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Abstract: Shorter product life cycles make Development/Production transition capabilities critical to the success of high-tech organizations. This report studies the development to production transition (DPT) process, and the critical factors of transition and their strategic importance to the managers of high technology firms. DPT case studies are highlighted in the semiconductor, investment casting and Department of Energy subcontractor industries to examine how DPT was used as it pertains to their product lines.

ON DEVELOPMENT/PRODUCTION TRANSITION IN HIGH TECHNOLOGY ORGANIZATIONS

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EMP - P8919

ON DEVELOPMENT TO PRODUCTION TRANSITION IN HIGH TECHNOLOGY ORGANIZATIONS

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ABSTRACT:

Shorter product life cycles (PLC) make development/production transition capabilities critical to the success of high technology organizations since the introduction and growth phases are the most profit producing areas on the PLC curve. Factors both internal and external play a role on this success or failure of the organization to transfer technology from research and development to manufacturing. It is the aim of this paper to describe the DPT process, discuss critical factors of transition and their strategic importance to managers of high technology firms. Cases in the Semiconductor, Investment Casting and Department of Energy Subcontractors industries are examined to identify how the DPT process works within different corporate environments.

INTRODUCTION

Experts agree that most new products go through a typical life-cycle of concept, definition, design, development, production, operation and phaseout (1). While much of the available literature focuses on concept through development improvements as one subject, or on production improvements as another subject, little has been written on the transition between development and production. It would be an extreme oversight to ignore the importance of this transition, especially in light of today's extremely competitive environment along with shorter product life cycles. This paper will look at this development to production transition (DPT) by focusing on three case studies from very different industries and how each company utilizes DPT as it pertains to their particular product line.

THE DPT PROCESS

DPT bridges the gap from development's initial concepts and feasibility to production's goal of manufacturing at the lowest possible cost. It is often referred to as a prototype or pilot phase with a nature and structure local to a particular organization (2). Successful DPT is measured by its ability to bridge this gap. While the invention, innovation and development stages of the product lifecycle follow a natural process, the jump to production often entails many barriers. These barriers are listed on the following page (2):

DEVELOPMENT	PRODUCTION
Cost secondary	Cost primary
Technical management with assistant engineers	Product Manufacturing management with sustaining engineer core
Work performed by specialists and engineers	Work done by trained operators
Tight control possible required	Manufacturing tolerance
Small throughput and volume	Large throughput and volume
Low inertia	High inertia
Dedicated attention	Large batch philosophy
Judgment criteria	Pass/fail criteria
Extensive rework practical	Rework impractical
Flexible equipment	Narrow equipment latitude
Uninterrupted flow	Staging delays
Little documentation	Extensive documentation
Changes routine and easily implemented	Changes difficult to implement
Real-time analysis, traceability and feedback	Non-routine analysis difficult, feedback delay results in losses
QA separable function	QA necessarily integral

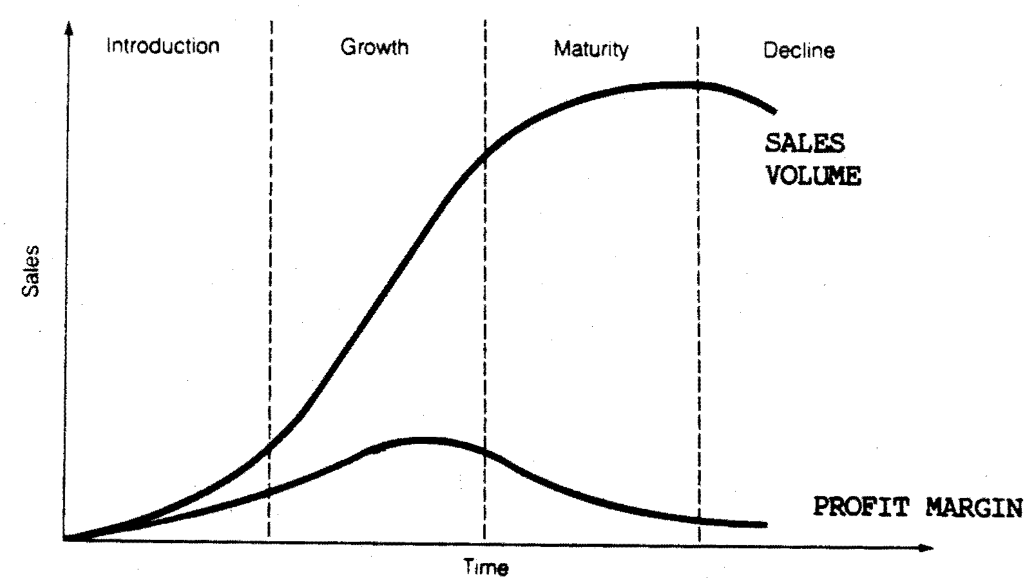
While some of these barriers cannot be changed, they must be recognized and taken into account to ensure successful DPT. Overcoming these barriers is critical because of the strategic importance of successful DPT.

