects of other products, thus increasing their profitability and market attractiveness. Requiring the technology to "buy its way onto the plane," as the economy of new technology insertion is commonly described in the aerospace industry, results in local optimization of the company's resources, yet that philosophy is consistently what governs IPT analyses. Given that many manufacturing processes are common to a variety of products, it would be beneficial for a product development program that is considering making changes to a process to share the costs, and consequently the rewards, across the company. Arguments have been made that cost-sharing is not feasible in a defense procurement environment, given that the "color of money" for a particular program must remain distinct. However, most firms fund their capital equipment and IRAD projects out of company overhead, so there are few valid regulatory reasons for not trying to get the most value from that money by taking advantage of improved process technology wherever feasible in the organization. The difficulties usually lie in making people aware of what technologies are available and how technology developed elsewhere in the organization could apply to other programs. Thus the organizational structure of the firm is of critical importance in decision making about new technology introduction.

These concepts are not new, but they bear repeating given the changes in organization that have accompanied the switch to an IPPD environment. In particular, the shift towards the exclusive use of IPTs that is currently taking place in the manufacturing sector may bring with it the unanticipated side-effect of isolating team members from broader questions of how technology is employed across the company. Compared to the traditional functionally-based organization, the organizational link between different disciplines has shifted far down into the organizational hierarchy, with direct communication now taking place between design and manufacturing at the engineering level (see Section 1.3). While this enables concurrent engineering, it also eliminates some of the high-level communication that used to take place between functional managers, thus weakening the impact strategic information can have on decision making. At the same time, the IPT format may unintentionally act to exacerbate the weakness of strategic evaluations at the product development level (see Section 2.4.2). Lacking close interaction with a centralized functional department, team members may be so focused on the development of their single product that they are unaware of how the technologies they are considering could be used by other teams. As one manager who is responsible for authorizing capital equipment purchases in his organization explained during the Phase I interviews, "You never see dramatic capital improvement ideas coming from the IPT level." The team-based nature of IPTs lead them to have a myopic focus and consequently see only their way of using a given technology.

This is not to suggest that the IPT format should be abandoned, as its benefits are indeed significant (see Section 2.3.5.1). However, unless some way is found to re-incorporate strategic information into technology transition decisions, IPTs will remain inferior to functional organizations along the strategic dimension of decision making. The intent of this research is therefore to identify ways in which the firm can recapture the benefits that were provided by a functional-based information structure linked at higher organizational levels. The firm's technology strategy should act as a guide for cross-company technology use. Bringing awareness of the technology strategy down to the IPT level therefore becomes a critical factor in overcoming the potentially isolating effects of a team-based organization. In turn, the technical and cost analyses performed by IPTs as they consider a particular technology transition may prove to be beneficial to the formulation of future technology strategies. As the following sections will show, how different groups in the technology transition value chain interact and how decisions are made can determine the future level of impact that the technology has on the organization, not just on the product currently in question.

9.2.3 Impact of Strategic Technology Transition on Current and Future Product Development

In the research case studies, both the high speed machining process and the electroless plating process can be viewed as strategic technologies that were introduced through effective transition initiatives. Two aspects of those development projects stand out in particular to distinguish them from the others: the existence of plans for the implementation of the technology on other product lines and the impact that the technology had on the design of the product. As emphasized throughout Chapter 6, the importance of the HSM technology for Company B lay not in its ability to machine the same parts at a higher speed but in its ability to fundamentally change the design of the product. While Company B may have been slow to incorporate HSM into its formal strategic planning system, managers on the Beta program did appear to have the ability to recognize HSM as a strategic technology – in this case, one that had the ability to reduce weight and cost through a shift to unitized design. This appreciation of the technology as more than a time saving incremental improvement was evidenced by the approvals necessary to begin the IRAD program, allocate funding for retrofitting the AMT machines, start manufacturing test parts, and perform the adoption analysis for the Beta program. Once the test parts for the Beta program began circulating through the organization, information exchange occurred between the trailing edge IPT and other programs in the company that served to spread awareness of the benefits of HSM and incentive for other programs to use it. Since this happened early on in the development, the company was able to plan their HSM capacity to meet the demands of several programs across the organization.

Likewise, in the plating development at Company C, the task team members recognized the importance of communicating across the IPPD architecture in order to optimize not only the fabrication of a metalized surface but how the quality of that surface could affect the design of the frequency-selective elements. Changes were made to both aspects of the product – its design and its manufacture – to improve the net outcome. Such positive results can only be achieved through a recognition of the process technology as having more of an influence than in only the physical realm of its application. At the same time, the IPT was able to consider how the technology might apply to other projects in the organization and to plan their new plating facility in a flexible layout that can accommodate the future needs of different programs. A technology used in this way, or as the HSM process was used, becomes a strategic technology for the company. Its potential benefit to the firm is thus dramatically magnified, since both the individuals involved in the process and the organizational structure for the technology transition have taken into account strategic information that will serve to guide the future uses of the technology.

Contrary to the initial expectation that the generation of the firm's technology strategy takes place exclusively at the senior management level, the cases based on focal inclusion relationships shared the unexpected outcome of strategy arising from the IPT level (see Section 8.2.2). Since the IPT in these cases has access to both technical, financial, and programmatic information, as well as the ability to predict and enhance the strategic possibilities of the process, they were able to shape the subsequent use of that technology within the firm. Information flow out of the IPT level, in particular to other teams and to the higher management levels, was also vital to giving visibility to the results of their analyses and to promoting awareness of the technology's benefits to other programs in the organization. Management's recognition of strategic input coming from the IPT level is therefore seen as another key aspect of the ability to effectively deal with strategic technology transition.

