Influencing Process and Cultural Change in the Aerospace Industry

by

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Submitted to the Sloan School of Management and the
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Abstract

Aerospace equipment manufacturers have expressed considerable frustration with the lack of success in implementing process and cultural change initiatives within their organizations. The objective of this report is to offer more successful methods of designing and executing change initiatives in the aerospace industry.

This report provides an analysis of three particular change initiatives in execution at Pratt&Whitney Aircraft at the time of this writing. The successes and failures of three initiatives are analyzed and compared in the context of the major barriers to change faced by the industry. The arguments made in the discussion and in the following conclusions suggest that success depends on the application of entrepreneurial marketing and negotiations theories:

1. Solving a quantifiable, pressing source of pain for the customer
2. Results selling by providing a solution versus solely a technology
3. Focusing on a single customer with the budget and power to employ the new technology
4. Understanding the positions and interests of the parties involved
5. Establishing a bargaining range when faced with resistance
6. Enabling a give and take of concessions and tradeoffs in the bargaining process

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LFM Class of 1999

I also wish to thank my fellow members of the LFM class of 1999 who provided support, ideas and camaraderie. Good luck in all your future endeavors.

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I wish to thank my fiancée, Michele Ref, for her steadfast support and continued understanding during the last two years. Her love has been the source of the strength I needed to survive the challenges of the LFM program.

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1. General Introduction

1.1 Problem Statement

Fundamental changes to product development and production processes can be difficult to effect in the aerospace industry. Change initiatives often labor for years without gaining ground, succeed only in attaining limited implementation, or simply disappear once the champion has moved to another position.

During the mid 1990's AlliedSignal's jet engine division, for example, put considerable effort into lean initiatives. The shop floor lean manufacturing initiative met with considerable resistance, culminating in a threat by the workforce to join the Teamsters Union. This resulted in considerable management turnover and an almost complete secession of lean manufacturing "Kaizen" efforts.

At the same time, a lean initiative aimed at streamlining the product design process was also meeting considerable resistance – this time from the engineering community. Efforts to convince engineering to switch CAD platforms (to establish a common platform for CAD engineers, manufacturing engineers, and NC programmers) had been dragging for several years without significant progress.

Even the most prominent of change initiatives (although often not recognized as a change intitative), the development of a new product, is fraught with frustration in aerospace equipment manufacturing companies. New product technologies are slow to be incorporated, manufacturing difficulties are perpetuated far too often in new designs, and conflicts between development and production activities are frequent.

1.2 Hypothesis

New product development is preceded by a rigorous set of analyses, conceptually equivalent to the creation of a business plan, which is submitted for approval by the firm's investors. Many change initiatives, however, jump to execution without adequate preparation of a business plan or marketing strategy. In an already challenging environment for change, this compounds the difficulty of successfully implementing change.

While a well-developed business plan for change may promise an optimal solution for the business as a whole, it is almost guaranteed that some functions, departments and individuals will see their roles negatively affected or distracted by change. Thus, the second element required to successfully achieve change is to provide for the ability to negotiate win-win or compromised solutions in order to gain the necessary support from key players.

1.3 Objectives

The intent of this essay is to provide criteria that will enable management to better gage and improve the potential for the success of change initiatives. This includes a basis of entrepreneurship and negotiations theory and a more tangible assessment of three comparable change initiatives at Pratt&Whitney – one of which was drastically more successful than the others.

More specifically, the essay begins with a review of the concepts employed in the analysis. This review is followed by an introduction of the three case initiatives that will be analyzed. The case initiatives themselves are software development projects – cost estimation tools. In order to convey both the barriers to change that are faced by aerospace equipment manufacturers as well as methods of overcoming these barriers, the three case initiatives are then analyzed in the context of the functionality designed into the three cost estimation tools. The discussion is concluded with summary recommendations for forming and championing change initiatives.

1.4 Scope

The lifecycle of a change initiative can be divided into three distinct phases; selection, preparation, and execution (see figure 1.4-1).

Figure 1.4- 1: Lifecycle of a Change Initiative

During the selection phase change initiatives are considered based on the problem statement, potential solution, and investment estimates. While firms do conduct these studies at high levels, such as in the case of new product development, the studies that spawn many change initiatives are performed at the grass-roots level of the organization.

During the preparation phase the target customers, context for the execution of the initiative, and metrics are further refined. Specific resources and infrastructure are allocated at this point as well. The selection and preparation steps discussed can together be equated to the development of a business plan for a new venture – detailing the market opportunity, technology, value proposition, timing, team, and required investments.

Techniques such as cross-functional teaming and critical path management are widely employed to increase the efficiency of the third phase – execution. While these practices focus on the tactics of day to day activities, the underlying foundation for change established in the selection and preparation phases is often not sufficiently mature. Initiatives often jump too quickly from grass-roots concept to execution.

This essay focuses on the entrepreneurial themes that can be applied to the preparation and execution phases of the change initiative lifecycle. Negotiation theory is included as well, as it is also critical to these phases. A discussion of business and technology strategy is important in the context of the selection phase, but is beyond the scope of this report.

1.5 Context

Many of the ensuing discussions involve the product development process. Although not all change initiatives in the aerospace industry involve product definition and the design process, many do require design issues to be addressed. This is significant based on the predominance of engineering culture in the industry and the fact that design trades are a constant negotiation over cost, schedule, and product performance. The change initiatives analyzed in the following chapters were chosen for discussion by the author, in part, because they each target changes to the product development process and their use is intended to effect product designs.

Since the discussions make frequent mention of gas turbine engines, a few key definitions are necessary for clarification since the terminology is different from company to company. The terms "component" and "part" are used interchangeably to refer to the smallest sub-unit of the overall product – for example a turbine blade is one of tens of thousands of parts or components in a gas turbine engine. The term "module" is used to refer to a major sub-assembly of the overall product, where an entire gas turbine engine is typically comprised of about eight major modules. For example a turbine blade is one of hundreds of different parts that make up the turbine module of a gas turbine engine. The turbine module itself, to continue the example, extracts energy in order to power the compressor, fan, and gearbox modules of a gas turbine engine.

1.6 Organization

The balance of this report is divided into nine sections. Chapter two begins with a discussion of the concepts used in the ensuing analysis. Chapter three introduces the cost tool initiatives that will be analyzed. Chapters four through six break down the functionality of the three tools, exposing the barriers encountered and the responses of the teams developing each cost tool. Chapter seven takes a deeper look into the issues of people as barriers to change. Chapters eight and nine present specific recommendations for the successful pursuit of change initiatives. Chapter ten concludes the main body of the report, summarizing the factors for success at a higher, conceptual level.

2. Introduction to the Analysis of Change Initiatives

2.1 Introduction

This chapter introduces the themes that will be employed in the evaluation of the three cost tool initiatives. The first section presents a framework for understanding exactly how tools, such as the cost tools, represent change in their effects on workflow activities. The second and third sections introduce entrepreneurship and negotiations themes, respectively. The hypothesis is that the success of one of the change initiatives, in comparison to the other two initiatives, depended on its attention to these themes.

2.2 Framework

Cultural change is tightly linked to process change. When the procedures of normal workflow are changed, people inevitably must adjust and adapt. Since this report analyzes the development and introduction of three software tools, it is necessary to understand how these tools change workflow. This will then become the context for the discussion of barriers and solutions.

The elements of workflow can be conceptually divided into three levels[1]; knowledge transfer, knowledge translation, and knowledge transformation. "Knowledge" itself can also be classified three ways[2]; data, information, and knowledge:

2.2.1 Knowledge Transfer

Knowledge transfer can be defined as the method and timing of raw data flow between two sites (people or computers, for example). This flow can occur through a variety of media, including verbal, written, and electronic media.

2.2.2 Knowledge Translation

Data must often be translated into different forms to be useful to different users. For example, while quality inspectors can use dimensional measurements directly to verify product conformance, process engineers cannot make direct use of the raw data. Individual measurements must be collected and translated mathematically into statistical

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[1] Paul Carlile, From Transfer to Transformation: Working through Knowledge Boundaries in Product Development, MIT/CIPD Working Paper Series, 1998

information to serve the needs of the process engineers. Thus the raw *data* has been translated into useful *information.*

2.2.3 Knowledge Transformation

Two users can be separated far enough in function such that direct use of data and information is not easily achieved. For example, while statistical process information can be used directly by manufacturing process engineers, this information may not have any direct use for design engineers. Conformance with blueprint tolerance limits – not statistical performance – may be all that is of interest to the design community. Thus, when tradeoffs must be made between design tolerance limits and statistical performance in manufacturing a new role must be performed.

In the case of statistical process information, for example, the role of knowledge transformation must be performed in order to provide grounds and means for negotiating trades between the objectives of manufacturing and the objectives of engineering. Thus additional *knowledge* is required (captured in people's minds or captured electronically) to facilitate trades between *data* and *information* from two functions that do not benefit from direct analytical linkages.

Change at each of the three levels can trigger resistance from the organization. This resistance can form significant barriers to the progress and ultimate success of change efforts. Discussion of how the three change initiatives analyzed in this report dealt with these barriers is based on entrepreneurship and negotiations theories.

2.3 Entrepreneurship Theory

Entrepreneurial marketing of new technologies is usually thought of in the context of new business ventures. The entrepreneurial perspective, however, applies to the development of new, workflow-changing technologies within an organization as well. Thus the tenets of entrepreneurial marketing are common themes in the ensuing chapters. These tenets have a strong customer-focus theme, which relates not only to the immediate users of the new technology (presumably at low levels in the organization), but also the senior management of the organization. The tenets of entrepreneurial marketing[3] include:

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[2] Roger E. Bohn, Measuring and Managing Technical Knowledge, Sloan Management Review, Fall 1994

[3] Kenneth P. Morse, John T. Preston, MIT Entrepreneurship Lab, March 1999

a) Solving a quantifiable source of pain for the immediate customer of the technology.

b) Targeting a source of pain that is pressing to the organization as a whole at that time.

c) Results-selling by delivering a solution versus providing solely a technology, which requires efforts by the customer to demonstrate benefits.

d) Providing a solution that is an order of magnitude improvement over the current practice.

e) Focusing on a single customer with both the budget and the organizational power to implement the new technology or process on a production basis.

These points may seem obvious to the reader, however it will be demonstrated by example that those pursuing change seldom address them correctly and completely. Only when each of these conditions is met does the prospect of success increase significantly.

2.4 Negotiations Theory

The negotiation themes[4] will also be relatively obvious to the reader. Basic negotiation themes include:

a) Understanding the positions and interests of the parties involved.

b) Determining the issues in negotiation.

c) Establishing a bargaining range.

d) Participating in give and take – allowing concessions and tradeoffs in the bargaining process.

These practices enable effective negotiators to move the negotiation from a competitive proposition to a more collaborative outcome by expanding the range and scope of options in included in the discussion. In negotiations terms, the intent is to pursue an integrative (win-win) solution versus a distributive (win-lose) outcomes (see figure 2.4-1[5]).

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[4] Lewicki, Litterer, Minton, Saunders, *Negotiation*, 1994

[5] Mary Rowe, Negotiation and Conflict Management Class Presentation, February 1999

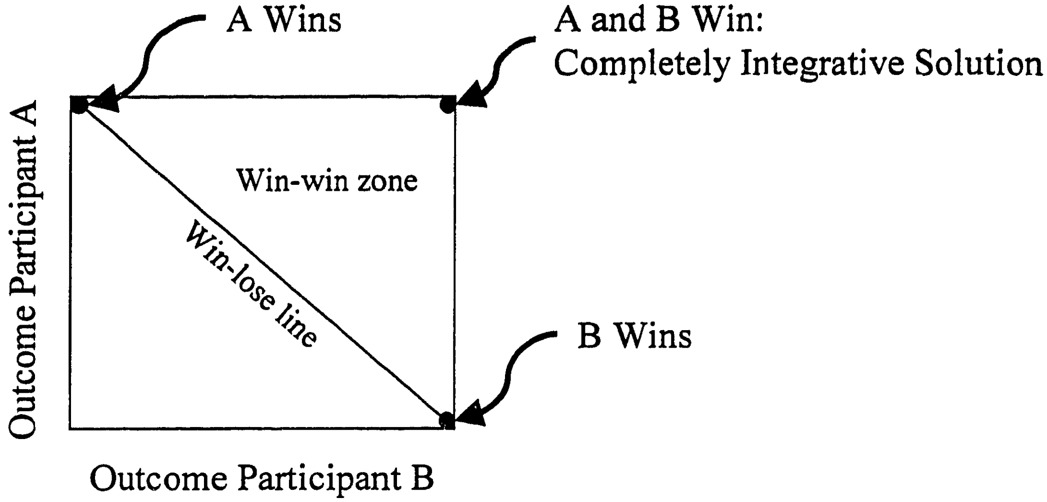

Figure 2.4- 1: Negotiation Outcomes

Not only do negotiation theories apply to human interaction, but also to the interactions facilitated by tools. This point speaks directly to the knowledge transformation topic discussed earlier in this chapter (and the designed role of the cost tools). When a tool performs in the role of knowledge transformation, effectiveness at facilitating negotiations between functions within an organization is vital.