STRATEGIC IMPORTANCE OF DPT

"Many high-technology products are characterized by a short product lifecycle (PLC) - a short life on the market, a steep decline stage and the lack of a maturity stage" (4). This discussion will serve to illustrate the importance of a smooth DPT in the high technology marketplace.

Product life cycle refers to "the sales history of a product over its lifetime" (4). Lifecycles provide a basis for visualizing the different stages of a product's life, its ability to satisfy market needs, and alternatives for market positioning of the firm. "The PLC is typically presented as having a bell shaped form and is divided into introduction, growth, maturity and decline stages" (4). Figure 1 (3) shows a typical single-product lifecycle.

FIGURE 1 Product Life Cycle



High technology firms are being faced with shorter product life cycles or products that spend a short time on the market (5)(6). These curves are characterized by an overall shortening of the PLC curve, with a steep decline and lack of a maturity stage (Figure 2). The shape of the PLC curve is a function of the rate of technological change. The competition in high technology markets forces large expenditures on research and development to come up with better and more

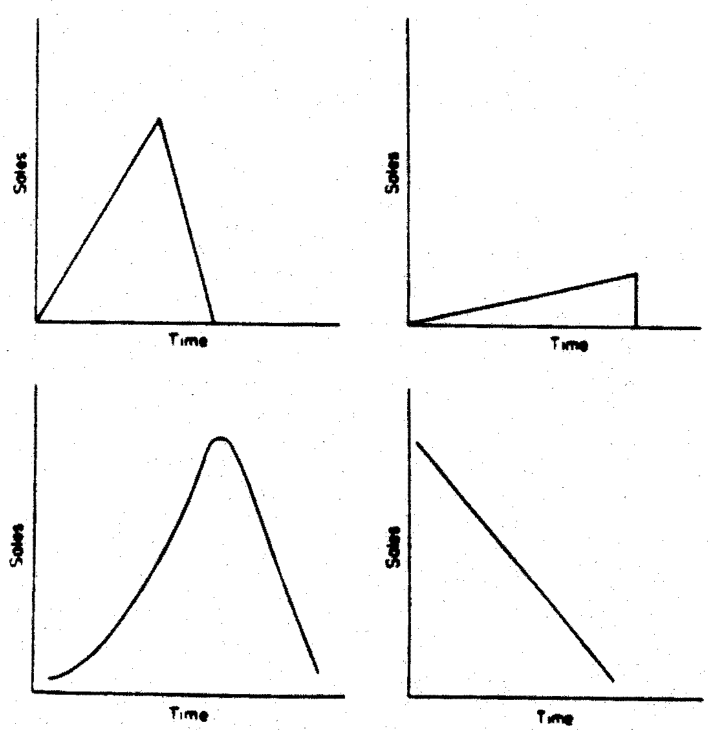


FIGURE 2. EXAMPLES OF "SHORT" PLC PATTERNS

cost-effective products. This results in a high rate of technological change and product turnover, where innovative or improved products frequently appear to replace their predecessors (4)(7). It must also be noted that profit margins change over a product's life cycle (Figure 1). A leadership position and early market entry are often critical to the financial success of a new product, allowing firms to justify the high development costs typically required.

A shorter product life cycle has several overall effects. The need to get the product to market quickly reduces the time available for development and transition to a manufacturable design (DPT). The time available for incorporating design changes based on feedback from customers is also greatly reduced. Another effect of shorter PLC's is an increase in the number of new products a firm must bring to market each year (7). The success of these products depends on achieving a high level of development and transition quality (8). This critical need to accomplish DPT's better, faster and more often in today's world has further elevated the importance of a strong, successful DPT process.