As in all areas of new management research, however, it is important to note that not every approach is right for every situation. For example, the IPT at Company A did indeed appear to understand that the resin transfer molding technology held the potential to change the design of the wing parts, via its ability to incorporate metal fasteners into the composite structure or to integrate several components into a single RTM part. Both of these design changes could have simplified the assembly process for the sinewave spars and lowered material and labor costs. The team decided not to take advantage of these auxiliary benefits, however, since the design of the parts had already been finalized. They felt that the costs and time incurred in changing the designs would have outweighed the benefits. Given that this decision was made, the important thing for Company A to do now is to find a way to capture the knowledge that was gained during the development process. If the IPT had thought more about the future uses of the RTM technology in the organization, then perhaps that knowledge would be more readily accessible to future engineers. In that way, even if a complete implementation of a new technology is not well suited to the current product, the IPT will have established an information structure for the communication of their experience. The benefits of thinking strategically about manufacturing technology adoption can thereby extend beyond the current implementation.

9.2.4 Architectural Innovation of the Organization

Given the continued prognosis for tight R&D investment budgets in the manufacturing sector, the future of new manufacturing technology insertion appears to lie in the identification and adoption of strategic technology. In order to meet this challenge, firms will need to find ways to stimulate the cross-functional and cross-group communication that was shown through the hypotheses to be most conducive to high levels of information flow. To this end, the theory of strategic technology transition presented here draws on the concept of architecture in product development [Abernathy and Clark, 1985; Henderson and Clark, 1990; Rechtin, 1991; Ulrich and Eppinger, 1995]. Just as physical parts must be assembled and functionally integrated into an architecture for the overall product, the individuals and groups involved in the development of those parts must be assembled and integrated into an architecture of the organization. This organizational architecture is equivalent to the firm's organizational structure, in that it controls which groups work together, what information is shared, and how decisions are made concerning competing elements. Innovations in architecture can therefore be thought of not just as ones that affect the architecture of the product but as ones that affect the organizational structure of the technology transition process.

As the HSM and electroless plating case studies showed, strategic technology transition requires the establishment of unique information structures. Different groups must be brought together beyond the management hierarchy or authority structure in order to stimulate innovation in how manufacturing processes can influence and improve product design. The usual arrangement of the IPT as an engineering group nested in a program-based hierarchy is not sufficient. Neither is using process R&D groups as hands-off consultants who may provide high-quality work to meet the current specifications but are unable to create a collaborative working relationship with the IPT that could possibly stimulate a mutually beneficial expansion of those requirements. Instead, the architecture of new product development must include the management of information flow structures. To put in place an effective technology transition process across the organization, this management will be required at all stages of the technology lifecycle, so that the information structures most conducive to an effective value chain can be established and/or encouraged. The information structure of a company is therefore seen as both a consciously constructed arrangement and an emergent one, in that relationships for information flow can be both managed through formal organizational design and cultivated through the establishment of a culture of innovation (see Section 9.3). Ideally, the architecture of the organization will be considered very early in the product development process, just as is the physical product architecture.

Information structures in product development need not be static. Just as each case studied in this research project made use of different groups and information flow paths, it is reasonable to expect that different companies and different technologies will also require different organizational structures to achieve effective technology transition. Subsequent diffusion of a manufacturing technology to other product lines may quite likely require re-structuring of the information flow paths used in the initial introduction of that process. That is, one set of flow paths may not be appropriate for all applications of a given technology or for all technologies in general. Different groups and individuals will need to be involved depending on the particular circumstances at hand, possibly including such discriminators as the maturity of the technology, the technical focus of the application, and the extent of adoption on the program (i.e., whether the technology will be used by multiple IPTs in the system or just one). The next section of this chapter will explore how the results of the research can be applied to improve information structures for technology transition in manufacturing firms, according to the above concept of an architectural innovation of the organization.

9.3 Implications for Industry: Creating a Culture of Innovation

In order to fully realize the benefits of a strategic technology, the firm must establish an organizational structure that promotes information flow and shared decision making among diverse groups such as R&D, IPTs, and production. In essence, the hypotheses disconfirm the practice observed in half of the firms studied in Phase I, in which relying on the management chain to funnel and filter strategic information to the team was thought to be sufficient for the effective incorporation of strategic information in technology transition decisions. Instead, the research results indicate that focal inclusion links to the IPT from cross-cutting groups like R&D and producibility engineering show greater promise for this purpose. IPT members should therefore be given greater access to strategic information and should be encouraged to make use of it when analyzing the benefits of competing technologies. While drawbacks to the unrestrained distribution of information exist, the hypotheses attempt to show that IPTs can benefit from increased access to strategic information, specifically through improved technology transition effectiveness.

Using the HSM case as a model, engineers who are responsible for the early stages of development activity should become members of the IPT that will use that technology. In this way, the later stages of the value chain can be used for the refinement of the technology for the specific application as well as for continued joint development to improve both the product and the process. By leveraging the strong technical expertise of the innovator with the cross-functional perspective of the IPT members, cognitive and organizational barriers are overcome in both groups. As described in the case study analysis, participation from the IPT members and from production operations in portions of the actual development work can similarly result in increased effectiveness of the technology transition. Looking at the technology transition process over time, the later stages of the organizational value chain should also include planning for future uses of the technology, recognizing the contribution that the first IPTs associated with the technology transition can make to the formation of firm-wide technology strategy, given the high level of information present at their level. Although this should also be done on a broader scale as part of annual technology investment planning, the actual implementation of a new technology on a product has been shown to be a significant motivator for its adoption by others, since the benefits of the technology are then apparent through a physical artifact. Planning for future use could be accomplished through the nested IPT authority structure in cases of expanding the application of the technology from a single IPT to others in the same program or by a company-wide resource for the diffusion of manufacturing technology from program to program.