For example, a software tool designed to facilitate product design tradeoffs must address the fact that two main players – e.g. engineering and manufacturing – are measured against different criteria (product performance versus product cost), yet both must be involved in the decision-making process. This implies that raw data or even information alone is not sufficient for either side to effectively negotiate their interests. A means of connecting between measurement systems and providing for calculated trades and concessions by both sides is critical.

Despite the abundance of data found in most manufacturing companies, this level of knowledge is not commonly found in databases or analytical tools. Most often, people, who are assumed to have an adequate understanding of the systems, frameworks, and objectives of the functions they are working between, perform the knowledge transformation role.

2.5 Summary

The basis for understanding how tools (such as the cost tools evaluated in this report) impose change requires an analysis of how the tools change workflow within the functional tasks of the organization. The following chapter briefly introduces the cost tool initiatives after which the tools are evaluated using this framework. Throughout chapters four through seven it will be demonstrated that the relative success of one of these cost tool initiatives was based on two factors:

a) The team viewed the project as an entrepreneurial venture and marketed it to the organization accordingly.

b) The team paid particular attention, both in their actions and in the design of the cost tool, to the need to negotiate between functions and departments.

3. Three Change Initiatives Aimed at Cost Estimation

3.1 Background – the Issue of Cost

Aerospace equipment manufacturers are under considerable pressure from the airlines to reduce product price[6]. As a result, focus on product cost has increased significantly among manufacturers. The subject of this essay surrounds three initiatives aimed at providing cost-related information to Integrated Product Delivery Teams (IPTs) to assist in design/cost trades. The three initiatives are the Product Center Capability Catalogue, Process Capability Information System, and Advanced Cost Estimation System – by far the most successful of the three.

The information provided by the technologies of the three initiatives is intended to assist the decision making process of the IPD teams in selecting the most cost-effective of design and manufacturing options for Pratt&Whitney's PW6000 turbofan engine development program[7] as well as for future Pratt&Whintey products. The timing of the information provided by the cost tools is a critical strategic element in the design of the tools. It is estimated that approximately 80% of the cost of an aerospace product is locked down in within the first few months of commencement of design activities. Thus, the mission of the cost tools is to provide key information as early as possible in the design cycle. This contrasts the prior method of cost reduction that relied on downstream production experience alone – "design first, take cost out later." This time delay is a key issue in the inability of aerospace equipment manufacturers to effect cost reduction in later stages of the product lifecycle.

The effect of time delays on the ability to act on key information and initiate design changes relates to cost and schedule. As a product design progresses through development, the impact of design changes becomes increasingly costly for the organization (see figure 3.1-1). It is important to note that these effects are often cumulative, requiring greater and greater steps backward in the product development process the further along in the process design changes are introduced. Pressures to dramatically improve time to market reduce the ability to initiate design rework loops to

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[6] See Appendix A: Aircraft Engines – Industry Environment

address cost (or other) issues once they become visible later on – in the traditional method of operation. In fact, significant technical flaws are often the only issues capable of triggering a major redesign at any phase of the design cycle.

Thus, rather than altering product or process design, manual process intervention (e.g. manipulation of process variables, or "creeping up" on machining dimensions) is often accepted as normal business practice. Rework, repair, and scrap are seen as relatively cheap alternatives to effecting design changes, despite the cost reduction pressures the manufacturing business units endure.

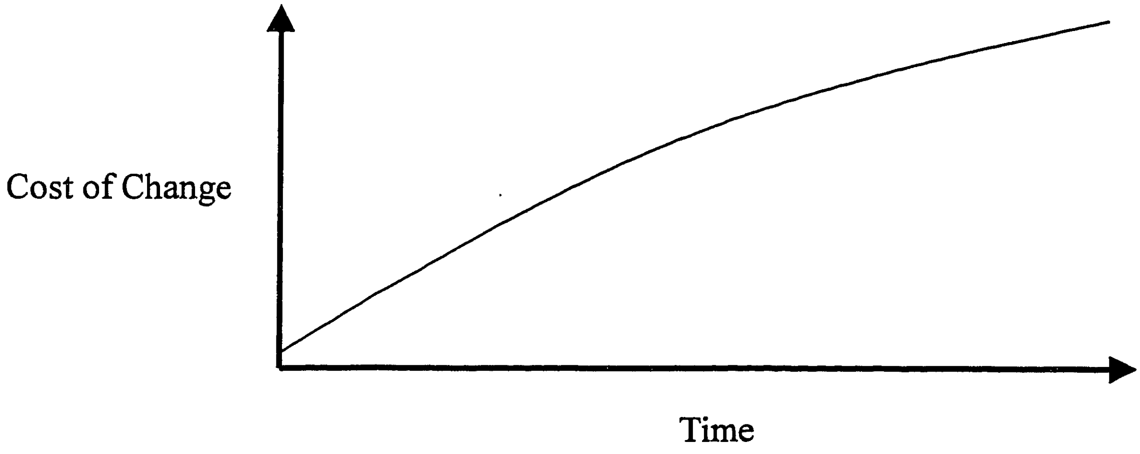

Figure 3.1- 1: The Rising Cost of Design Changes During the Product Lifecycle

3.2 Product Center Capability Catalogue (PC^3)

PC^3, the first cost tool initiative to be discussed, is a web-based product. At the highest level of the system, each web page represents a single business unit within Pratt&Whitney's manufacturing operations. Sub pages contain contact information, manufacturing cell layouts, standard geometric configurations of the cell's production parts, and design recommendations.

The intent of PC^3 is to provide design engineers easy access to this sort of manufacturing knowledge. This knowledge (general recommendations on part geometry and material selection) is based on experience with existing, production parts. Thus the time delay issue is addressed by relaying production experience with existing parts in hopes that the knowledge can be applied directly to new designs. Although the

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[7] See Appendix B: Competitive Environment – Setting the Stage

knowledge is not quoted in cost terms, the implication is that the recommendations represent the most cost-effective design options.

This web-based information source is not intended to replace communication between engineering and manufacturing personnel, rather it is intended to act as a source of strong guidance. Theoretically, PC^3 ensures best practices, and standards established through production experience will be more frequently carried forth into new products of similar configuration.

The director of the compression systems engineering department championed PC^3. Several engineers from the compression systems engineering department currently manage the PC^3 effort. PC^3 is supported by compression systems engineers collocated with Pratt&Whitney manufacturing business units producing compression systems hardware.

At the time this paper was written, several years of effort had been invested in PC^3. PC^3 had been implemented in the compression systems manufacturing plant, but efforts to expand the PC^3 initiative across the rest of the business units were proceeding slowly. Feedback suggested that use of the PC^3 system was limited[8].

3.3 Process Capability Information Systems (PCIS)

From the user's perspective, PCIS is a software product designed to capture and convey process capability information calculated from live manufacturing data. PCIS also does not directly report cost from existing production experience, however it is intended, like PC^3, to imply the cost impact of design options.

Normal process variations that exceed product specification limits are the primary source of defects, which result in scrap, rework, and repair costs (SR^2). The Cp family of statistical indicators is widely used to predict defects based on normal process variation. Mathematically, Cp is the ratio of the specification limit range of a geometric feature to the normal variation of the manufacturing process.

$$Cp = \frac{USL - LSL}{6\sigma}$$

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[8] Component Design Chiefs, Pratt&Whitney, PC^3 presentation, September 1998

Variants of Cp (e.g. Cpk) capture not only the ratio of relative ranges, but also the shift between the process average (X) and the specification limits.

$$Cpk = \min\{\frac{USL-\overline{X}}{3\sigma}, \frac{\overline{X}-LSL}{3\sigma}\}$$

The PCIS effort aims to capture measurement data from production real-time, calculate Cpk values, and present the resultant information electronically to customers in manufacturing and engineering. The intent for the PCIS data is twofold:

a) For use in identifying specific geometric features on existing, production parts that have process capabilities below tolerable limits. The hope is that highlighting this information will spur efforts to effect changes that will reduce the predicted rate of defects to acceptable levels. This would be accomplished by improving the performance of the existing manufacturing process, by 1: seeking alternate manufacturing processes with the desired process capabilities, or by 2: relaxing design specification limits.

b) For use as reference information in the design of new products. Geometric features in new designs could be evaluated by comparison to similar features on existing, production parts. Thus, statistical process capability data from parts already in production can be used to highlight potential problems when design, sourcing, and capital investment decisions are still flexible.

PCIS is a complex system of software. Software is required to collect data from electronic measurement probes on machining centers, coordinate measuring machines, electronic gages, as well as data entered manually into workstation terminals. Software is required for the transfer of data across secure internet channels from supplier sites in addition to Pratt&Whitney's internal manufacturing units. Software is also required for the manipulation and storage of the data such that it is intuitive for the users to query. Finally, additional software is required to act as the front end, or graphical user interface (GUI), for the users.

The design of each of these software elements is tied to the design of a complex language architecture that bridges the gap between manufacturing and engineering product language. For example, process measures communicated by manufacturing (either electronic or verbal) utilizes a hierarchy of specific part number (e.g. P/N 3600290), specific manufacturing operation sequence number (e.g. Operation 590), and specific inspection number (tied to each measured geometric feature on the part, e.g. MQI 81). Engineering, on the other hand, communicates product measures using a hierarchy of specific engine model (e.g. PW6000), specific part name (e.g. combustor), specific part feature (e.g. flange), and specific feature attribute (e.g. diameter).

A team of technical staff in the manufacturing technology department (MT) is developing PCIS. MT is part of a larger support and liaison organization (manufacturing systems engineering – MSE) that has dual reporting responsibility to engineering and production manufacturing. MT is chartered with the development of electronic technologies to assist in the day to day and strategic efforts of their two customer organizations. Members of the PCIS team come from backgrounds in information technology and manufacturing support.

At the time this paper was written, almost ten years had been invested in elements of the PCIS project. Software elements for basic data collection had been implemented, but the other software and language architectural elements were still in development. The statistical data was being referenced by some of the manufacturing business units for process control, but was not in use elsewhere. Efforts to entice engineering to begin using the available data were slow moving.

3.4 Advanced Cost Estimation System (ACES)

ACES is a system of several third-party software codes designed to derive cost information for the user. The individual software elements (different algorithms) were selected to match the product and process information available at each phase of product development – from concept to production. In general, the software system is designed to collect data and operate directly from the tools already in use for product and process definition (i.e. CAD/CAM programs).

Some of the cost generating algorithms in the system are integral to the software as purchased. Many of the more complex algorithms are developed by Pratt employees and programmed into the software. Additional elements of the software transfer actual data from Pratt&Whitney's financial and production databases for use in the calculations.

The intent of ACES is to provide real-time cost feedback to cross-functional integrated product teams (IPTs). Available in increasing accuracy as part definition evolves, this data electronically highlights the sensitivity of a part design to the geometric and process options being considered by the IPT. The hope is that, with this information as guidance, IPTs will be able to make more cost-effective choices during product development when design and process options are still flexible.

ACES is championed by the vice president of engineering at Pratt&Whitney. ACES development is managed by a specially assembled cost tools group in engineering's own cost management/finance organization. Members of the cost tools group come from backgrounds in manufacturing, finance, information technology, and business. ACES implementation is supported by cost engineers collocated with design teams. The cost engineers have a dual-reporting role to engineering and the program management offices.

At the time this paper was written, less than one year had been invested in the ACES project. During the first six months of development, in addition to a pilot of the software system, a complete cost model was generated for one of the PW6000 parts with the highest predicted cost overrun. Since the completion of the initial development phase, management interest from both engineering and manufacturing have been extremely high. The ACES development team is currently working to manage an overwhelming demand from management for ACES.

3.5 Summary

Each of the three cost tool initiatives has the potential to offer significant benefits to Pratt&Whitney in achieving its product cost goals. This potential is based on conveying information and knowledge from production experience with existing parts as a proxy for the future impacts of new designs. The key issue is the fact that the tools require significant change to Pratt&Whitney's de facto design process:

a) Implementation of each of the initiatives requires the usage of new tool sets across a wide range of organizational functions.

b) The tools force a shift of responsibility and accountability for product cost within the organization – leaning more than ever toward the design engineering community.

c) Data and knowledge collection must change to support the functionality of the tools.

d) The tools replace some of the interface and knowledge transfer roles of existing liaison organizations.

The success of ACES in comparison to the limited success of PC^3 and PCIS are the subject of the following four chapters. Arguments can be made that the relative success of each cost tool initiative was based on differing levels of potential business impact. The following chapters, however, paint a different picture. The four chapters breakdown the impact of the three cost tools on workflow, exposing the barriers to change that were encountered. The discussions continue with how each of the initiatives approached these barriers to change.