The case studies that follow on Intel Corp, Precision Castparts Corp., and Westinghouse Hanford Company, examine the DPT process within their unique environments. Each case is written in a form representative of its organizational culture, complementing the degree DPT is emphasized and its strategic importance.

CASE STUDY : INTEL CORPORATION

Intel was founded in 1968 and quickly acquired a reputation as an innovator, creating computer chips such as the dynamic RAM (Random Access Memory), EPROM (Erasable Programmable Read-only Memory) and the microprocessor. These products revolutionized electronics by making possible small, inexpensive, powerful computing systems. Intel remains the world's largest manufacturer of microprocessors and has set the standard for computer architecture. Given this record, it isn't surprising the New York Times stated that "Intel is widely considered one of the most innovative companies in the world" (9).

Beginning with 12 employees and a first year revenue of $2,672, Intel has grown to 20,800 employees and 2.9 billion dollars in revenue in 1988. The company has ten major U.S. locations, major international sites and sales offices around the world. Intel is a Fortune 200 company.

Major products include microprocessors, microprocessor peripherals, microcontrollers, EPROMs, microcommunication products, OEM modules and systems, and PC enhancement products. Please refer to Appendix A for a detailed description of each one of the products.

Major customers of Intel's microcomputer components, modules and systems are OEM manufacturers that incorporate them into their systems. About one third of the company's revenue comes from sales to electronic distributors who resell to customers, allowing a broader customer base. Personal Computer Enhancement products are sold through a network of over 1500 retail computer stores.

The company is divided into five major business units. They are: Microcomputer Components Group, Systems Group, Components Technology and Manufacturing Group, Sales and Marketing Group, and the Administrative Group. Please refer to the organization schematic shown in Figure 4.

This case will focus on two of Intel's business units; the Microcomputer Components Group and the Components Technology and Manufacturing Group. These two groups form the team which make design, development and world class manufacturing of state-of-art microcomputer components a reality. The discussion will be limited to Intel's major component products, the microprocessor product line.

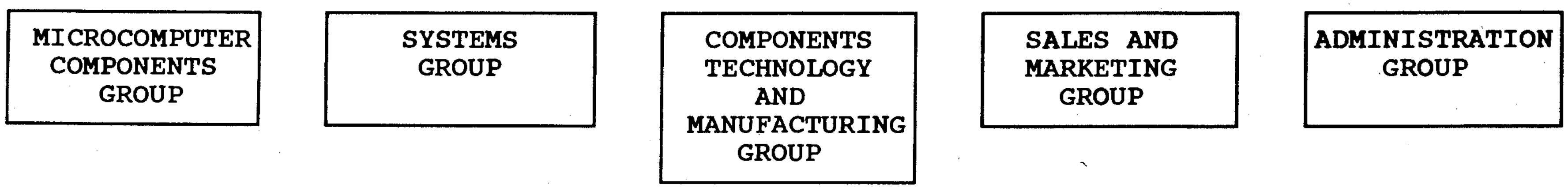


FIGURE 4. ORGANIZATIONAL SCHEMATIC

The Microcomputer Components group's charter is to "be the architectural and technological leader of the Semiconductor Industry. This has been traditionally an area of strength for Intel and the objective is to further enhance the company's position" (10). Providing design engineers with technology tools is one of the key elements for achieving this goal. The company has invested 3 percent of revenue or 27 percent of the Research and Development budget on Electronics Design Automation and tripled staffing in this area since 1985.

Sophisticated computer-aided design tools and simulation help designers utilize previously designed proven parts from past circuits to speed design of new parts. Representation and simulation of a chip helps to identify bugs and get them solved before the chip ever goes to manufacturing. To further shorten the cycle time from product definition to volume production, Intel's design and process engineers work together "from the concept stage to ensure Intel's products are designed with manufacturing in mind" (11). Design for manufacturability means reduced time and cost by eliminating major redesign efforts.

"To be a world class manufacturer" is the charter of the Components Technology and Manufacturing Group. As product complexity continues to rise steadily, so must Intel's efficiency as a manufacturer" (10). Intel manufacturing begins at a prototype organization, called a Technology Development Center, that exists as part of the Components Technology and Manufacturing Group and "is devoted to exploring new manufacturing techniques for producing logic chips. Once the process is perfected, it is transferred to one of Intel's production wafer fabrication facilities" (11). Minor design revisions are made at this stage if necessary.