The approach advocated above is very similar to what took place at Company B. The HSM technology transition was a very bottom-up process with lots of communication and shared development work between the innovator, the first IPT, production operations, and even suppliers. The personal initiative shown by Mr. Smith was a strong factor in the success of the project, and his position in the authority structure as a member of the cross-cutting producibility engineering group contributed to his ability to make and use information linkages between other groups. However, his efforts also fell somewhat outside the company's established organizational structure for technology development; that is, he was not a member of the manufacturing R&D group normally responsible for the introduction of new manufacturing technology in the company. As was discussed in Chapter 6, this calls into question the repeatability of Company B's current organizational structure. While focal inclusion was certainly evident in that particular case, the individuals involved admit that a great deal of effort was required to bring together the right people and maintain the momentum of the process. In addition, Mr. Jones and other IPT members expressed regret at the reduction of their involvement in the final stages of development and as the technology was diffused to other programs, explaining that they felt they still had more to contribute. Although they were responsibly for performing a majority of the analyses that led to the recognition of HSM as a strategic technology in the company, the recognition of their contribution to the strategy generation process did not extend to their being asked to remain involved in planning subsequent implementations of the technology to the same extent.

Still, Company B's experience comes closest to the interpretation of strategic technology transition as described above. Bottom-up information flow, outside the authority structure, produced better results than the top-down processes seen in several of the other cases. The key, then, is to understand the elements of the HSM technology transition that were more effective and to determine organizational mechanisms to work around the apparent lack of repeatability. One element which has been discussed previously in the literature [Allen, 1977 *et al*] is the concept of rotating personnel between the R&D and product development arenas. This could perhaps be accomplished by an organizational "loan" of R&D engineers to the IPT as the technology transition progresses, after which they would return to the central R&D group to refresh their technical focus and work on new development projects. Another more novel solution is to formally designate key individuals in the organization whose responsibilities include the transition of technologies across programs. This role should be more strategically involved than that of the typical process improvement resources found in many manufacturing organizations.

Drawing from the research results, the critical elements of this new technology transition function focus on establishing the company's organizational architecture for technology transition. Specific responsibilities to achieve this might include:

- the recognition of opportunities for strategic manufacturing technologies (i.e., those that can reduce cost and schedule)
- close monitoring of R&D investments to identify those characteristics which have the ability to improve product design
- continual polling of product programs, *at the IPT member level* (not just program management), to identify program needs for manufacturing technology and product performance (e.g., the weight reduction needs of the Beta program)
- strong networking skills to maintain and execute communication linkages between all stages of the innovation life cycle, and
- creation of new information structures in the organization to educate all personnel on (1) the content and goals of the company's technology strategy, (2) current and future R&D initiatives, and (3) opportunities for the diffusion of technologies from program to program.

Managing this new combination of authority and information structures will involve both "push" and "pull" elements of technology insertion. While a central body might be responsible for establishing and managing information structures for technology transition, individuals from all phases of the technology life cycle – R&D, product development, and production operations – must be involved to ensure the direct transfer of both tacit and explicit knowledge. These individuals would necessarily vary with the particular technology or program involved.

Putting these ideas together, it becomes apparent that balance is needed between a formal technology plan and a flexible organizational structure. While many aspects of technology strategy can be planned in advance, some of the best ideas often emerge only after the work is underway. In the case of the HSM technology transition, the strategy for the implementation of high speed processes across the company came about only after the IRAD project had been completed and test parts were manufactured for one of the IPTs on the Beta program. A certain level of managerial foresight was of course required to get to that point, but the strategy of using the technology wherever possible on the Beta airframe did not appear until the technology transition was well underway. Similarly, in the two cases at Company C, the research shows that while the company had built in an organizational mechanism for a consulting relationship between the process R&D group and the product teams, it wasn't until the AMT engineers stepped out of their usual role and became involved with the IPT as full members that they were able to generate high levels of information flow at the IPT level.

The evolutionary nature of such technology transitions echo the importance of recognizing and cultivating emergent information structures. Companies therefore need to create a culture for technology transition that anticipates and rewards changes in information flow paths. While rewarding something that has not happened yet is obviously a rather nebulous goal, the most effective organizational structures are most likely ones that foster the personal initiative and networking opportunities that will give future "Mr. Smiths" the autonomy and resources to pursue their ideas. Potential human resource incentives in this area include continuing education in secondary functional areas to foster diversity in individuals' backgrounds, company interest groups to encourage cross-boundary networking, and formal communication mechanisms for the *early* publication of success stories. Team-based incentives, such as recognizing and rewarding IPTs that identify cross-company opportunities for implementing new manufacturing technologies, can also help to align the authority structure of the firm with the goal of getting teams to use strategic information in their analyses.

The amount of information required to eliminate the communication gap between the IPT and the firm's strategic planners is potentially quite small, falling somewhere between the scope of a broad "mission statement" and a comprehensive R&D investment schedule. The strategy literature [Hax and Majluf, 1996 *et al*] provides details of the formulation of the strategic information; this work concentrates instead on the distribution of that content. At a minimum, product development teams should be informed as to which technologies are being pursued, what the anticipated benefits are (from both manufacturing and design perspectives), and who in the R&D or process development groups to contact for more information. Wider distribution of information about the company's development activities would certainly be a necessary first step for companies where even this basic level of strategic information does not reach the working level of the organization. Additional information on new business development, including the nature of future product introductions and anticipated key technology requirements, could also lend greater weight to strategic considerations in the evaluation of which technologies to use on current products.