4. Tool Design: Knowledge Transfer

4.1 Introduction

PC^3, PCIS and ACES all act to change the flow of data between its sources and its users. This change is intended to improve the timeliness and accessibility of the data transferred by replacing verbal links with electronic ones. The basic objective of the three tools was to electronically overcome the effects of distance between data sources and its users – the individuals with the power to act on the data. This chapter begins with a discussion of where this power lies in aerospace organizations and how the power shifts over time. With the context of power in mind, the discussion continues by evaluating how the three tools are designed to perform data transfer. Even at this basic level, barriers to these tools existed and were handled differently by the three cost tool development teams.

4.2 Power over the Design of the Product

An understanding of the target users of the three cost tools must precede discussion of the technical design of the tools. This is important since the ownership and control of design and process decisions (and thus the ability to effect design changes) is not static during the engine development process. As background, the product development process for gas turbine engines (similar to other aerospace products) can be divided into five phases: Concept, Detailed Design, Hardware Build for First Engine to Test (FETT), Development Testing and Production[9]. These phases do not exactly match the published IPD process flow of Pratt&Whitney, but do reflect the critical time points from a design-flexibility perspective.

Looking at the actual tasks performed at each of these phases of product development, then, shows how control of the product shifts significantly over time (see figure 4.2-1):

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[9] See Appendix C: Product Development Process for details

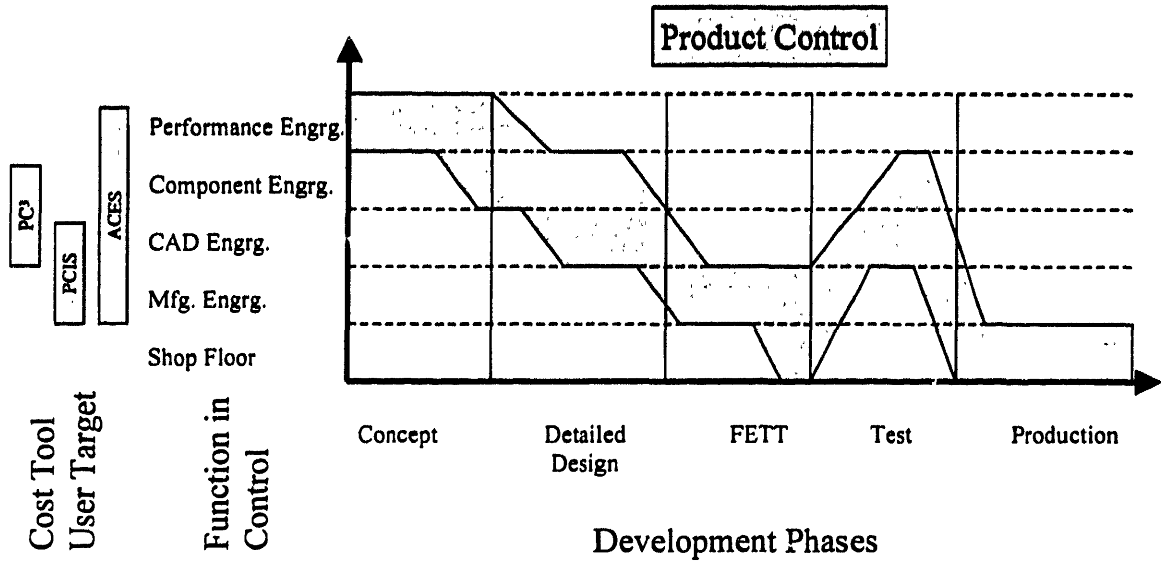

Figure 4.2- 1: Shift of Product Control During the Phases of Product Development

PC^3 primarily targets component and CAD engineers with its system. PCIS targets manufacturing engineers as well as CAD engineers since the information provided can be used for process control. ACES, however, targets all of the engineering functions. The level of control over the product at each development phase, however, influences the cost reduction potential of the cost information being transferred by each tool.

4.2.1 Concept

Phase one of development for gas turbine engines consists of system level design trades (such as bypass ratio, pressure ratio, temperatures, spool speeds, stage counts, structural configuration, and manufacturing technologies – for gas turbine engines). An iterative loop persists between the component technical community, manufacturing, and service functions to provide support to the systems engineers and business/program management until a suitable business plan for the overall product is achieved.

Performance engineers maintain a large portion of the control during phase one since many of the decisions made during this phase are based on the systems analysis models. This ownership structure can even cause frustrations within the component design community since systems engineers may include assumptions about component capabilities that are unrealistic expectations of the advancement of technology that the engineers can provide.

4.2.2 Detailed Design

During phase two, component design teams proceed with the technical analyses necessary to achieve product definition that meets performance and other requirements. This phase is concluded with the sign-off of blueprint documents, which contain geometric dimensioning and tolerancing (GD&T) as well as other manufacturing specifications that are necessary to ensure dimensional and metallurgical properties are maintained in production. The GD&T and other specifications control not only the end product, but also restrict the manufacturing process and material options available to the manufacturing business units.

Control during phase two shifts between several functions. Initially, component design configuration, sizing, and material depend on thermal, aerodynamic, and mechanical analyses. Thus, analytical functions (component engineers) maintain a large portion of the control. As the analyses begin to gel into the physical form of a component, control begins to shift to the CAD engineer who works to capture this information, manufacturing input from manufacturing personnel, and drafting standards to arrive at a blueprint.

4.2.3 Hardware Build for First Engine to Test (FETT)

During phase three, a document called operations sheets is developed for each new part in the product. This document, created by manufacturing engineering, specifies the process steps to be taken during fabrication as well as the corresponding GD&T and inspection criteria for each step. From the operations sheets, NC programming, tooling, and inspection gages are created. The process concludes with the monitored production in the manufacturing shops of the research hardware for FETT. While the research hardware may or may not be geometrically different from the end production hardware, the major distinction is that it is not revenue-generating for the company.

Control during phase three primarily rests with manufacturing engineers who are responsible for coordinating the fabrication of the research hardware for FETT. Despite the manufacturing engineer's control over process and geometry decisions, flexibility is limited. As discussed earlier, the detail incorporated in a completed blueprint specifies not only component geometry, but also processing, handling, construction, and inspection methods for manufacture.

4.3.4 Development Testing

During Development Testing the results of engine tests are analyzed and reviewed. Should performance or durability problems arise, control jumps quickly back up the food chain. What occurs then is effectively a reiteration of the design process for the affected components.

4.3.5 Production

Although production workers maintain ultimate control over the product during production, this control is limited. The blueprint and operations sheets dictate geometry and process steps. Raw material input configuration also limits flexibility. Geometric flexibility within tolerance limits and control over process parameters is about all the production workers can manipulate during the production phase. Should significant production problems arise or field failures occur, control can jump back to design as in phase four.

During phases four and five, immediate control over the product remains with manufacturing engineering and the production workforce. The increasing cost of change severely limits design flexibility. Given the need for involvement by analytical and other functions to evaluate, approve, and implement change, the business/program management function remains as a central node for the flow of these activities. As a result, for even minor changes to a blueprint the corresponding administrative costs alone can be in the thousands of dollars.

4.3 Distance

The three cost tool initiatives at Pratt&Whitney represent only one of many attempts by the Pratt&Whitney as well as other aerospace companies to resolve the problem of delay created by the distance between functional elements[10]. The intent of the three cost tool initiatives has been to form an electronic bridge to eliminate the apparent separation of manufacturing experience from decision-making centers early in the design process.

The extent to which each of the tools connects to all the applicable knowledge sources varies. While PC^3 is limited to Pratt&Whitney's internal manufacturing facilities, PCIS and ACES incorporate connections to data and knowledge from Pratt&Whitney's

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[10] See Appendix D: Closing the Distance Between Functions

supplier base. In this manner, PCIS and ACES enable more thorough evaluation of trades between the design of raw material (such as castings) and the machining that occurs downstream at Pratt&Whitney. These trades represent more of the volatile design discussions compared to the relatively well-understood issues of machining.

The effects of distance and production pressure limit the ability for companies to bring people together to conduct knowledge transfer. Even for new product development, production pressure restricts manufacturing personnel from participating full-time in the design process. This reality has prompted most aerospace companies to develop liaison functions within their organizations. Manufacturing systems engineering (MSE) at Pratt&Whitney is equivalent to AlliedSignal's manufacturing project engineering function (MPE) – both liaisons between design engineering and manufacturing. Several levels of the liaison role can exist, compounding the "telephone effect." At AlliedSignal, for example, a function called "function 5.1" exists even between manufacturing engineering and the shop floor.

The mission of liaison functions in general is to reduce the disruptive effects of development activities on production manufacturing by assuming the burden of much of the necessary information flow. Production pressure and distance place a high cost on direct interaction and team activities, but by providing much of the necessary information flow between functions, PC^3, PCIS, and ACES reduce the amount of direct interaction required. Although the three systems cannot completely replace the need for direct human interactions, they can reduce the cost of this interaction by reducing the amount of face-to-face interaction required. This does, however, place the tools in direct competition with human bridges to the distance problem; a topic to be discussed in chapter seven.

4.4 User Interface

Individuals performing specific, independent tasks, such as the creation of a finite element model, a CAD drawing, or operations sheets are the target customers for the three cost tool technologies. Each of the aforementioned tasks is required in sequence in the flow of a project from concept to production. Based on the pressures to deliver each intermediate product and the visibility these tasks receive (especially in critical-path managed programs), human resources performing line tasks are a precious commodity.

Thus new tasks or technologies are difficult to impose on the line functions since they require extra effort and time.

The calculation of cost information is not a physical barrier to the completion of a blueprint by a CAD engineer. Even if cost analysis is required by edict, a CAD engineer may be tempted to leave it to the end of the blueprint generation task. This is done because the prevailing pressures on the individual favor completion of the blueprint in order to initiate tooling fabrication. While the requirement for cost analysis in this case has been fulfilled, the spirit of the activity has not because the cost calculation becomes merely a reporting task versus a design driver.

PC^3 and PCIS are independent software systems, requiring users to perform activities outside their standard toolkits. As a result, the impact these two initiatives has had on the adoption and proper use of their technologies has been limited. ACES, on the other hand, is designed so that key elements of its software operate integrally to the software toolkits required for major product development tasks, such as CAD blueprint generation. The cost task, then, is performed concurrently and automatically as the CAD work proceeds. This, at least, provides a greater likelihood that the cost information will be used proactively in the product design.

Designing cost analysis to be a byproduct of other, necessary tasks eliminates the problem PC^3 and PCIS have suffered of being a "free link" in the chain of activities that connect concept to production. The ACES effort demonstrates one of the first elements of entrepreneurial marketing in this case. While PC^3 and PCIS offer information at the expense of extra work, the integral nature of the ACES tool significantly reduces the overhead of use – increasing the value proposition to the individual user over the old way of business. This is critical since the end cost benefit to the organization may not be the greatest driver for each function with the power to affect cost (e.g. performance and component engineers traditionally pay more attention to product performance and schedule issues).

4.5 Architecture Conflicts

PC^3, PCIS and ACES are all change initiatives dependent on software solutions. While software is somewhat of a special case, the issue of competition with other initiatives is almost always relevant. Each cost tool would perform optimally using an object-based strategy for data and information storage. Edicts from Pratt&Whitney's Enterprise Resource Planning initiative (ERP), which is managed by the finance and information technology departments, prevent the adoption of this architecture.

Using experience with existing production hardware as a proxy for the future impact of new designs, partial matches between component attributes such as geometric configuration, GD&T, and material, for example, must be made electronically to find the appropriate production data/knowledge. In this context, relational databases do not provide as efficient a search capability as does object-based architecture. The ERP initiative at Pratt&Whitney, however, restricts all software to using relational databases, which can be incorporated into ERP's own Oracle database.

At the time this report was written, PCIS had had little success in securing permission to pursue an object-based system. ACES, since its results marketing had carried visibility up to the highest levels of management, has had significantly more flexibility in directing software strategy toward a more effective object-oriented architecture. PC^3 was developed from the beginning to operate in a relational format. This structure by design limits the efficiency of the manual queries performed by the user.

4.6 Summary

Each of the three cost tools acts to speed and improve the quality of knowledge transfer in the product development process. Some difficulties, such as user interface and software design restrictions, immediately present themselves as barriers to the design and implementation of these systems. More significant barriers become apparent only as the human issues surface. Competition with other existing initiatives, such as the examples of liaison functions and the information systems organization, provide the first signs of a need to look deeper into the barriers to change initiatives:

a) The cost tools, as a medium of knowledge transfer, represent a threat to the role of human liaison functions.

b) The difference between the needs of the engineering and finance organizations (e.g. related to information systems) generates conflict since the objectives of the two organizations are not exactly aligned.

The next chapter begins to deal with the issue of conflict between functions. The discussion looks into how the translation of information into different forms can overcome some of the inter-functional conflict by analytically linking objectives.

5. Tool Design: Knowledge Translation

5.1 Introduction

Recognizing the fact that the data gathered and delivered by the three cost tools crosses many functional boundaries in the organization, knowledge translation becomes an important issue. The format of data useful to one function may not have much meaning to another function. Thus the data must be translated into multiple formats for the information to be useful in discussions between the functions.