The existence of this prototype organization ensures that both product and process are manufacturable before transfer to high volume production takes place. Time-to-market has also been reduced using this development production transition strategy. Details of the transfer process from the Technology Development Center to the production wafer fabrication facility cannot be part of this discussion as this information is considered proprietary.

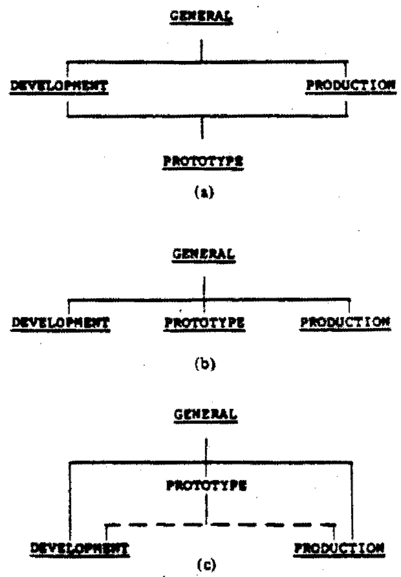
In a business where "time to market" is the difference between success and failure and is often measured in weeks", the strategy is working. "Four years ago, it took the company 64 weeks to take even a relatively simple new chip from conception to profitability. Intel set a goal of getting the time down to 52 weeks for small chips largely through design-and-manufacturing coordination. One member of the 386 chip family made it in 48 weeks. What's more, Intel hadn't even finished the 386 before starting on its next generation model, the 486. Getting the 486 out fast is essential, if Intel is to keep computer designers from defecting to a new technology" (12).

Keeping communication open is another key to making things happen fast. Constructive confrontation is encouraged and taught. "Problems are a normal part of business; they are meant to be solved, not feared or hidden. Dave House, vice president and general manager of the Microcomputer Group, noted in an interview a few years ago: "When a good solid problem is discovered, we study the daylight out of it. How big is it? What color is it? How much does it weigh? Everyone studies, looks, jabbers about the problem and admires it, like putting it on a pedestal. Finally somebody breaks the code, grabs it and stomps it to death. Everybody cheers" (9).

Intel is clearly a technological success, but as much emphasis has been put on management as it has on technology. Dun's Review named Intel one of the five best managed companies in America. In talking about Intel's early days, Gordon Moore, founder and chairman, said "I think we envisioned an environment that would motivate exceptional people to perform consistently at high levels of achievement. We recognized that this would require unusual freedoms in individual decision making and that such freedom would work only in a professionally disciplined atmosphere" (9). "Intel has earned a reputation as a disciplined, hard-driving company" (9). It's also a great place to work.

DISCUSSION:

The existence of the prototype organization at Intel eliminates many of the barriers inherent to the development production transition as shown on Page 3. None of the "This new design isn't yielding enough good units and we can't isolate the problems, even with development on it for months! Our normal products use the same line and come out fine; this one just isn't ready for manufacture!" or "We showed it can meet all specifications, and even make a few runs which yielded working units. Manufacturing must be doing something different from what we instructed, or the line isn't under control" (2) exists. An organization, whose goal is DPT ensures technology continuum. Please refer to Figure 5 (2).



Design for manufacturability is another element of the success of the company with DPT. It is widely understood that cycle times are drastically reduced by avoiding costly redesigns. Also, designers want to begin working on the next technology, not reworking old designs.

Top Management supports and is committed to the DPT process through "design for manufacturability" and the Technology Development centers. The open communication style and structure of the company has consistently provided a good forum for the innovation process, including DPT. Good attitude and high levels of motivation exist throughout the organization because of the founders' approach to management. Each one of these factors contributes to a smooth DPT.

CASE STUDY : PRECISION CASTPARTS CORPORATION

INTRODUCTION

Precision Castparts Corporation (PCC) is comprised of ten separate manufacturing facilities located throughout the United States. Each plant has a different distinct focus in investment casting to support primarily Aerospace and Medical Prosthetic markets. In the Portland, Oregon metropolitan area, PCC has three plants, each employing from 800 to 1200 people, as well as the corporate headquarters. This case study will address the DPT process at the Titanium Business Operation (TBO) plant in Portland.