In summary, rather than having the IPT perform a time-consuming technical and cost analysis which will be tossed aside when upper management alone considers the strategic issues associated with a technology transition, distributing strategic information to the team level would speed decision making, eliminate unproductive time, and provide incentives to team members to consider *all* of the important elements when making their decisions. This in turn reinforces the IPPD philosophy of decision making at low levels and improves team members' satisfaction by giving them the confidence that their work has contributed to the long-term prosperity of the firm. In addition, the promulgation of strategic thinking through the organization will in itself act to make technology strategy part of the schematic representations of product development personnel, thus contributing to the breakdown of cognitive barriers to the use of strategic information in future decision-making. The first step towards including this type of information, however, will require more effort in the strategy development process to generate technology plans that can be used to guide project level decisions. In addition, IPT members will need to undergo training in how to interpret strategic statements, and the firm must develop qualitative and quantitative methods through which to compare strategic, technical, and cost factors on even footing. It is hoped that this burden will be offset by the significant improvements in product development capability, cycle time, and IPT effectiveness that the wiser distribution of strategic information promises.

9.4 Implications for Organizational Theory

The main theoretical contribution of this work comes from an elucidation of the need for strategic information distribution to the IPT that runs counter to current product development practices. In creating this understanding, the research has drawn from a variety of academic literature, including innovation management, systems engineering, and organizational studies. This interdisciplinary base has provided a unique and comprehensive view of technology transition within an organizational context. The research has served to codify the variety of information structures in use in industry for the distribution of such information and has explored the impact that different structures have on the process of technology transition. In advocating the benefits of the focal inclusion information structure, the research has focused on identifying ways to recapture the information flow paths between programs that were lost in the switch from a functionally based organization to the IPT format. The results attempt to unify the best characteristics of each authority structure by drawing attention to how the establishment of information flow paths for distributing the firm's technology strategy can improve the effectiveness of the IPT's contribution to technology transition initiatives. In this way, the technology strategy of the firm is thought to guide not only actual technical development but also cross-company technology implementation, through the formulation of organizational structures for technology transition. Examination of the results points to the need for product development researchers to re-examine the historical absence of strategic information in IPT decision making and to consider the impact of strategy when advocating particular structures of team organization. The concepts of strategic technology transition and architectural innovation of the organization are introduced as a means to understand the dynamic nature of information flow structures in a technology transition environment.

In order to situate this research in the literature, comparisons should be made with previous styles of organizational design. The matrix style of project management at first glance may seem to be the most similar to the concept of focal inclusion recommended here. Indeed, in theoretical intent, the two forms are very similar, in that both rely on co-assignment of personnel between different groups in order to share knowledge and promote communication. In implementation, however, the matrix form has been traditionally used in manufacturing companies in a very different context from how the focal inclusion structure is advocated here. In particular, the matrix approach of having workers responsible to both a function and a particular product program has been primarily focused on sharing technical data between disciplines during the design phase of product development. That is, the organizational design was a matrix of engineering functions. The focal inclusion structure, as studied here, is primarily seen as a mechanism to promote the communication of both technical and *strategic* information, within a product development environment that includes *manufacturing* issues. This involves establishing connections not only across disciplinary boundaries but also across hierarchical ones.

The IPT itself, which has been assumed here as the authority structure under consideration, is also quite different from a matrixed team of engineers. As described in Section 2.3, IPT membership is broader, drawing individuals from non-technical as well as technical backgrounds. IPTs are also led by a single "heavyweight project manager" and maintained over the full lifecycle of the product development project, all the way into production. A focal inclusion link to the IPT, therefore, involves a much more tightly integrated and long-term relationship than that implied by the term "matrix management." The role of the technology transition function described in Section 9.3 above consists of bringing additional information into the IPT about how new technology could help the team's product development activity, as well as serving as a conduit for information to flow from the IPT to share experiences of technology insertion across programs. While these technology transition specialists may indeed be assigned to two different organizational groups at one time, their role has far greater strategic impact within the company than merely adding another technical perspective on new technology use. For this reason, the choice was made to establish new terminology (i.e., the "focal inclusion" structure) to distinguish this approach from the traditional concept of matrix management. In fact, the term "focal inclusion" contains an important message about the nature of this relationship: the focal point sources are *included* in the IPT and its activities, not just assigned to additional tasks.

The recommendations outlined in the previous section for the implementation of focal inclusion structures in the manufacturing sector may also bring to mind the "technology gatekeeper" concept documented in the literature [Allen, 1977; Roberts, 1979; *et al*]. Previous work has focused on how companies can bring innovative ideas from the external environment into their organization; a gatekeeper in that sense is an individual who is exceptionally up to date on the industry state-of-the-art and has the internal connections to bring awareness of those innovations into the company. The literature has therefore concentrated on the first one or two stages of the innovation life cycle (recognition of opportunity and possibly idea formulation), which typically take place within a laboratory-based R&D group. These studies have certainly contributed to the understanding of sources of innovation and the importance of communication networks. The research described here extends this work by focusing further downstream in the innovation life cycle, on the transition of technology from a laboratory environment into an actual product. This focus not only shifts the attention of "gatekeeping" activities from outside to inside the firm, but also explores the cognitive and organizational differences between groups that are located within the same company but that have very different responsibilities. In studying the relationships between groups all the way through the technology transition value chain – from R&D to product development to production operations – the research examines how information regarding broad company strategies for the use of technology can be made accessible and useful across the organization. The work represents the first application of the ideas of strategic information flow and technology decision making within an IPPD environment and therefore makes an important contribution to the understanding of this still-evolving approach to new product development.