For example, inspection data must be translated into statistical format for it to be useful to process engineers in calculating trends and predicting defects. This analytical connection between the raw data and the statistical information then enables the process engineers to convey the potential problem situations to quality engineers – even though the raw data to date confirms parts were within blueprint specifications.

The design of PC^3, PCIS, and ACES each deal with this issue differently. As the issue of translation is probed, more barriers to change are revealed.

5.2 Liaison Functions

Introduced in the previous chapter, PC^3, PCIS and ACES replace knowledge transfer elements of the liaison function. Liaisons do not just act in the role of knowledge transfer, however. Liaisons are needed to translate information from the different functions they serve in order to facilitate dialogue. Since the liaisons are not the actual process owners of the knowledge they are communicating, however, their level of understanding limits their ability to translate information correctly and completely.

Poor information translation leads to poor decision-making by those acting upon that information – such as design engineers. Thus the credibility of information translated by liaison functions can be suspect and, as a result, may not be weighed as heavily in decision-making as, for example, the results from numerical analyses.

The three software tools operate in the realm of information translation as well. Information provided by the PC^3 and PCIS systems come with little or no contextual background, however, to expose the underlying factors driving the presented results.

This means that, although knowledge is translated from one framework to another, the underlying algorithms are not expressed – perpetuating the credibility problem afflicting the human liaisons.

One method of understanding this issue is to look into the generation and flow of knowledge within manufacturing operations. Knowledge begins with raw data, such as measurements, processing time, or number of defects. The second step requires analysis of this information using, for example, root cause analysis or design of experiments. The concluding step is comprised of summary recommendations intended to eliminate the problem, such as dimensional tolerance limits, processing speeds, or fixturing methods. PCIS offers measurement data from manufacturing processes, but no analyses of the process to provide an understanding of the drivers of the data. PC^3 provides the summary recommendations, but again not the intermediate analyses. ACES, on the other hand, incorporates much of the intermediate knowledge and root cause information allowing forward and backward translation over a wide range of input parameters. ACES enables design teams to question and investigate the results they receive from the system and provides greater flexibility in analyzing input geometry configurations.

PC^3, PCIS, and ACES are not intended to completely replace the liaison role or direct interaction between functions with respect to knowledge translation. Regardless of the data and knowledge captured in the software systems, not one is capable of handling the nuances of new product designs that extend outside the bounds of existing experience. For the portions of each new product that do extend significantly beyond experience, direct interaction between functions as well as subsequent analysis, and testing will always be required. This new knowledge, then, can be built into the three cost tool systems – continuously improving their effectiveness.

5.3 Lack of Data

PC^3, PCIS and ACES all have the objective of translating operational data to forms that the design functions can act upon. For example, process variation (used for process control in manufacturing) could be analytically related to product performance variation – of prime interest to the design engineering community. In order to perform this translation, performance sensitivities to component variations must be established. Cost and schedule pressures, however, limit product testing and thus the ability to conduct sensitivity analysis through design of experiments techniques.

For example, evaluating changes to a turbofan engine front frame design would require multiple failure tests to evaluate the engine's ability to hold together in the event of extreme imbalance due to fan blade separation. In highly dynamic failure events – such as a fan blade failure – few computational analyses or component tests can provide much insight into the overall effect of design changes/variation. This implies high testing costs to generate useful data. Even then, the FAA requirement to certify a resulting design change necessitates a *successful*, full-engine, destructive test – each a multi-million dollar proposition.

Although the front frame case is an extreme example, this condition exists to varying degrees for determining almost any type of performance sensitivity. The efforts necessary to generate the necessary knowledge (drivers, sensitivity, etc.) may be prohibitively expensive even with the least amount of testing. None of the case initiatives provide a complete solution to the translation problem. ACES does, however, translate the available knowledge into a common language – cost. The cost language increases the organizational visibility of the impact of design options. This visibility, then, is intended to prompt discussion between the parties involved with the component, even if all the data necessary for a complete analytical link does not exist.

5.4 Financial Accounting

PC^3 and PCIS offer manufacturing data only. As described in the previous section, this format can be difficult to employ in design trade studies without analytical connections to performance measures. Although PCIS data can be manually equated to defect rates, the cost impact of defects – i.e. based on manual intervention, rework, repair, or scrap – cannot be directly determined from the data. Thus, while PC^3 and PCIS offer important information, neither offers the user – a design engineer typically removed from the manufacturing process – the basis by which to establish a business case for change. ACES, on the other hand, provides for the ability to translate between design and manufacturing data based directly on cost – while PC^3 and PCIS only *imply* cost.

Since the beneficiaries of producibility improvements (manufacturing) are divorced from the function implementing the change (design engineering), maintaining management support to influence adoption of the cost tools by design engineering is critical. Even though the cost information provided by ACES uses past experience as a proxy for future production numbers, operating using the language of cost has been enough to capture a large portion of senior management as proponents for ACES.

Financial accounting systems, however, represent one of the greatest barriers to the valuation and verification of change. The financial accounting system at Pratt&Whitney, like many companies, is designed to aggregate data for government reporting purposes. Elemental costs are then derived from the aggregated data on a labor hour or machine hour basis. This method of using overhead structures confuses not only fixed and variable costs, but also the variable costs of one part compared to another[11].

Given the complexity and subjectivity of decision-making based on the financial accounting system, PC^3 and PCIS do not link their data, information and recommendations to cost. ACES, on the other hand, reports true marginal cost. Under ACES, significant efforts have been and continue to be made to investigate and establish marginal cost information for each part, process, and feature type. While marginal cost information provides an excellent base for decision making, the more subjective realm of overhead rates is omitted. Thus total cost rollups still require the aid of the finance department in determining the appropriate overhead rates.

5.5 Competing Metrics

Cost data as a basis for translation in the ACES system has greater influence than just the ability to translate between design and manufacturing knowledge. Cost, in this market environment, plays strongly in the performance metrics of most functions within Pratt&Whitney – enabling a wide variety of functions to interact with the system as well as upward through the ranks of management. At the highest level, employees are all contributing to the same set of customer variables, such as product performance, cost, quality, delivery, and service. The design of metrics in each part of the organization, however, can conflict with those of other departments. At Pratt&Whitney, for example, pressure to reduce cost and thus increase profitability has manifested itself differently in different parts of the company.

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[11] See Appendix E: Financial Accounting

Traditionally, purchasing at Pratt&Whitney has been somewhat at odds with the company's own manufacturing operations. Measured on the price of the products they buy, purchasing agents are driven to switch raw material suppliers based on price competition. What is left out of this equation is the impact of changing suppliers on the quality and consistency of the parts. Although from one source to another these parts (such as castings and forgings) may still meet blueprint specifications, geometric variation within tolerance bands and the variation of metallurgical properties can impact the downstream machining operations, which are performed at Pratt&Whitney. Thus, a perceived gain from the perspective of purchasing may be executed at the expense of the larger business picture based on the impact on other elements of the value chain.

Continuing with this theme, Pratt&Whitney instituted a function called "commodity management." Commodity managers were tasked with negotiating raw material price reductions from Pratt&Whitney's suppliers based on volume orders. This was accomplished by consolidating raw material purchases across business units. Rather than negotiating the price of the PW6000 diffuser case casting independently, for example, the casting commodity manager would negotiate a per-pound price for all of Pratt&Whitney's castings from that supplier, presumably resulting in a lower casting cost for the PW6000 diffuser case.

The problems with this approach stem from the fact that much of the "raw material" purchased by aerospace equipment manufacturers cannot be truly considered a commodity. While the material ingredients for castings, for example, can be considered commodities, the castings themselves do not fit this description. There may be only a handful of suppliers world-wide capable of producing the complex castings needed in gas turbine engines. Even in the case where the buyer, such as Pratt&Whitney, owns the casting tooling, the end product can be so dependent on the process variables that a source transfer may require a tremendous investment to overcome learning curve effects.

Given the pressures placed on suppliers by commodity management, Pratt&Whitney's supply base has become less willing to divulge technical and process information to the design teams trying to reduce cost through technical solutions. This type of competition led to a reversal of strategy at AlliedSignal Aerospace. After trying commodity management, AlliedSignal backed off several levels – disbanding the function and reassigning purchasing agents to specific manufacturing business units within the company. AlliedSignal's new strategy was intended to drive more consistency between purchasing decisions and the overall value chain. This new strategy has improved AlliedSignal's ability to work constructively with suppliers to reduce cost.

The competitive environment established by the commodity managers afflicted both PCIS and ACES since both systems require supplier as well as internal data. At the time this report was written, neither PCIS nor ACES had been able to successfully acquire much of the technical and financial knowledge they sought from Pratt&Whitney's supply base. Although the ACES team attempted to use management connections to influence a change in the policies and behavior of the commodity managers, the issue was not being remedied quickly.

5.6 Summary

Design of the ACES tool took a major leap over the PC^3 and PCIS tools when it was decided that cost would be the operable language of the system. This is important, not only from the standpoint of entrepreneurial marketing, but also negotiations.

a) Cost is a parameter that could be directly applied to quantifiable sources of pain for the organization.

b) Cost provided a measure closely tied to the interests of functions at all levels of the organization. This tie across functions and vertically through the organization established grounds for negotiating tradeoffs between performance and manufacturing issues – a strong influence in the transformation of knowledge, the subject of the next chapter.

6. Tool Design: Knowledge Transformation

6.1 Introduction

While cost plays a strong integrating role across functions and between management layers, other factors detract from ACES (as well as the other systems') capability to provide perfect information. These barriers are impossible to eliminate by their very nature, but are important to recognize when considering the impact they will have on negotiating design/cost trades when there is still flexibility to alter the design of the product.

6.2 Information Delay

Information delay is one of the core barriers to change in the aerospace industry. Information delays prevent key information from influencing decisions early in the design process when flexibility to effect change still exists. This problem is exacerbated in the aerospace industry by the rate of new product development.

Product lifespan in the consumer electronics industry can be measured in months whereas product lifespan in the aerospace industry is measured in decades. Because production and field experience is so separated from the product development process, the technical community involved in product design can rarely follow the product through its lifecycle. Not only are people reassigned to other projects fairly quickly, the expected lifespan of an individual in a particular function – or even in the company entirely – is drastically shorter than product lifespan. The result is that knowledge retention can be relatively low from project to project. Even though the results of analyses and decisions may be well recorded, much of the underlying information and knowledge that drove the original decisions may be lost.

The majority of successful change initiatives can be categorized as local changes. Local changes can be defined as the changes one makes to the functional tasks they themselves perform. One of the key success factors is that the results of local change can often be measured almost immediately. For example, an analytical engineer performing finite-element analyses may program a short software script to automate aspects of post-processing tasks she must perform to evaluate the analyses. Since this individual is likely to perform these types of analyses on a frequent basis (every few days to a few weeks), the benefits of using this new software script can be realized in this short timeframe.

Larger, systems initiatives, such as PC^3, PCIS, and ACES are dependent on much longer feedback cycles. For example, design changes effected using guidance from the PC^3, PCIS, and ACES systems must wait months or years for production experience to validate the results. In this timeframe management interest and support for a change initiative may wane. Even with a strong management supporter, in the multi-year timeframe it is unlikely that this individual will remain in his current position in the organization. Thus a key source of influence is lost.

PC^3 and PCIS depend on actual downstream production experience to prove end cost benefit. Not only are PC^3 and PCIS handicapped by the element of time, but they are also at a disadvantage because it may be exceedingly difficult to attribute the impacts of the PC^3 and PCIS information. For example, if a PC^3-recommended datum structure is employed (to facilitate a particular fixturing scheme), the intuitively expected defect rate for the part may be lowered. In reality, however, it may be exceedingly difficult to prove how much worse the production numbers would have been with a less optimal datum structure.

ACES, on the other hand, addresses the time delay by quoting analytical results in terms of cost – as discussed in the previous chapter. While past experience is still used as a proxy for future production numbers, cost is a language better suited to quantify the downstream impact of design decisions. This methodology artificially eliminates the time delay problem.

6.3 Past Experience

The lack of knowledge carryover from one new product development program to another as well as schedule pressure favors designing new parts as similar to existing parts as possible. In addition, financial pressures to take advantage of existing tooling also forces the use of similar-to design philosophies. This cycle, unfortunately, tends to propagate bad as well as good designs.

The similar-to design approach often begins with the resurrection of old blueprints as templates for new designs. PC^3, PCIS, and ACES all provide information intended to expose the shortcomings of older designs in order to stop the propagation of sub-optimal specifications and geometry. Unfortunately, in the face of strong technical opposition from component engineers, for example, it may be difficult to force change with information that is based on past experience that is not 100% applicable to new designs.

As a general perception, some off-experience experimentation is expected of the engineering community in pursuit of rising technical performance goals. Although CAD engineers may be biased toward building off of older blueprints as templates, the analytical community can be an ally in adopting change. Once development tests are completed, however, receptiveness to experimentation and the power to implement these types of design changes disappear.

6.4 Negotiating Power

Described in chapter 4, control over change shifts between the functions in aerospace companies. This control is a source of power for the current owner. In advocating change, inevitably it will become necessary to convince individuals with the power of control over design, processes, or resources that a new approach or decision is warranted.