TBO contracts with Aerospace and Medical Prosthetic companies to produce castings using the investment casting (lost wax) process. These companies supply TBO with finished blueprints and metallurgical requirements for each casting. TBO in turn contracts vendors to construct wax injection tooling after TBO engineers have adjusted for shrinkage and distortion inherent to investment casting. Once complete, manufacturing may begin. (Refer to Appendix B for a brief synopsis of the investment casting process).

TBO, in its seven years of existence, has produced over 500 different casting configurations. TBO's high volume production process is comprised of many diverse product lines, ranging from jet engine fan frames weighing 300 pounds to medical prosthetic components weighing two ounces.

DPT AT TBO

The casting development phase focuses on meeting customer requirements and will normally consist of manufacturing one or more first article castings to prove dimensional conformance and metallurgical quality. Success is determined by the customer because they have the final authority to approve or reject these first article castings. Often times the wax injection tooling or casting process will be changed to correct rejected items, which may result in the need to run second generation first articles. If these second generation castings are also rejected, a third proving cycle may be required for customer approval. This proving process can be very time consuming and detrimental to the project schedule, as well as quite costly to TBO. Once final approval is granted, higher volume production orders can be manufactured. This transition into high volume production defines DPT at TBO. Figure 6 graphically shows TBO's development to production process.

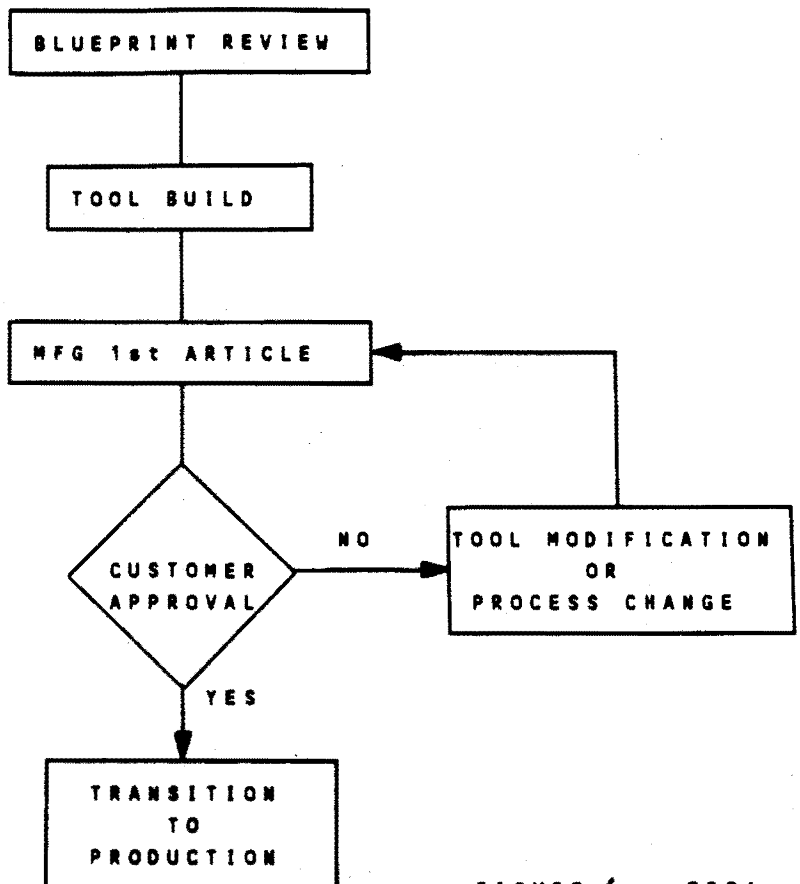
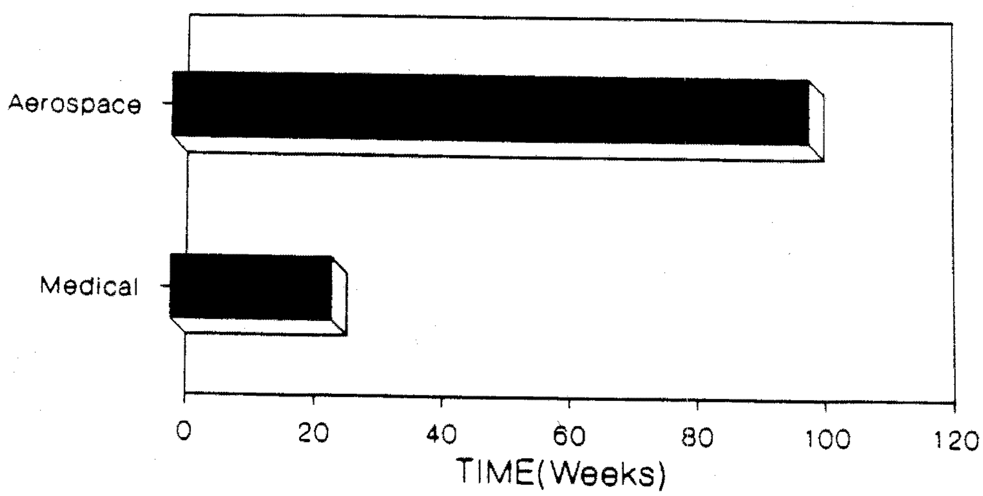