Finally, from a methodological perspective, the work also provides a contribution through the development of the information structure diagramming method and the synthesis of the organizational value chain for technology transition. Constructs to distinguish the important variations in organizational structure between companies were developed and analyzed in real world cases. While previous work has served to identify the basic stages of the innovation lifecycle, these tools provide a systematic way to assess how that process is enacted by the various groups and individuals within an organizational context. The method has also identified a highly useful format for recording and analyzing the history of a technology transition initiative, by means of a single graphic that captures all three of the dimensions of organizational structure: authority, information flow, and decision making.

9.5 Recommendations for Future Study

While the research takes a significant first step towards an understanding of the role of organizational structure in technology transition, opportunities exist for further work in several areas. One significant question remaining after the research analysis concerns the level of impact that information flow has on technology transition effectiveness. In particular, the results showed that even the case studies in which the IPT operated under the management chain structure were relatively successful. While a certain amount of their success can be attributed to the selection bias inherent in gaining company access to the case material, those results undermine the suggestion that a particular structure must be dictated within an organization in order for effective technology transition to occur. Further research is therefore needed to examine how companies can maintain such loose control over their information structure and still achieve reasonable results. A longitudinal study of companies' experiences with different organizational structures would serve to address this issue to some extent. The research would also be complemented by further investigation into successful ways to implement the focal inclusion information structure. Much of the effort in this work went into first classifying and then evaluating which structures were in existence in the industry. Now that the impact of different information structures on the technology transition process is better understood, more attention can be paid to the focal inclusion structure itself to examine why it was not more widely observed and how it might be implemented in a variety of circumstances. This could be accomplished through further case studies of firms using focal structures as well as through real-time observation of an implementation of the structure in a pilot scenario.

Another area of interest involves how different information structures are suited to the distribution of different types of information (e.g., technical, marketing, strategic). While this study was able to construct a history of the development in each technology transition, the retrospective case study approach did not capture every exchange of information between the parties. A quantitative analysis of both written and oral communications may well show that certain kinds of information may be transmitted more readily through management chain linkages, while others may be more suited to focal point contacts. Such a study might explain more accurately why Company A, for instance, failed to achieve a highly effective technology transition initiative even though the levels of participation and decision making in the IPT were quite high. As the discussion of the attenuation construct demonstrated (see Section 8.2.2), better metrics are needed for the assessment of information flow to different levels in the organization. The development of other measurement methodologies would also provide insight as to what kinds of information are filtered between management layers and why. This type of analysis will most likely require a more concurrent style of research observation, with a high level of access to both archival and conversational forms of communication. Subjective data could also be validated through other means, such as incorporating self-assessment by team members in the areas of information flow, organizational conflict, and job satisfaction.

Another interesting avenue for future work involves the longer-term evaluation of technology transition effectiveness, which would take into account the evolution of a technology over the course of several applications in the firm. Downstream measures of effectiveness, such as the number of design and process changes that a product requires after the initial technology insertion, would contribute to a more thorough assessment of the impact of different organizational structures. The availability of quantitative data on performance, cost, and schedule associated with the technology over the lifetime of the project would also be helpful in removing some of the subjectivity of the case study method. It would also be extremely interesting to study cases that broaden the range of technology transition effectiveness seen in this study. Looking at some of the "failures" in the industry would help to enrich the data set and to clarify the influence that information flow has on technology transition effectiveness.

Since this research has focused solely on the defense aerospace industry, another natural extension would be to study technology transition in other industries and sectors. In particular, the automotive industry appear to offer especially interesting opportunities for comparison for several reasons. First, auto manufactures were among the first adopters of the IPT format, giving them more experience with the structure and more time to develop efficient ways for implementing it. The auto industry's decade head-start over their aerospace manufacturing colleagues is also present in the market history of each industry, with both of them experiencing reduced demand and consequently reduced availability of discretionary funding for technology development. The methods of dealing with information flow present in the auto industry therefore could provide a preview of approaches yet to be introduced in the later-adopting aerospace firms. Examining how IPTs and technology transition are organized in a commercial, rather than military, environment could also produce some interesting comparisons as to how the market environment affects strategic technology planning. Within the aerospace industry, studies of the commercial aircraft business could also give greater insight into information flow across internal boundaries in firms that operate in both types of markets.

In addition to the extension of the research into other manufacturing industries, a final suggestion for future study in this topic area consists of a closer examination of how the changing competitive environment in the aerospace industry has affected the development and communication of technology strategies within firms. As the industry has undergone consolidation, many firms have found themselves to be composed of multiple R&D resources spread across both geographic and intellectual distances. In order to operate in a coherent manner, the firms will have to find ways to merge a diverse set of technology strategies and engineering resources at the new corporate level. Perhaps the recent mode of acquisition will need to be followed by a period of technology stock-taking, consolidation, coordination, and dissemination of R&D resources in order for the effective deployment of new technologies to continue.

REFERENCES

Abernathy, William J. and Kim B. Clark, "Innovation: Mapping the Wind of Creative Destruction," *Research Policy*, Number 14, 1985, pp. 3-22.

Abernathy, William J. and James M. Utterback, "Patterns of Industrial Innovation," from *Readings in the Management of Innovation* (Michael Tushman and William L. Moore, ed.), HarperBusiness, 1988, pp. 25-36.

Alexis, Marcus and Charles Z. Wilson, *Organizational Decision Making*, Englewood Cliffs, NJ: Prentice-Hall, 1967.