The three cost tools convey knowledge that is intended to contest design traditions in favor of reducing cost. The fact that the systems may contradict the tacit knowledge of the players involved implicitly suggests that the work performed by these individuals may not have been performed correctly. The implication of this suggestion is that self-defense mechanisms of the individuals may be triggered in order to preserve face, respect, position and power. Within the technical community, the most common self-defense mechanism is to draw the opponent onto the individual's technical turf – where the individual can be assured expert power over any opponent. What ensues is an endless spiral of technical arguments that cannot be won by the proponents of change. Thus, where change requires the active support of the individuals integral to the target processes, change must be handled carefully.

What is missing in the PC^3 and PCIS tools is the logic behind the data and recommendations put forth by the systems. Without this information there is no viable avenue to depersonalize any conflicts between the results from either of the two cost tools and the tacit knowledge of the players involved in the design decision being made. The conflicts will be viewed as attacks on the methodologies used by the players and thus represent an attack the technical capabilities of the players. What results is the aforementioned self-preservation response.

ACES, on the other hand, advertises all the data, logic, and hypotheses behind each recommendation or equation incorporated into the cost algorithms. The accessibility of core data and algorithms allows the key players to review and compare the principles and inputs used for both the ACES and their own analyses. Conflicting results that can be traced back to assumptions and inputs do not trigger a self-preservation response since this information is not necessarily related to the technical capabilities of the players. In fact, this review process acts to enhance organizational learning across functions.

Conflicting results based on the actual analysis methods (as opposed to inputs and principles) can also be negotiated more effectively with ACES. Walking through the algorithms in the ACES models engages the players technically and provides for the opportunity to negotiate a give and take – adjusting the logic on either side where appropriate, which adds to the learning rather than generating personal conflict.

The ability to delve into the details of each rule in the ACES cost algorithms provides the opportunity to consider effecting changes to manufacturing processes (to change the rules) in addition to the option of changing the design. The details of the rules may also expose alternative design change options – as opposed to the single solution offered by the other systems. The implied process follows the classic negotiating strategy of give and take, allowing individuals to demonstrate their ability to contribute and concede gracefully on other points.

ACES, in general, provides for more integrative negotiations, compared to the distributive style imposed by the single point solutions the other two systems are anchored to. The ability to delve into details and methodologies can objectify negotiations by separating data and processes from the technical capabilities of the individuals who are acting on them.

6.5 Summary

PC^3, PCIS and ACES all attempt to *estimate* the performance of future products by relating production experience with past designs. Only ACES provides for interactions and concessions that accept the fact that the information cannot be 100% predictive. By capturing and exposing the underlying design and manufacturing logic as well as operating in the common language of cost, more collaborative design negotiations can take place. This is an important factor in that it opens up a range of solutions and allows for calculated concessions to be made by both sides.

7. People as a Barrier to Change

7.1 Introduction

PC^3, PCIS, and ACES have had more than technically driven barriers to overcome. People are inherently difficult to change. Tactically, each effort has worked to overcome these barriers in order to demonstrate value and gain momentum for the project. As will be discussed, the results varied drastically.

7.2 Reward Systems

Although the engineering communities in the aerospace industry enjoy comfortable salaries, they in no way compete with salaries and growth rates in the software industry, for example. The average annual raise for engineers at aerospace firms is often only a few percent. A seven or eight percent raise may represent the highest percentage raise within engineering in aerospace companies. Thus, the primary source of reward for many is job satisfaction – through power, technical challenge, and verbal recognition.

Given the limitations on financial rewards, the ability of the proponents of change to "bribe" individuals financially to adopt change is low. If it is necessary to tempt an individual in order to achieve support for change, the other, less tangible sources of reward must be considered. Since only a very few initiatives within aerospace can, alone, claim responsibility for dramatic product or profitability improvements, this can be exceedingly difficult to achieve.

Improvements based on utilizing PC^3 and PCIS information may be realized only by functions downstream of engineering, and at a much later date (often years). This is a direct result of PC^3 and PCIS avoidance of correlating to cost and accounting data. The result has been the limited ability of the proponents of PC^3 and PCIS to offer intangible rewards to engineering for the adoption of these systems. At best, the two systems claim to offer performance improvements for engineering by reducing delays in information transfer. Unfortunately the effort to research and validate the information for each design case as well as the learning curve on these systems may very well negate any benefits.

The ACES strategy of reporting cost as an output links to an immediate source of reward for the user. Across aerospace, metrics for engineering have evolved to include product cost as well as product performance. Thus, engineers working with ACES can immediately demonstrate contribution based on the cost information rendered by ACES. During the development of ACES, the team capitalized on this fact by focusing on delivering a complete cost *solution* for a specific component of the PW6000 that brought visibility to the IPT ACES was working with.

Although the ACES data cannot be conclusive without production experience (that will occur only years down the line), at the time of this writing ACES provided the most robust cost *estimation* information available to Pratt&Whitney. The critical nature of cost information to the future of the PW6000 program (and to other development programs across aerospace), however, drives companies toward cost estimation technologies – despite the fact that they cannot be 100% accurate in their predictions.

7.3 Schedule and Resources

The pressures of production – whether it be production of a blueprint or fabrication of parts – can severely limit resource availability. Access to process/technical experts may be reduced and access to production equipment and hardware may be restricted by pressure to focus on revenue-generating operations. In fact, the grass-roots nature of most change initiatives exacerbates this problem. Without restriction on launching initiatives, so many initiatives can exist at any given time that resources become overcommitted – unable to achieve results on any initiative in a timely manner. This problem is not limited to small initiatives by any means. Major product development initiatives are also burdened by this problem. The high lead-time for production tooling (such as for castings and forgings) and pressure to use production facilities for revenue-generating activities often leads development programs to use alternate manufacturing techniques and facilities for research and development hardware than are intended for the production hardware. The disassociation of development manufacturing experience from production manufacturing experience affects not only blueprint design, but also delays the feedback of production data.

Pratt&Whitney, like AlliedSignal and others, has pushed to resolve this problem for new engine programs. Production sources – whether they are chosen for cost or strategic reasons (such as offset agreements or risk sharing partnerships) – are now selected before detailed design begins. In addition, management pushes for fabrication of research and development parts in the production facilities. Nevertheless, other initiatives without this level of management commitment suffer. Incorporation of new technologies/processes is difficult to accomplish with out production experience as testimony to the benefits, yet it is difficult to secure production resources for efforts that are not yet revenue-generating.

PC^3 and PCIS include information and data from production experience, however they have yet to be accepted for use in any large capacity on development efforts. Any limited use has been hard to track – in order to quantify the benefits of the information. On the other hand, the ACES project focused its development efforts on a particular component in the PW6000. This part, the diffuser case, held a very visible position based on its projected cost overrun and the lead-time expected for complex casting tooling. Interaction with production resources – in this case design and manufacturing engineers – was especially difficult to secure because of the schedule pressures on these individuals to complete their functional tasks. Nevertheless the ACES team was able apply enough pressure to be granted an adequate amount of time with the individuals. This was a key success factor for the ACES effort. Rather than delivering solely a technology, as PC^3 and PCIS were doing, the ACES team was able to deliver the results of using the technology on the PW6000 diffuser case. The cost information provided gave the diffuser case IPT as well as management immediate insight into the cost drivers of this troublesome part. Visibility for the ACES project and management pull for the technology increased exponentially when the results for the PW6000 diffuser case were demonstrated.

7.4 Middle Management

Self-preservation behavior, discussed in the previous section, is not limited to front-line employees. Middle management often sees greater risk in change – especially when the change represents adjustments to organizational structure or functional responsibilities. While most of the front-line employees will always be needed to perform the necessary tasks of production – regardless of organizational design – the same does not hold true for management.

Upper management, in general, is transportable in the event of organizational change. Often, in the aerospace industry, upper management moves frequently between positions – providing further insulation against any negative effects of change on careers. Middle management, in comparison, is fairly static – comprised of individuals promoted up to supervision from front-line technical roles. These individuals may likely spend their entire careers locally in these functional areas. Given functional specialization, transportability of these individuals is relatively low. In addition, whereas upper management will be actively reassigned in light of organizational change, middle management does not have the luxury of this kind of safety net.

Low transportability and lack of a safety net for middle management has predictable effects on their response to change initiatives. The power base for these individuals includes the ability to control human resources, dictate decisions, and control or limit information flow. Management roles over line functions – producing blueprints or manufacturing hardware – are, in many cases, fairly well protected unless a change initiative seeks to alter the basic business itself, or shift operations geographically. The more threatened ranks of middle management reside in functional support areas or liaison organizations. In fact, many of these groups may themselves be championing their own versions of change, which, of course, have self-preservation built in.

PC^3, PCIS, and ACES all represent, to a certain extent, a replacement for liaison functions at Pratt&Whitney, such as product center engineering and manufacturing systems engineering – described in earlier sections. Even more importantly, the three initiatives (championed from the manufacturing technology, compression systems engineering, and engineering finance departments, respectively) competed with eachother for customers and visibility. Given the size of the market the technologies intend to serve, PC^3 and ACES have yet to come head to head in competition. The relationship between PCIS and ACES, however, has been more strained.

By design, ACES includes the process capability data calculated by PCIS as well as the complex language architecture PCIS developed to translate between manufacturing and engineering product languages. At the working level, the PCIS team openly welcomed ACES since PCIS had been struggling for years to develop a customer base. Management, on the other hand, reacted differently. The true end customer of the PCIS data was seen as the IPTs – not ACES. With ACES in the middle – effectively absorbing the work of PCIS – visibility of the PCIS effort would be obscured, perhaps leading to the reevaluation of PCIS as a unique entity in the organization.

ACES was better connected than PCIS to upper levels of management and could have flexed this power to shift the alignment of PCIS management. Retribution, however, could have hampered ACES development. Given that marketing for ACES depended heavily on demonstrating results, delays were not acceptable. The ACES team opted to share visibility and credit for the overall effort with PCIS management. Although the long-term design of PCIS and ACES into the organization has yet to be determined, the short-term results needed to sustain the effort were achieved.

7.5 Expanding Development – The Ease of Finding Customers

A change initiative begins its life in a specific position in a company's organization and process. PCIS at Pratt&Whitney, for example, began life in the manufacturing technologies department, focusing on the database that collected production inspection data. Driving the incorporation and expansion of a new technology or process off of this starting position is a difficult task. PCIS, like most initiatives, needed to expand itself in two directions. Conceptually these two directions can be described as horizontal and vertical (see figure 7.5-1).

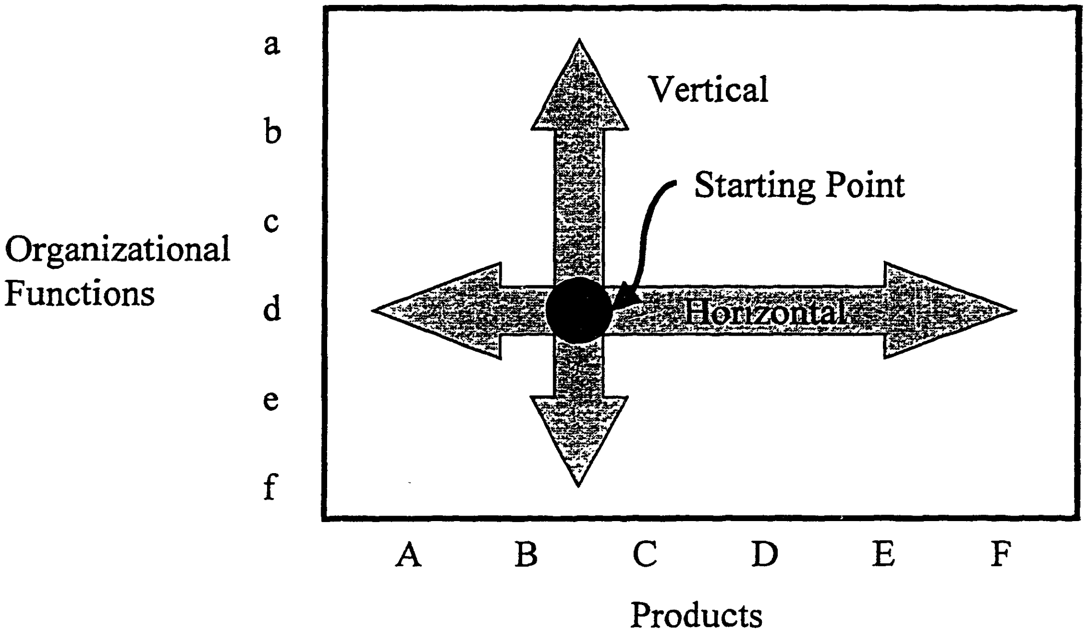

Figure 7.5- 1: Multiple Direction of Development of New Technologies

Horizontal expansion of PCIS necessitated deployment across Pratt&Whitney's manufacturing business units, suppliers, and a variety of systems in order to capture the data from all of Pratt&Whitney's hardware. The vertical expansion of PCIS necessitated the development of user interfaces and the deployment of the system to the customer base. Tackling expansion in both directions simultaneously conceptually increases in difficulty as the square of the rate of expansion in any one direction. Thus, a strategic choice must be made with regard to the sequence and direction expansion will follow over time.