FIGURE 6. TBO's Development to Production process.

TBO's DPT process normally does not require the quick transitions typical of high tech electronics firms. Most of TBO contracts are developmental in nature, in that the customer is developing a new jet engine due for production in three to four years. In contrast, medical customers require a much shorter development phase - typically 20 to 30 weeks as shown in Table 1. While high tech electronics firms face stiff competition, TBO is an industrial leader with much less external competitive pressure.

TABLE 1. Contrasting Development Times Large Aerospace vs. Small Medical Castings.



BACKGROUND

To understand and further discuss DPT at TBO, the organization structure must first be analyzed. TBO is a classical functional organization as shown in Figure 7. Each function is performed by a group independent of the others. As is typical of functional organizations, each functional manager is concerned with the success of his or her own group (2). In addition, TBO's many functional groups have different and overlapping goals and standards determining success. This sets the stage for interdepartmental conflict when specific casting projects must move quickly and efficiently through the organization. Some of the differing functional goals are outlined as follows:

FUNCTION	GOAL/STANDARD
Engineering and Quality Control	Meeting customer dimensional and metallurgical requirements.
Planning and Sales	Meeting customer delivery timelines and quantities.
Investment Casting and Metalworking Operations	Low manufacturing cost.

The functional goals are not clear-cut within the organization. Each person may view the goals, as well the authority and responsibility to meet these goals differently. To highlight this point, a survey was conducted with various members of six key functional groups. The actual survey and results are in Appendix C.