Allen, Thomas J., *Managing the Flow of Technology*, Cambridge: MIT Press, 1977.

Ancona, Deborah G. and David F. Caldwell, "Bridging the Boundary: External Activity and Performance in Organizational Teams," *Administrative Science Quarterly*, Volume 37, 1992, pp. 634-665.

Ancona, Deborah G., "Groups in Organizations: Extending Laboratory Models," Chapter 9 from *Group Processes and Intergroup Relations* (ed. Clyde Hendrick), Newbury-Park, NJ: SAGE, 1987, pp. 207-230.

Ancona, Deborah Gladstein and David E. Caldwell, "Cross Functional Teams: Blessing or Curse for New Product Development," *MIT Management*, Spring 1991, pp. 11-16.

Astley, W. Graham and Andrew H. Van de Ven, "Central Perspectives and Debates in Organizational Theory," *Administrative Science Quarterly*, Volume 28, June 1983, pp. 245-273.

Bates, Kimberly A., Susan D. Amundson, Roger G. Schroeder, and William T. Morris, "The Crucial Interrelationship Between Manufacturing Strategy and Organizational Culture," *Management Science*, Volume 41, Number 10, October 1995, pp. 1565-1580.

Beyerlein, Michael M. and Douglas A. Johnson (ed.), *Advances in Interdisciplinary Studies of Work Teams*, Volume 1: "Theories of Self-Managing Work Teams," Greenwich, CT: JAI Press, 1994.

Beyerlein, Michael M., Douglas A. Johnson, and Susan T. Beyerlein (ed.), *Advances in Interdisciplinary Studies of Work Teams*, Volume 2: "Knowledge Work in Teams," Greenwich, CT: JAI Press, 1995.

Britannica Online, available: <http://www.eb.com>, accessed July 12 - 26, 1996. Reference searches include the following:

- Adopt
- Diffusion
- Diffusivity
- History of Technology
- Random Walk
- Technology

Britannica Online: Merriam-Webster's Collegiate Dictionary, available: <http://www.eb.com>, accessed July 12-17, 1996. Reference searches include the following:

- Adopt
- Diffusion
- Technology

Browning, Tyson R., "Systematic IPT Integration in Lean Development Programs," Massachusetts Institute of Technology, Department of Aeronautics and Astronautics, Unpublished Master of Science Thesis, June 1996.

Burns, Tom and G.M. Stalker, *The Management of Innovation*, 1961.

Carroll, John S. and Eric J. Johnson, *Decision Research: A Field Guide*, Newbury Park, CA: SAGE Publications, 1990.

Chandler, Alfred D., Jr., *Strategy and Structure*, Cambridge: MIT Press, 1962.

Child, John, "Organizational Structure, Environment, and Performance: The Role of Strategic Choice," *Sociology*, Volume 6, 1973, pp. 1-22.

Christensen, Clayton M., "Exploring the Limits of the Technology S-Curve," *Production and Operations Management*, Vol. 1, Number 4, Fall 1992, pp. 334-357.

Clark, Kim B. and Takahiro Fujimoto, *Product Development Performance*, Boston: Harvard Business School Press, 1991.

Clarke, Ken and Howard Thomas, "Technological Change and Strategy Formation," from *The Strategic Management of Technological Innovation*(Ray Loveridge and Martin Pitt, ed.), Chicester: John Wiley and Sons, 1990.

Clausing, Donald, *Total Quality Development: A Step-by-Step Guide to World-Class Concurrent Engineering*, New York: ASME Press, 1994.

Cleland, David I., *Strategic Management of Teams*, New York: John-Wiley & Sons, 1996.

Cohen, Wesley M. and Daniel A. Levinthal, "Absorptive Capacity: A New Perspective on Learning and Innovation," *Administrative Science Quarterly*, Volume 35, 1990, pp. 128-152.

Cooper, Robert G. and Elko J. Kleinschmidt, "Winning Businesses in Product Development: The Critical Success Factors," *Research-Technology Management*, Volume 39, Issue 4, July/August 1996, pp. 18-29.

Davis, Stanley M. and Paul R. Lawrence, "Problems of Matrix Organizations," *Harvard Business Review*, Volume 56, May-June 1978, pp. 131-142.

de Neufville, Richard, *Applied Systems Analysis*, New York: McGraw-Hill Text, 1990.

DiMaggio, P.J. and W.W. Powell, "The Iron Cage Revisited: Institutional Isomorphism and Collective Rationality in Organizational Field," *American Sociological Review*, Volume 48, 1983, pp. 147-160.

Dougherty, Deborah, "Interpretive Barriers to Successful Product Innovation in Large Firms," *Organization Science*, Volume 3, Number 2, May 1992, pp. 179-202.

Dutton, Jane E. and Robert B. Duncan, "The Creation of Momentum for Change through the Process of Strategic Issue Diagnosis," *Strategic Management Journal*, Volume 8, 1987, pp. 279-295.

Dutton, Jane E. and Susan E. Jackson, "Categorizing Strategic Issues: Links to Organizational Action," *Academy of Management Review*, Volume 12, Number 1, 1987, pp. 76-90.

Eisenhardt, Kathleen M., "Building Theories from Case Study Research," *Academy of Management Review*, Volume 14, Number 4, 1989, pp. 532-550.

Eppinger, Steven D., Daniel E. Whitney, Robert P. Smith, and David A. Gebala, "A Model-Based Method for Organizing Tasks in Product Development," *Research in Engineering Design*, Volume 9, 1994, pp. 1-13.

Fiske, S.T. and S.E. Taylor, "Social Categories and Schemas," Chapter 4 from *Social Cognition* (2nd ed.), Reading, MA: Addison-Wesley, 1991, pp. 96-140.