Given the highly functional structure of aerospace companies, vertical expansion requires efforts across functions, branching out from the organizational starting point of the initiative. Involvement of supporting and intermediate functions as well as customers becomes necessary, however, as outlined in many of the sections in this report, this represents an exceedingly difficult sales effort.

Horizontal expansion is a relatively easy proposition compared to vertical expansion. Again, given the functional structure of aerospace companies, it is often likely that horizontal expansion will not require many interactions outside the organizational starting point of the initiative. In the case of PCIS, expansion of the technical elements of the software system required interaction only with MIS, who had representatives on the technical team early on.

Although horizontal expansion can be a quicker, easier method of achieving progress than vertical expansion, this may not be the ideal approach to championing change. The marketing value of delivering results to the end customer, as described in multiple sections of this report, are not achieved as well with a horizontal approach as they are with a vertical approach. Put another way, a horizontal expansion delivers technology first, whereas a vertical expansion delivers results first.

One exception to this recommendation on the sequencing of expansion, of course, is the case where horizontal expansion is necessary to build infrastructure elements that are enablers for pursuing vertical expansion. For example, at AlliedSignal lean manufacturing efforts were hampered by inconsistencies in the design of operations sequences across parts. For a given production cell, the sequence of operations steps were standardized across a few high volume parts in order to establish a common process flow enabling the redesign of the cell layout. The lean effort attempted to use these cases to vertically market the results of flow to the bottom line of the business. Continuing demand for parts that did not share the standard flow meant that flow was frequently interrupted, preventing the cell from demonstrating the planned departure from job shop operation. In this case it would have been more effective to standardize operations sequences, or outsource all of the parts produced in each target cell prior to pursuing vertical expansion.

PC^3 and PCIS both expanded horizontally at a much faster pace than vertically. PC^3 developed a complex set of informational web pages for an entire manufacturing facility prior to addressing many of the customer issues such as linkages to other complementary information and data systems. PCIS also focused on horizontal technical expansion prior to addressing customer concerns such as user interface design and an analytical link between the PCIS process capability data and financial data.

ACES, on the other hand, had a strong vertical focus early on. Development was focused on one part – the PW6000 diffuser case – and thus one customer. The analytical software, connection to upstream data systems, and downstream user interface were all a part of this launch project. This approach enabled the ACES team to deliver results from the technology – rather than delivering just technology – in only three months compared to the years of work behind PC^3 and ACES. The demonstration of these results from the ACES technology was an important element in the marketing campaign for the project.

7.6 Summary

By focusing on a single component of the PW6000 – and thus a single customer – ACES was able to leverage the limited influence it had to gain access to the necessary resources and deal with individual resistance. This intense focus enabled the ACES effort to pursue a strategy of developing the cost-tool technology at the same time as delivering useful results for the PW6000. Delivering results for a customer (albeit one customer) that was in desperate need of the service proved to be a major win for the effort. The anecdote from the entrepreneurial world is that "venture capitalists fund pain-killers – not vitamins," since the impact for the latter cannot be immediately felt by the target customer.

7.7 General Summary

Chapters four through six described the technical challenges facing change initiatives with respect to workflow change. While both PC^3 and PCIS address many of the issues of knowledge transfer and translation, only ACES deals significantly with knowledge transformation issues. The two most important elements of the ACES design across these issues are:

a) Use of cost as an operating language – which enables communications across functions and taps into an influential metric shared by most departments.

b) Open access to algorithms, rules, and data – which provides a basis for technical negotiations during design trades.

Beyond the technical design of ACES, the execution of the project acted to overcome many of the human barriers to change discussed in chapter seven. The effort's entrepreneurial focus on delivering desperately needed results to the PW6000 program provided a solid foundation to overcome many of these barriers. Chapters eight through ten continue this discussion by elaborating on frameworks and methodologies that capture the essential factors that led to the success of ACES relative to PC^3 and PCIS.

8. Recommendations – Strategy

8.1 Introduction

The past four chapters not only exposed major barriers to change, but also gave comparable examples of success and failure. The analysis of the three cost tool initiatives was intended to raise the reader's awareness of important barriers to change and to demonstrate possible methods of countering the effects. This chapter begins a section of three chapters that take the reader beyond awareness by consolidating thoughts from the previous sections of the report.

This chapter discusses proactive measures that can be undertaken by an organization to provide for a more receptive environment for change. Chapter nine provides a methodology for the crucial step of preparation between a concept for change and execution. Chapter ten concludes the report with a discussion of important practices to be employed during the execution of a change initiative.

8.2 Strategic Targeting

Whether one is in the position of participating in a change initiative or funding one, a strategic analysis of the initiative's targeting is one method of gauging potential for success. Successful targeting can be described as the consistent overlap of value, opportunity, and capability.

a) **Value Proposition**. The value proposition of a change initiative is essentially its intended contribution to its customers. This value must be measured in the same currency as the metrics by which each customer is evaluated (e.g. financial, delivery, quality, etc.). This value proposition must be analyzed at each level of management in order to identify a consistent value chain that begins with the direct customer of change and ends with the end customer of the firm. Note that the value proposition of the technology must be directly measurable – not implied. For example, PCIS provides a benefit that cannot be measured by the user (a design engineer), only by manufacturing downstream. PCIS enables design engineers to implement more producible designs by using process capability data, but the design engineer himself is unable to quantify the benefit – it is only implied at that stage.

b) **Opportunity**. Opportunity can be defined as the existence of a problem in immediate need of a solution. The timing and targeting of change must be consistent with the ability to implement results using the new technology or process. Opportunity means not only the ability to act on results, but also that the results cure a source of pain for the customers in the value chain.

c) **Capability**. Capability is tied to the abilities of the team that has been assembled to pursue change. These abilities include more than technical competency in the core and supporting technologies or systems. First, technical capability and authority to act upon the results of change and deliver to the customer is highly valuable. Second, a strong leadership element is always necessary to overcome barriers and inertia.

8.3 Enablers

At a high level, an organization can develop infrastructure elements that facilitate change. These elements can be viewed as enablers, aiding in the formation of business plans for change as well as helping break down internal barriers.

a) **Activity-Based Costing**. The value proposition for change almost always includes financial elements – especially as the value chain is evaluated up the organizational ladder and on to the end customer of the firm. As elements of change are evaluated, traditional financial accounting systems obscure impacts. In many cases, a financial evaluation of technical trades may not be possible at all – driven by the lack of analytical connections between product performance and market price. Pursuit of an activity-based costing system would greatly enhance the business plans of change initiatives.

b) **Metrics**. The design of metrics is an obvious strategic issue for companies. Although activity-based costing can clarify the immediate benefits or consequences of individual or departmental actions, consistency between the metrics of different departments is key. One possible method of achieving consistency and eliminating competition is by stipulating that the reward for an individual group is contingent upon all the groups in the department meeting their objectives for that period. This strategy can be implemented at every level of the organization. The baseline by which improvements are measured, however, is a tough issue. Where possible, tying baselines to competitor capabilities or industry standards (versus arbitrary values) provides the company justification in shifting the baseline (and thus influence) over time and avoids conflicts of interest within the organization.

c) **Organizational Design**. The issue of collocation or internal vertical integration versus functional division is not a clear subject. The general trend in aerospace has been to disband functions and reassign individuals to production organizations that directly support delivery to the end customer. This is intended to drive customer focus and the alignment of objectives. Operating within this objective, temporary groupings may be warranted to facilitate information transfer – such as is necessary to address systems issues in product development. The long-term formation of functional groups (such as support or administrative departments) versus assigning the individuals directly to production departments should be avoided unless a viable competitive alternative for this service exists – whether or not the alternative is in-house. The existence and occasional use of alternative sources for these services reduces monopoly power and increases customer focus by forcing the functional groups to compete for business.

d) **Marketing Training**. The successful negotiation of barriers to change is often tied to standard themes of entrepreneurial marketing. Internally to large organizations, education in this field may be lacking. Whether training is conducted in-house or at a local university, investments made in this type of continuing education for employees would be invaluable.

e) **Management Commitment**. Commitment, in negotiation terms, is the adherence of a party to a particular demand without any intention of changing position. Inertia will always lead functional elements in an organization to continue operating in traditional ways despite most pressures to change. Where management has the opportunity to control the development process – such as the authorizing of funding or subsequent tasks in a stage-gate environment – management can flex commitment power in the interest of change. Management can refuse to allow a development project to proceed to the next stage without meeting certain objectives – objectives that may only be possible to achieve through change.

8.4 Summary

Strategic analysis can aid an organization in refining the business plan of change initiatives as well as providing an opportunity to pick out the most promising projects for support. In addition to providing focus at a high level, enabling elements will assist the chosen projects in achieving results. These enablers increase the knowledge translation space available in dealing with cross-functional and cross-departmental issues – an easier proposition than transformational challenges.

9. Recommendations – Preparation

9.1 Introduction

The pursuit of change can be broken down into further detail than the three-step process described in chapter 1. The added refinement (see figure 9.1-1) will aid managers in preparing to successfully deal with barriers to change.

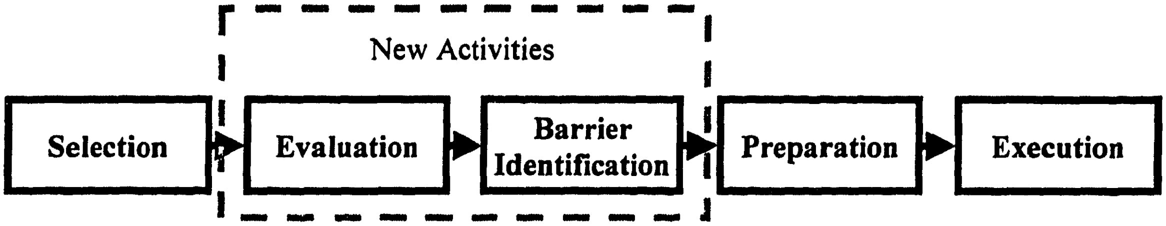

Figure 9.1- 1: Refined Lifecycle of a Change Initiative

9.2 Selection

The selection step is the strategy element of the process. This step, discussed in chapter eight, looks at the overlap of the value proposition, opportunities to achieve immediate returns on the investment in change, and the capabilities required to effect change. This analysis should help firms be able to not only evaluate individual change initiatives, but also prioritize between them – reducing overcommitment and maximizing the usage of critical resources.

9.3 Evaluation

During the evaluation step, the level of impact of the new technology to the fundamental workflow of the organization is determined. The questions that need to be answered in this stage are:

a) To what extent will the proposed process change affect knowledge transfer, translation, and transformation?
b) What functional tasks must change and who owns these tasks?
c) What functional tasks or roles will be made obsolete?

9.4 Barrier Identification

As a result of the workflow evaluation, it should be easier to identify the potential barriers to change, many of which were exposed in chapters four through six. The issue of knowledge transformation, especially, will lead directly into the people-related barriers discussed in chapter seven. The applicable questions at this stage are:

a) What barriers is the change initiative likely to encounter?
b) What players will be the source of this resistance?
c) What are the interests of these of these players?

9.5 Preparation

With a solid business case and an understanding of the potential barriers to change, more effective preparations can be made prior to execution. This knowledge will enable those championing change to target the right players (as participants and/or customers) with the right value proposition to garner support for the effort.

An understanding of the interests of the players will provide insight into strategies to engage these individuals in an integrative versus distributive manner. This evaluation can be summarized by charting the interests of each player (power, security, intellectual interests, reward/recognition) against the official position of their function (workflow, product control) and the customer needs of the organization (see figure 9.5.1).

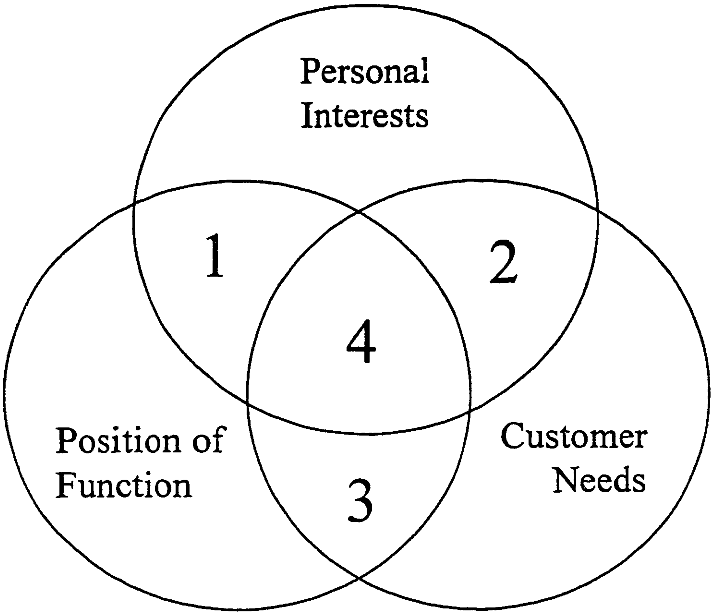

Figure 9.5- 1: Negotiation Opportunities

The ideal, but rare, situation is the overlap of a player's position, interests, and customer needs – zone four. Zone one, in contrast, may represent the strongest point of resistance, where the player's interest is to defend elements of his function that do not serve a value-added service to the end customer of the organization. A constructive solution to zone one resistance may be negotiated by focusing initially on zone four elements or zone two elements to engage the individual's interests and thus build a trusting relationship. Zone two is especially interesting in that it offers an opportunity for the player to contribute and satisfy interests that may not have been tapped into within the constraints of his functional position.