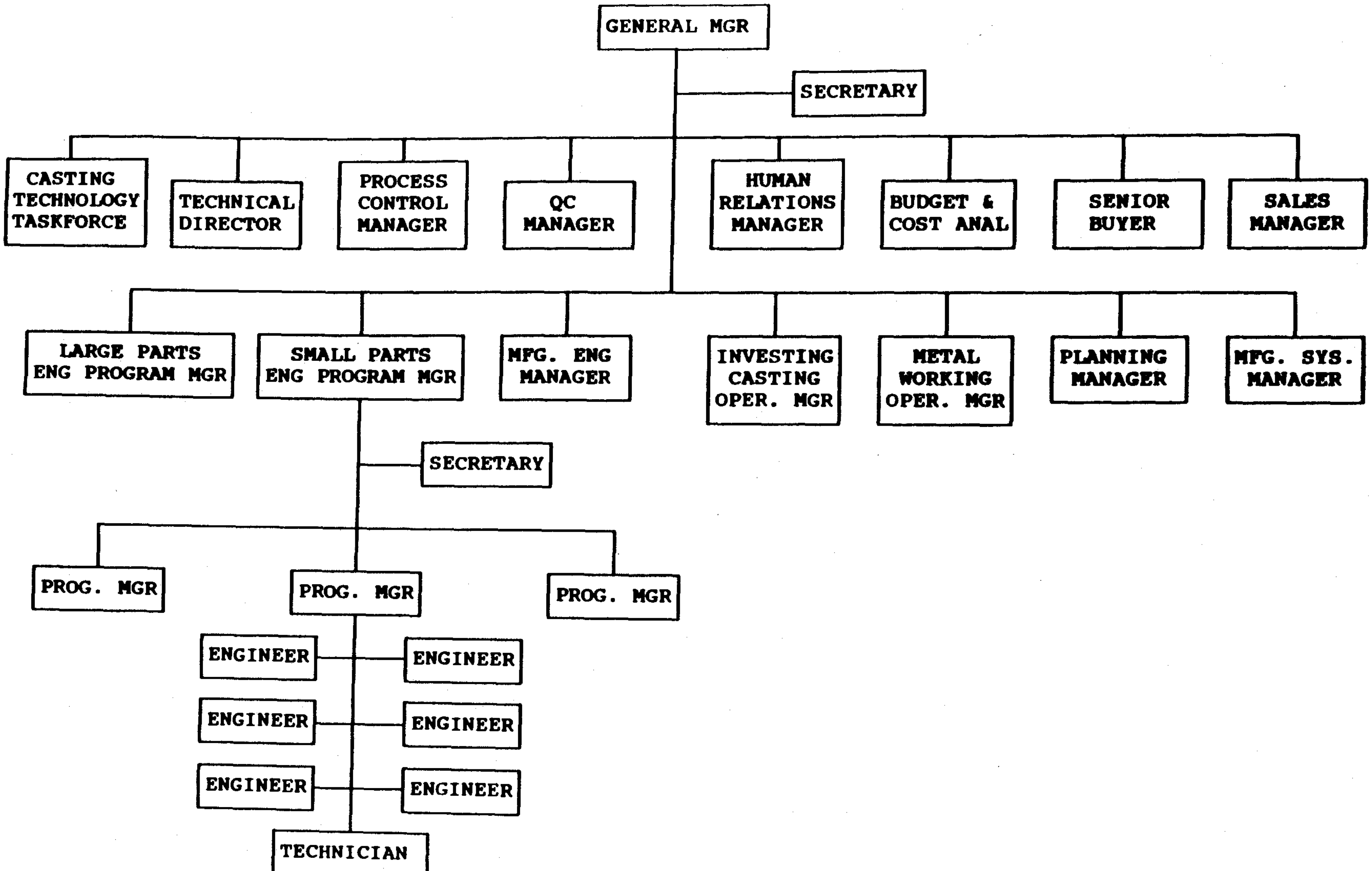


FIGURE 7. TBO's Functional Organization Structure

SURVEY ANALYSIS

In reviewing the survey data, some interesting departmental trends were found: the Planning Department was seen to have more authority than responsibility in both development and production processes, and is focused on on-time delivery. Their high authority and lower responsibility points to their ability to delegate responsibility to other functional departments.

Engineering is also concerned with on-time delivery, but to a lesser degree than Planning. Engineering's responsibility outweighs authority before and after the transition, with greater emphasis on development. Of all the functional groups, Engineering was seen to have more overall authority and responsibility for on-time delivery and customer requirements. This suggests that Engineering is an informal project leader group, yet lacks the authority to act as the leader.

Like Engineering, Metalworking Operations was seen to have more responsibility than authority before and after the transition. However, the greatest emphasis is in the production manufacturing phase, as opposed to Engineering's development emphasis. This is consistent with their departmental goal to reduce manufacturing costs. Once they have learned the specific manufacturing process for a new casting design, they can begin to focus on manufacturing cost reduction and improved efficiency.

Investment Casting Operations were seen as well balanced between authority and responsibility before and after the transition, although they tend to have slightly more responsibility than authority. It appears that this group sees little change before and after DPT.

Sales did not play a key role in the survey. It is assumed that their major role is strictly customer interface with no formal authority and responsibility for meeting the customer requirements for a project.

Quality Engineering was not seen to have much authority and responsibility in meeting the customer requirements. This is surprising since they have the final formal authority to accept or reject castings based on customer dimensional and metallurgical requirements and responsibility to determine whether castings are acceptable to ship to the customer.

These six functional groups were chosen from the 15 total organizational groups because they direct their efforts in manufacturing castings. The other groups are basically support groups to maintain the process, materials, personnel and equipment necessary to support plant operations.

The results of this survey revealed three important points:

1) Authority is not clear-cut,
2) The functional groups have shared responsibility,
3) There is an informal shift in authority and responsibility among some departments during the development - production transition.