Frischmunth, Daniel S. and Thomas J. Allen, "A Model for the Description and Evaluation of Technical Problem Solving," *IEEE Transactions on Engineering Management*, Volume EM-16, Number 2, May 1969, pp. 58-64.

Galbraith, Jay R., *Designing Complex Organizations*, Reading, MA: Addison-Wesley Publishing, 1973.

Galbraith, Jay R., *Organizational Design*, Reading, MA: Addison-Wesley Publishing, 1971.

Gersick, Connie J. G. and J. Richard Hackman, "Habitual Routines in Task-Performing Groups," *Organizational Behavior and Human Decision Processes*, Volume 47, 1990, 65-97.

Gladstein (Ancona), Deborah L., "Groups in Context, A Model of Task Group Effectiveness," *Administrative Science Quarterly*, Volume 29, 1984, pp. 499-517.

Gladstein (Ancona), Deborah and James Brian Quinn, "Making Decisions and Producing Action: Two Faces of Strategy," from *Organizational Strategy and Change*, (Johannes M. Pennings and Associates, ed.), San Francisco: Jossey-Bass Publishers, 1985, pp. 198-216.

Hackman, J. Richard and Charles Morris, "Group Tasks, Group Interaction Process, and Group Performance Effectiveness: A Review and Proposed Integration," from *Advances in Experimental Social Psychology, Volume 8* (Leonard Berkowitz, ed.), New York: Academic Press, 1975, pp. 45-99.

Haddad, Carol, "Operationalizing the Concept of Concurrent Engineering: A Case Study from the U.S. Auto Industry," *IEEE Transactions on Engineering Management*, Volume 43, Number 2, May 1996, pp. 124-132.

Hannan, Michael T. and John Freeman, "The Population Ecology of Organizations," *American Journal of Sociology*, Volume 82, Number 5, 1977, pp. 929-964.

Hax, Arnaldo C. and Nicholas S. Majluf, *The Strategy Concept and Process*, Upper Saddle River, NJ: Prentice-Hall, 1996.

Henderson, Rebecca M. and Kim B. Clark, "Architectural Innovation," Administrateive Science Quarterly, Volume 35, 1990, pp. 9-30.

Hernandez, Christopher M., "Challenges and Benefits to the Implementation of Integrated Product Teams on Large Military Procurements," Massachusetts Institute of Technology, Sloan School of Management, unpublished Master of Science Thesis, June 1995.

Hickson, David J., Richard J. Butler, David Cray, Geoffrey R. Mallory, and David C. Wilson, *Top Decisions: Strategic Decision-Making in Organizations*, San Francisco: Jossey-Bass Publishers, 1986.

Hutt, Michael D., Beth A. Walker, and Gary L. Frankwick, "Hurdle the Cross-Functional Barriers to Strategic Change," *Sloan Management Review*, Spring 1995, pp. 22-30.

Janis, Irving L., "Sources of Error in Strategic Decision Making," from *Organizational Strategy and Change*, (Johannes M. Pennings and Associates, ed.), San Francisco: Jossey-Bass Publishers, 1985.

Kantrow, Alan M., "The Strategy-Technology Connection," *Harvard Business Review*, July-August 1980, pp. 6-21.

Kaplan, Robert S. and David P. Norton, "Using the Balanced Scorecard as a Strategic Management System," *Harvard Business Review*, January-February 1996, pp. 75-85.

Katz, Ralph and Thomas J. Allen, "Project Performance and the Locus of Influence in the R&D Matrix," *Academy of Management Journal*, Volume 28, Number 1, 1985, pp. 67-87.

Katzenbach, Jon R. and Douglas K. Smith [1993a], "The Discipline of Teams," *Harvard Business Review*, Volume 71, March-April 1993, pp. 111-120.

Katzenback, Jon R. and Douglas K. Smith [1993b], *The Wisdom of Teams*, Boston: Harvard Business School Press, 1993.

Klein, Janice A., "Lean Aircraft Initiative Organization & Human Resources (O&HR) Survey Feedback – Factory Operations," Massachusetts Institute of Technology White Paper, LEAN #95-02, March 17, 1995.

Klein, Janice A. and Patrick M. Maurer, "Integrators, Not Generalists, Needed: A Case Study of Integrated Product Development Teams," *Advances in Interdisciplinary Studies of Work Teams*, Volume 2, 1995, pp. 93-115.

Klein, Janice A. and Gerald I. Sussman, "Lean Aircraft Initiative Organization & Human Resources (O&HR) Survey Feedback – Integrated Product Teams (IPTs)," Massachusetts Institute of Technology Case Study, LEAN #95-03, April 7, 1995.

Krackhardt, David and Daniel J. Brass, "Interorganizational Networks: the Micro Side," from *Advances in Social Network Analysis* (S. Wasserman and J. Galaskiewicz, ed.), Thousand Oaks, CA: SAGE Publications, 1994, pp. 207-229.

Levi, Daniel and Marguerite Lawn, "The Driving and Restraining Forces which Affect Technological Innovation in Organizations," *The Journal of High Technology Management Research*, Volume 4, Number 2, 1993, pp. 225-240.

Lewin, K., "Frontiers in Group Dynamics," *Human Relations*, Volume 1, 1947, pp. 5-41.

Loehr, Linda, "Between Silence and Voice: Communicating in Cross-Functional Project Teams," *IEEE Transactions on Professional Communication*, Volume 34, Number 1, March 1991, pp. 51-56.