Zone three represents the easy target for change – a functional element directly tied to end customer needs that are not in the player's interest set. For example, repetitive or difficult tasks may be representative of zone three space. The danger with zone three changes is that they may be so far from the player's interest set, that it may be difficult to garner the necessary attention to support the effort. More specifically, apathy, rather than direct resistance, may hamper the progress of change if the player's involvement is vital to the effort.

9.6 Summary

The level of preparation discussed represents a more integrated approach than is typically in practice. The more integrated approach (see figure 9.6-2) begins by targeting an overlap between the value proposition and the opportunity (timing) to demonstrate results to the business. Recognizing barriers to change that are driven by changes to workflow, the integrated approach also constructively links in the right human resources (power/control nodes) to gain control over the processes, functions, and individuals connected to these barriers.

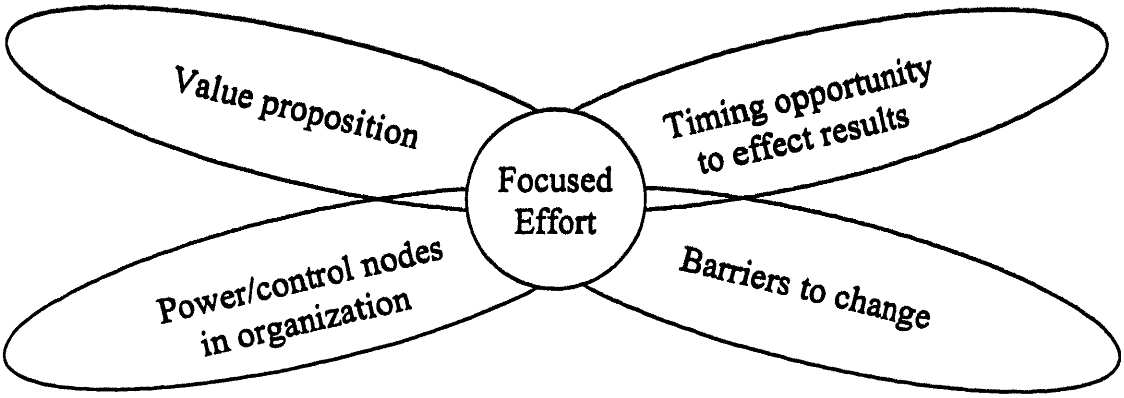

Figure 9.6- 1: Integrated View of Planning Change

A detailed analysis of the players involved (power/control nodes) allows for the negotiation of the value proposition down to the level of each player. This negotiation space will ensure support at the functional levels necessary for a smooth execution.

10. Recommendations - Tactics

10.1 Introduction

Tactical recommendations with respect to change initiatives relate to the day to day activities of a change-management team – the execution of the change initiative. The execution step has only changed in that it requires an increased focus on delivering tangible results, versus a technology for others to act upon. With the right targeting and value proposition, developing the new technology "on-line" can be attained – providing the fastest path toward tangible results.

10.2 Directing Progress

Pursuit of change, as discussed earlier, should be focused initially on a single, well-targeted customer. Although challenging from the perspective of human resource control, development should address all the elements necessary to deliver a complete set of results to the customer, which he can immediately act upon. Delivery only of sub-elements of this system, no matter how widely expanded across the potential customer base, cannot produce results for any one of these customers. Delivering results, versus technology or recommendations, is a key element of successful entrepreneurial marketing.

10.3 Developing Technology on-line Versus off-line

Although the pressure to develop new technologies "off-line" is usually great, developing technology "on-line" can have enormous benefits. Developing change in the context of line activities, such as active product development programs or production parts, not only enables the initiative to deliver useful and timely results, but also acts to forge connections with the best human capital.

In an environment of production pressure, the most capable individuals are likely to be assigned to the most pressing issues of the department. Working with these people, as opposed to liaisons, provides access not only to the best information, but also to the individuals with the authority to act upon the results produced by the change initiative.

Competition for line-function human resources may be hampered not only by production pressures, but also by the interests of the management chain controlling these resources. Where necessary, the leadership of change initiatives must be prepared to share credit and visibility in order to limit self-preservation responses by other elements of management.

While focus and resources help speed progress, speed itself is valuable to the success of a project. Given the dynamic nature of staffing – especially in management ranks – speed alone can improve the chance that the support network for a change initiative will remain intact for the duration of the project. Speed towards results has downward-marketing effects as well. Given the professional risk associated with change initiatives, retaining resources requires a continued expectation of rapid success and management visibility. Once the expectation of success is put into doubt or management interest is lost, the most talented resources will divert to other projects or transfer to other groups in search of more promising ventures.

10.4 Leadership

People-related barriers may represent the most difficult challenges to those pursuing change. These barriers are difficult to design away with technical solutions. Success depends, in part, on the focus on a key customer and delivering results. Success also depends on a well-developed ability by those leading change to negotiate with competing initiatives and between functions with conflicting objectives.

Overcoming active resistance at one end of the spectrum or apathy at the other end requires a continuing leadership ability to assess players' interests and negotiate creative solutions. Although a strong business case can provide a considerable source of power through the management chain of command, this source of power, in the author's experience, does not represent a long term solution to resistance at the working level.

10.5 Summary

Although there is a perception that influencing change in the aerospace industry is an exceedingly difficult challenge, this is not entirely the case. The effective application of entrepreneurial marketing and negotiations theories can mitigate the impact of the major barriers that exist in the industry.

Despite differences between aerospace and other industries in program timelines, the order of magnitude of financial commitments relative to sales volume, and industry growth rates, it does not seem likely that the barriers (or solutions) presented in this report are unique to aerospace. Further comparative research between industries might not only verify this hypothesis, but also provide a wealth of relevant examples to enhance the learning on this subject.

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Appendix A: Aircraft Engines – The Industry Environment

General Information

There are only three original equipment manufacturers (OEM) of mid-thrust (20-40klbf) and high-thrust (40-100klbf) commercial jet engines today. These companies are Pratt&Whitney, General Electric and Rolls-Royce. The timing of the research for this report coincides with a specific competition in the mid-thrust arena between Pratt&Whitney and GE.

The lifecycle of a jet engine and the corresponding financials make for a tough environment for original equipment manufacturers (OEMs). The key time points in the engine lifecycle are the program launch date, the date of design certification by the FAA, and the breakeven date when the discounted revenue stream passes the investments that were made in the development of the new product.

Commercial Product Lifecycle

Program launch through FAA certification in the past required 48 months and an initial investment of \$1B[12] for Pratt&Whitney. Engines are sold to the airlines at substantial discounts in order to establish an installed base. This effort is reflected financially as an additional "investment" of \$1B. Positive gross margins are only achieved through the sale of spare parts, which are sold at significant multiples of fabrication cost. Breakeven typically occured approximately 14 years from launch. The useful life of a particular engine design, however, may be 30 years or more. For example, Pratt&Whitney's JT8 program launched in 1964 has delivered over 14,000 engines to-date. The JT8D and its derivatives will probably still be flying on various platforms well into the next century.

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[12] Bob Leduc, VP Commercial Engines, Pratt&Whitney, Presentation to MBA Interns, July 1998

Changing Customer Requirements

In 1960, the relative cost of fuel to the lifetime ownership/operating cost of an airliner was 50%. Today, fuel cost represents only 15%-20% of the total cost[13]. In addition, airline competition has forced income per passenger-seat-mile down by almost 50%[14]. Thus, whereas power and fuel efficiency – technical parameters – drove the jet engine marketplace in the past, these parameters are mere entry requirements today with the focus in competition being cost.

Beyond acquisition costs, reliability and predictability also play a major role in the financial models of the airlines. In response to the competitive environment in air transport, commercial airline customers today are pushing more of the cost variability of jet engines on the engine OEMs in addition to just the development and acquisition costs. Airlines without in-house core competencies in engine repair are starting to demand "power by the hour" (PBH) arrangements with the engine OEMs[15]. The structure of PBH agreements requires the engine OEM to assume the financial burden of engine maintenance. The airline's financial obligation in a PBH arrangement is to pay the engine OEM a per-hour usage fee.

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[13] D.L. Grose, The Boeing Company, Presentation to MIT Aerospace Product Development Class, October 1998

[14] Walt Gilette, The Boeing Company, Presentation to MIT Aerospace Product Development Class, October 1998

[15] Peter Smith, PW6000 Program Manager, Pratt&Whitney, August 1998

Appendix B: Competitive Environment – Setting the Stage

Current Competition

The most visible competition between Pratt&Whitney and GE is the engine overhaul and repair market. Despite the trend toward PBH arrangements, significant revenues for existing contracts are still generated through the overhaul and repair market. Since there is no way for an engine OEM to restrict which companies overhaul their products, GE has been able to claim three times the OH revenues of Pratt&Whitney – despite the fact that Pratt&Whitney currently has three times the installed base of GE. Although both Pratt&Whitney and GE are in a race to build their overhaul and repair businesses through acquisition (Pratt&Whitney plans to almost triple its Engine Services Division by the year 2000), Pratt&Whitney is equally concerned with trends in original equipment sales.

Sobering Data

Over 70% of new engine sales are GE products – a large percentage of which is represented by the CFM56[16]. The roots of this situation date back to the early 1970s when Boeing believed the narrow body 757 aircraft would be the leading seller in the marketplace. Based on this information, Pratt&Whitney invested its resources in the development of the PW2000 – aimed at the 757. CFM, a 50/50 partnership between GE and Snecma of France, developed the CFM56 for the Boeing 737 platform, displacing the Pratt&Whitney JT8D. As of April 1999[17], 3,361 737's have been produced compared to only 859 757's. The production rate of the 737 stands at 27 aircraft per month versus a rate of only 5 aircraft per month for the 757. In the early 1990's Boeing requested that Pratt&Whitney develop and certify an engine for the 737 to compete with the CFM56, however Pratt&Whitney was not in a financial position at the time to make that investment, as it posted its first ever loss to Wall Street.

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[16] General Electric Company 1998 Annual Meeting, Executive Speech Reprint, April 1998

[17] The Boeing Company, Public Web-Site, May 1999

Pratt&Whitney's New Product Goals

Pratt&Whitney's response to price erosion from commercial airline customers and competition with GE and Rolls-Royce has been to focus on significantly reducing development costs, per-unit engine fabrication costs, and predicted maintenance costs. Based on the erosion of the price of engine acquisition and additional competitive pressures on PBH rates, Pratt&Whitney estimates breakeven will push even further out – past 14 years.

In addition to structural changes in the design process through IPD, much of the development cost reduction is being driven through the pursuit of reduced physical testing requirements – both for development and for certification. Pratt&Whitney's argument to the FAA for reduced testing is based on the increasing sophistication of computer analyses performed by engineering and the technical similarity of many new parts to existing certified parts.

The Next Generation of Products for Pratt&Whitney

Pratt&Whitney is currently investing in two engine development programs to regain market share from GE. The PW6000 is being developed to compete with the CFM56 on price to the customer (i.e. PBH rate) as well as on manufacturing cost – to complete the financial case. The PW8000 is a follow-on product that will benefit in cost from using the same core as the PW6000 but will offer geared fan technology. Geared fan technology (already employed on small turbofan engines) will provide airline customers with improved fuel efficiency and reduced noise emissions on large aircraft. Reduced noise opens significant markets in Europe where noise restrictions limit aircraft operations.

General Barriers to Entry

Beyond technical issues, the CFM56 offers significant barriers to entry for the PW6000 and PW8000. The 737 is a short-haul aircraft, which means that return on assets (ROA) for the operators is driven to a large extent by the rate at which an aircraft can be turned around from one flight to the next. Airlines such as Southwest, America West, and United Shuttle compete aggressively on this metric. Southwest currently leads this battle, demonstrating a turn time of 18 minutes from the time an aircraft arrives at the gate to the time it's pushed back from the gate to begin its next flight. Thus, reliability, part commonality and interchangeability are keys to the success of maintaining a high operability status for these airlines. Southwest Airlines, United Shuttle, and Alaska Airlines – to name only a few – each operate only one type of aircraft to support this strategy.