Maidique, Modesto A. and Peter Patch, "Corporate Strategy and Technological Policy," from *Readings in the Management of Innovation* (Michael Tushman and William L. Moore, ed.), HarperBusiness, 1988, pp. 236-248.

March, James G., *A Primer on Decision Making*, New York: The Free Press, 1994.

March, James G., "How Decisions Happen in Organizations," from *Organizational Decision Making* (Zur Shapira, ed.), Cambridge, UK: Cambridge University Press, 1997.

March, James G. and Johan P. Olsen, *Rediscovering Institutions: The Organizational Basis of Politics*, New York: The Free Press, 1989.

Marples, David L., "The Decisions of Engineering Design," *IRE Transactions on Engineering Management*, June 1961, pp. 55-71.

McCord, Kent R. and Steven D. Eppinger, "Managing the Integration Problem in Concurrent Engineering," Massachusetts Institute of Technology Working Paper, International Center for Research on the Management of Technology, #95-93, 1993.

Mintzberg, Henry, "Patterns in Strategy Formation," *Management Science*, Volume 24, Number 9, May 1978, pp. 934-948.

Mintzberg, Henry, Duru Raisinghani, and André Théorêt, "The Structure of 'Unstructured' Decision Processes," *Administrative Science Quarterly*, Volume 21, June 1976, pp. 246-275.

Nadler, David A. and Michael L. Tushman, "A Model for Diagnosing Organizational Behavior," *Organizational Dynamics*, Volume 9, Issue 2, Autumn 1980, pp. 35-51.

Nevins, James L. and Daniel E. Whitney (ed.), *Concurrent Design of Products and Processes: A Strategy for the Next Generation of Manufacturing*, New York: McGraw-Hill, 1989.

Pappas, Chris, "Strategic Management of Technology," from *Readings in the Management of Innovation* (Michael Tushman and William L. Moore, ed.), HarperBusiness, 1988, pp. 229-235.

Pfeffer, Jeffrey, *Organizations and Organizational Theory*, Boston: Pitman, 1982.

Pfeffer, Jeffrey and Gerald R. Salancik, *The External Control of Organizations: A Resource Dependence Perspective*, New York: Harper & Row, 1978.

Phadke, M.S., *Quality Engineering Using Robust Design*, Englewood Cliffs, NJ: Prentice Hall, 1989.

Pugh, Stuart, (Don Clausing and Ron Andrade, ed.), *Creating Innovative Products Using Total Design*, Reading, MA: Addison-Wesley Publishing, 1996.

Rechtin, Eberhardt, *Systems Architecting*, Englewood Cliffs, NJ: Prentice-Hall, 1991.

Rice, R.E. and C. Aydin, "Attitudes Towards New Organizational Technology: Network Proximity as a Mechanism for Social Information Processing," *Administrative Science Quarterly*, Volume 36, 1991, pp. 219-244.

Roberts, Edward B., "Stimulating Technological Innovation: Organizational Approaches," *Research Management*, November 1979, pp. 26-30.

Roberts, Edward B., "Managing Invention and Innovation," *Research Technology Management*, January-February, 1988, pp. 11-29.

Roberts, Edward B. and Alan R. Fusfeld, "Staffing the Innovative Technology-Based Organization," *Sloan Management Review*, Spring 1981, pp. 19-34.

Roberts, Edward. B. and Alan L. Frohman, "Strategies for Improving Research Utilization," *Technology Review*, March/April 1978, pp. 32-39.

Rogers, Everett M., *Diffusion of Innovations*, The Free Press: New York, 1995.

Schoen, Donald R., "Managing Technological Innovation," *Harvard Business Review*, May-June 1969, pp. 156-167.

Shapira, Zur (ed.), *Organizational Decision Making*, Cambridge, UK: Cambridge University Press, 1997.

Simon, Herbert A., *Administrative Behavior: A Study of Decision-Making Processes in Administrative Organization*, New York: The Free Press, 1957.

Thomas, Robert J., *What Machines Can't Do: Politics and Technology in the Industrial Enterprise*, Berkeley: University of California Press, 1994.

Tushman, Michael L. and Lori Rosenkopf, "Organizational Determinants of Technological Change: Toward a Sociology of Technological Revolution," *Research in Organizational Behavior*, Volume 14, 1992, pp. 311-347.

Ulrich, Karl T. and Steven D. Eppinger, *Product Design and Development*, New York: McGraw-Hill, 1995.

Van de Ven, Andrew, "Central Problems in the Management of Innovation," *Management Science*, Volume 32, Number 5, May 1986, pp. 590-607.

Wheelwright, Steven C. and Kim. B. Clark, *Revolutionizing Product Development*, New York: The Free Press, 1992.

Whitney, Daniel E., "Manufacturing By Design," *Harvard Business Review*, Volume 66, Number 4, July-August 1988, pp. 83-91.

Womack, James P. and Daniel T. Jones, *Lean Thinking*, New York: Simon and Schuster, 1996.

Womack, James P., Daniel T. Jones, and Daniel Roos, *The Machine that Changed the World*, New York: Rawson, 1990.

Wrapp, H. Edward, "Good Managers Don't Make Policy Decisions," *Harvard Business Review*, Volume 45, Number 5, September-October 1967, pp. 91-99.

Wynn, Eleanor and David G. Novick, "Conversational Conventions and Participation in Cross-Functional Design Teams," *Conference Proceedings: Conference on Organizational Computing Systems (COOCS)*, Association for Computing Machinery, Milpitas, CA, 1995, pp. 250-257.

Yin, *Case Study Research*, Applied Social Research Methods Series, Volume 5, Thousand Oaks, CA: SAGE Publications, 1994.