The CFM56, which powers most of the newer standard short-haul aircraft, also supports the competitive strategy of these airlines. Since first certified in 1979, CFM56 variants have maintained a high degree of commonality in order to facilitate the speed of service and lower training requirements. With over 100 million hours of cumulative operating experience, CFM has not only improved the reliability of the components in the CFM56, but has also improved service processes. Tying into the overhaul and repair market mentioned earlier, CFM is able to extrapolate product and process improvements based on demonstrated experience and can thus offer progressive competitive pricing to the customer based on the predicted savings from future improvements. Pratt&Whitney, on the other hand, does not share the same experience or practices and currently offers PBH arrangements that increase with time – tied analytically to the Consumer Price Index.

Pratt&Whitney has already booked orders for the upcoming PW6000 on the Airbus A318 platform. Although airlines seem eager to purchase the PW6000, this is a double-edged sword for Pratt&Whitney. Since the CFM56 represents a monopoly in its class, it is likely that the airlines are seeking to introduce competitive pressures by buying PW6000 engines. This means that, on a technically level playing field, cost will be the determining factor as the competition plays out.

Appendix C: Product Development Process

Phase 1: Concept

The duration of the concept phase averages several years based on available technologies and market conditions. During this phase design trades are made on the basic architectural elements of the design. Engineering uses analytical models at this stage to predict high-level engine performance and efficiency. Cost engineers supporting these studies generate cost information (for design trades) by scaling data from production parts that present the greatest similarity to the caricature parts of the new engine. Due to the lack of product definition at this stage, the accuracy of cost prediction is relatively low. This phase is concluded with the official "launch" of full-scale development of the product. The physical products of this first phase are a systems requirements document (SRD) and a components requirements document (CRD) specifying the technical objectives and interface requirements for each component in the engine. This information is used to guide the efforts of component IPTs during the following phase. Design changes during this phase require systems analyses to be redone.

Phase 2: Detailed Design

The duration of the detailed design phase averages six months. During detailed design, large quantities of engineering and manufacturing resources are assembled into IPTs to perform the analyses necessary to develop a complete set of blueprints for each part. Cost engineers still perform in a reporting role, however liaison engineers from the MSE department and manufacturing engineers from target production sources are relied on more heavily for producibility and cost *guidance*. Adding to the impacts described in the previous phase, impacts of a design change during this phase not only include repetition of the analyses performed by the specific component team, but also repetition of the analyses of other component teams. This is due to the fact that components in a gas turbine engine (and between the engine and the airframe) are linked mechanically, aerodynamically, thermodynamically, hydraulically, and (in some cases) electronically.

Changes to one component may affect the function of other components, thus requiring the additional changes.

Phase 3: Hardware Build for First Engine to Test (FETT)

This phase is technically the second half of the detailed design phase and typically lasts six to eight months. During preparations for FETT, capital investments are made in the fabrication of tooling to produce the first set of hardware to the blueprint specifications developed in the previous step. Some analytical work continues as the design is tweaked, but the focus shifts toward preparing for engine testing. Adding to the impacts described in the previous phases, impacts of a design change during this phase include the rework or replacement of manufacturing tooling and the rework or obsolescence of parts already being manufactured.

Phase 4: Development Testing

This phase can last for several years. During this phase, tests are conducted to verify and adjust product performance and durability. The product is also tested to refine its compatibility with mating systems (such as the airframe in the case of gas turbine engines). Finally, specific performance, endurance, and safety tests are conducted to satisfy FAA requirements. In parallel, manufacturing facilities are readied for production. This includes not only production equipment and tooling, but also inspection and repair tooling. The results of this phase are FAA certification for the product type itself and for the manufacturing methods and facilities used to produce the product. Adding to the impacts described in the previous phases, impacts of a design change during this phase include engine retesting and tooling rework or replacement. Engineering resources may also be more difficult to secure during this phase as many of the component design teams are likely to have been disbanded and the individuals assigned to other projects.

Phase 5: Production

During the beginning of the production cycle, engines are produced for flight testing by the airframe manufacturer in order to achieve FAA certification for the airframe installation of the product. Once this certification has been granted, higher volumes are produced as the product enters revenue service. Adding to the impacts described in the previous phases, impacts of a design change during this phase include service bulletins and warranty service to the customer base to replace obsolete hardware. A significant amount of logistical, training, and maintenance documentation must also be changed.

Appendix D: Closing the Distance Between Functions

Product Centers at Pratt&Whitney

Seeking economies of scale in manufacturing, Pratt & Whitney divided its production facilities up and down the eastern seaboard of the United States based on manufacturing processes. For example, turbine blades (small, machined investment castings) for all product lines are machined in North Haven Connecticut. Cases (large, machined structural castings and forgings), another example, are machined in Middletown Connecticut. Each of these "product centers" focused on a particular type of component in the engine. Note that the base castings, forgings, and sheet metal (as well as some parts in their entirety) are sourced to third-party suppliers.

A significant portion of the engineering community was uprooted from the central design facility in East Hartford, Connecticut and relocated to the product centers. The intent of the relocation was to collocate design activities with manufacturing activities and thus achieve better cost-focus early in the product development process.

Two issues derailed the engineering relocation strategy of the product center concept. First, engineers sent to the product centers did not spend the bulk of their time designing new products. Instead, now reporting to production management at the product centers, these engineers were dragged into the day to day fire fighting of the business units. Their time was consumed by evaluating discrepant hardware and repair procedures – becoming an even more efficient crutch for a system resistant to expensive redesign options. Second, because of the cross-component human interaction required to address systems design issues, the remaining engineering community in East Hartford held on to the design process. At best, the design engineers at the product centers acted as liaisons when questions arose in East Hartford.

Job Rotation at AlliedSignal

AlliedSignal structured the roles of the engineers it relocated to production facilities differently from Pratt&Whitney. By order of management, design engineers assigned to the manufacturing facilities were specifically restricted from involving themselves in the day to day fire fighting. Instead, these engineers worked on proactive efforts such as lean manufacturing and defect reduction. These engineers were also trained to lead value-engineering events on new designs applicable to their engineering and manufacturing departments. The fire fighting, on the other hand, was left to the engine platform teams that consisted of business, project, customer support and others as well as engineers. The platform teams, with connections both within AlliedSignal and out to the firm's end customers were better positioned to respond to day to day service and delivery issues.

AlliedSignal rotated engineers from these "learning assignments" in manufacturing to central design locations during the launch of new programs. This strategy facilitated the transfer of manufacturing knowledge into new product designs while maintaining strong systems integration linkages.

Movement of Teams at McDonnell Douglas

The former McDonnell Douglas offered yet another solution on its F18E/F development program[18]. Favoring systems integration, McDonnell Douglas concentrated design engineering talent geographically early in the design program. In contrast to the other examples, manufacturing personnel were relocated from the factory to the central design area full-time. When the program shifted into detailed component design, the central design area was disbanded. In contrast to the other examples, not only the manufacturing personnel returned to the factories, but also the design engineers. The component teams – with both design and manufacturing functions represented – moved with the product throughout development. This approach represents a high investment in human capital, however the results of the F-18E/F program with respect to technical, cost, and schedule issues were successful across the boards.

Delayed Product Definition at GE

The strategy employed by GE Aircraft Engines allows for greater control of the design by manufacturing[19]. Design engineering provides the minimum definition necessary to ensure performance key characteristics are maintained – delaying much of the manufacturing process specifications. Control of the design is then transferred to

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[18] Mario Vitale, Program Manager F-18E/F, McDonnell Douglas Aircraft, Presentation to MIT Aerospace Product Development class, October 1997

[19] Ed Crow, VP Engineering, Pratt&Whitney, Interview, August 1998

manufacturing, allowing greater flexibility in choosing manufacturing and construction options as the design is solidified.

Pratt&Whitney's Latest Efforts

Pratt&Whitney is currently pursuing an intermediate strategy. Manufacturing elements are being redistributed within the factories to focus on entire "modules" of the engine – versus specific parts. Design functions in the central facility in East Hartford are being relocated to these module centers. The intent of this strategy is to effect the relocation of design activities by accommodating some of the requirements of systems integration. Regardless of organizational design, however, raw material and vended parts are still sourced from third party suppliers. Thus, without continued travel between sites, concurrent engineering still cannot occur. The three cost tool initiatives, as well as other knowledge-based software projects were conceived to complement this new strategy.

Appendix E: Financial Accounting[20][21]

Marginal Cost Versus Average Cost

Ideally, when evaluating design, process and sourcing decisions one would be interested in measuring the incremental financial change to the business. More specifically, if a control volume could be placed around the entire business – enabling the precise measurement of revenues and expenses – change initiatives would be evaluated by measuring the impact on these two variables for the business. The economic terms for these variables are marginal revenue (MR) and marginal cost (MC). Mathematically, marginal cost per unit produced, for example, is the first derivative of total cost (TC) with respect to production quantity (Q):

$$TC = FC + Q * VC$$

Where total cost (TC) is the sum of fixed costs (FC) and variable (Q*VC) costs:

$$MC = \frac{d}{dQ} TC$$

In order to provide accurate information on part-specific decisions/changes, FC, VC, Q and thus TC and MC must be calculated separately for each part.

Example fixed costs for aerospace equipment manufacturers include:

a. Support services (engineering, purchasing, other specialties)
b. Rent
c. Building services (heat and electricity)
d. Equipment depreciation
e. Administrative

Variable costs include:

a. Raw material (purchased hardware such as castings)

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[20] Bazel, Nikolai and Grove, *Financial Accounting*, South-Western College Publishing, 1995

b. Perishable tooling (drills, lathe inserts, etc.)
c. Direct energy consumption (utilities for machines)
d. Direct labor (machine operators)

Rather than evaluating change on a marginal cost/marginal revenue basis per unit, Pratt&Whitney's financial accounting system uses average cost per hour of labor (AC). Average cost per hour is calculated by dividing total costs (TC) by total labor hours (TL) for that period:

$$AC = \frac{TC}{TL}$$

This hourly rate is then further broken down into labor and overhead components. The labor rate is an inflated version of the actual union labor rate to account for fringe benefits such as medical insurance. Overhead is then a percentage applied to the labor rate to generate the balance.

This practice does not distinguish between simple versus complex processes. For example, the energy, maintenance, and depreciation costs for a manual drill press (a several hundred-dollar acquisition) are quite different from the respective costs of a large five-axis machining center (a million dollar acquisition).

The actual labor content between processes is also not accounted for. For example, the manual drill requires 100% attendance, while a heat treatment unit may operate unattended for a day.

Support services (such as engineering, maintenance, and logistics) are also not distinguished between parts. For example, complex parts with high defect rates may require significantly more support (analysis, rework, repair, inspection, marshalling, and scheduling) compared to simpler and better designed hardware.

The list of inequities caused by this average cost method of accounting is much greater than what has been described in this report, but the message is obvious. The true marginal cost or marginal revenue impact of a design, process, or sourcing decision is extremely difficult to calculate. For example, a new part may be sourced to a vendor because the internal price based on the factory hourly rate is a higher dollar value than the

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[21] Pindyck, Rubenfield, *Microeconomics*, Prentice Hall, 1998

supplier price. In reality, the marginal cost of producing the part in-house may actually be less than the supplier price – and would thus lower the average cost at the facility.

Additional problems are created by this average costing system. For example, an investigation into the core economics of the business unit where the PW6000 diffuser case will be machined determined that the local overhead rate is 20% less than that of the overall facility. What was discovered is that many of the business units in that facility were effectively subsidizing a business unit with a local overhead rate more than two and a half times greater than the facility average. The flat, average overhead rate policy has affected not only in-sourcing and out-sourcing decisions, but also the marketing of Pratt&Whitney's products. Specifically, the cost of components produced in the subsidizing business units inflates the reported cost of the end products. Thus the rollup costs used by marketing and finance to establish pricing and to calculate return on investment by product are not entirely accurate.

Alternative Measures

Since Pratt&Whitney's financial accounting system confuses design and process decision making, an alternative measure to labor hours has been developed. This indicator is called "buy-to-fly ratio." The buy-to-fly ratio is the ratio of the weight of a part as received by Pratt&Whitney (prior to machining) divided by its weight post-machining. The assumption is that a lower ratio means less work – and thus less cost – has been invested in a part than what is invested in a part yielding a higher buy-to-fly ratio. Pratt&Whitney is pushing to move its parts from an average buy-to-fly ratio of 10 to a buy-to-fly ratio of 2. The fallacy of this metric is that it does not consider the cost impact on upstream processes. For example, an internal Pratt&Whitney team would be greatly rewarded for reducing the buy-to-fly ratio of the PW6000 diffuser case to 1 – i.e. no machining. The corresponding cost of the casting, however, would have to increase by an order of magnitude – vastly outweighing the benefits seen in machining. Obviously an extreme example such as this would not pass, however the open loop of this dynamic does exist.

ABC at AlliedSignal

AlliedSignal's gas turbine engine business, in comparison, comes somewhat closer than Pratt&Whitney to activity based costing. Support services and tooling, for example, are charged directly to the parts they serve. AlliedSignal's system is by no means perfect, however. In addition, neither system can distinguish costs within a process. For example, one may be interested in determining the cost impact of the tolerancing on the machining of a particular diameter. If that operation combines the rough and finish machining of many hundreds of features (as is common), it may be difficult to discern this information if the resolution of cost data is only to the operation-level.

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