With no clear cut authority, the organization vacillates between which functional group possesses the greatest informal authority. While authority competition can be advantageous, organizational vacillation brings about confusion, personality clashes and disputes over control. Also, as a result, other functional groups' delegated responsibility will shift with priorities and workload as determined by the current authoritarian group.

Secondly, shared responsibility also has its drawbacks. As Albita points out: "Sharing responsibility can get the job done, but usually is less effective, resulting in a weaker technical and operations base for manufacturing new products than an independent approach" (2).

Finally, the survey results show an informal shift in authority and responsibility during DPT. It is imperative that this shift be understood by all the functional group members. With so many groups sharing the authority and responsibility to manufacture development and production castings, the roles that each member plays is quite vague. This vagueness and lack of specific responsibility hinders smooth development and production, as well as the transition between the two. According to McGregor's Theory X model on employee behavior: it is human nature to do as little work as possible (1). If a person's role is not clearly defined, they will assume that another functional group member will perform the task and see that the project is completed.

DISCUSSION

A large portion of this case study has focused on the organizational structure and the authority/responsibility roles of each functional group because these are key components of a successful DPT process. TBO's functional organizational structure has the benefits of rapid transfer of knowledge between development and production since the same people within each functional group typically maintain their former responsibilities to some degree. Also, experience gained from one project can be applied to successive programs. In addition, this experience can be easily shared with other members of the same functional group to enhance the technical knowledge base.

On the other hand, this structure has many disadvantages: first and foremost, the functional organization sets up natural barriers to the efficient flow of communication, and communication is the vital link to smooth DPT. Also, as evidenced by the survey, no distinct lines of authority or responsibility are drawn which often results in crucial items being overlooked and a lack of interdepartmental teamwork. This structure may stifle some employees, causing them to only partially utilize their abilities, motivation and creativity (1). As a result, an employee will only want to do the minimum that is required. Since the duties are not clearly defined or understood at TBO, the employee's value to the company is not fully realized and the whole organization suffers. In addition, employees who strive to do a good job can become frustrated. As Shannon points out, "There are three main mechanisms through which the organization can frustrate the mature employee: the formal organizational structure, managerial controls and authoritarian leadership" (1).

To overcome these shortcomings and ensure interdepartmental support for a crucial project, upper management has in the past emphasized a project as a rallying tool to unify the functional groups. Unfortunately, each rally usually ends in short order with each group returning to its old familiar style.

SUGGESTIONS

As discussed above, TBO has a confusing organizational structure with functional lines of authority and responsibility not defined. This confusion in turn inhibits effective DPT on specific projects since no one department has the power to see a project through development and production. This could possibly be overcome with a matrix organizational structure within the existing functional organizational structure. For each substantial project, a project leader forms a team drawn from the various functional groups, providing the focus required during the development and transition stages. The project leader would be the focal point and have the formal authority to run projects efficiently during the development phase, leading to improved communication, project integration and teamwork. Once production is underway, the project team may be disbanded. In short, the functional organization is adequate for TBO's production process and market focus.

Finally, TBO could benefit from a higher plane authority to act as a stabilizing force between functional groups by coordinating, expediting and enhancing communication (1).

CASE STUDY : WESTINGHOUSE HANFORD COMPANY

BACKGROUND AND MAJOR BUSINESS THRUSTS

The Hanford area is a government-owned contractor-operated site which employs about 12,000 people. The site occupies several hundred square miles of desert outside of Richland, Washington. Business areas at Hanford cover a wide range of activities from environmental and biological research, to production of defense isotope materials, advanced nuclear and space power systems testing, and waste recovery/disposal work. As shown in Figure 8, the research and development contractor at the Hanford site is Battelle's Pacific Northwest Laboratory. Operation of reactors, material processing and waste recovery facilities are the responsibility of Westinghouse Hanford Company. The overall organizational structure and large majority of project selection and funding are controlled by the Department of energy (DOE), with regular performance monitoring by the local DOE office. This current organizational separation between development and operations contractors offers an interesting case study of the development to production transition process.

SUMMARY OF TYPICAL TECHNOLOGY TRANSITION PROCESS

The Department of Energy strongly encourages the transfer of government-funded technology and devices to other government entities as well as the private sector. However, in the majority of cases, a technology or device is developed to meet

OVERALL BUSINESS STRUCTURE AT HANFORD

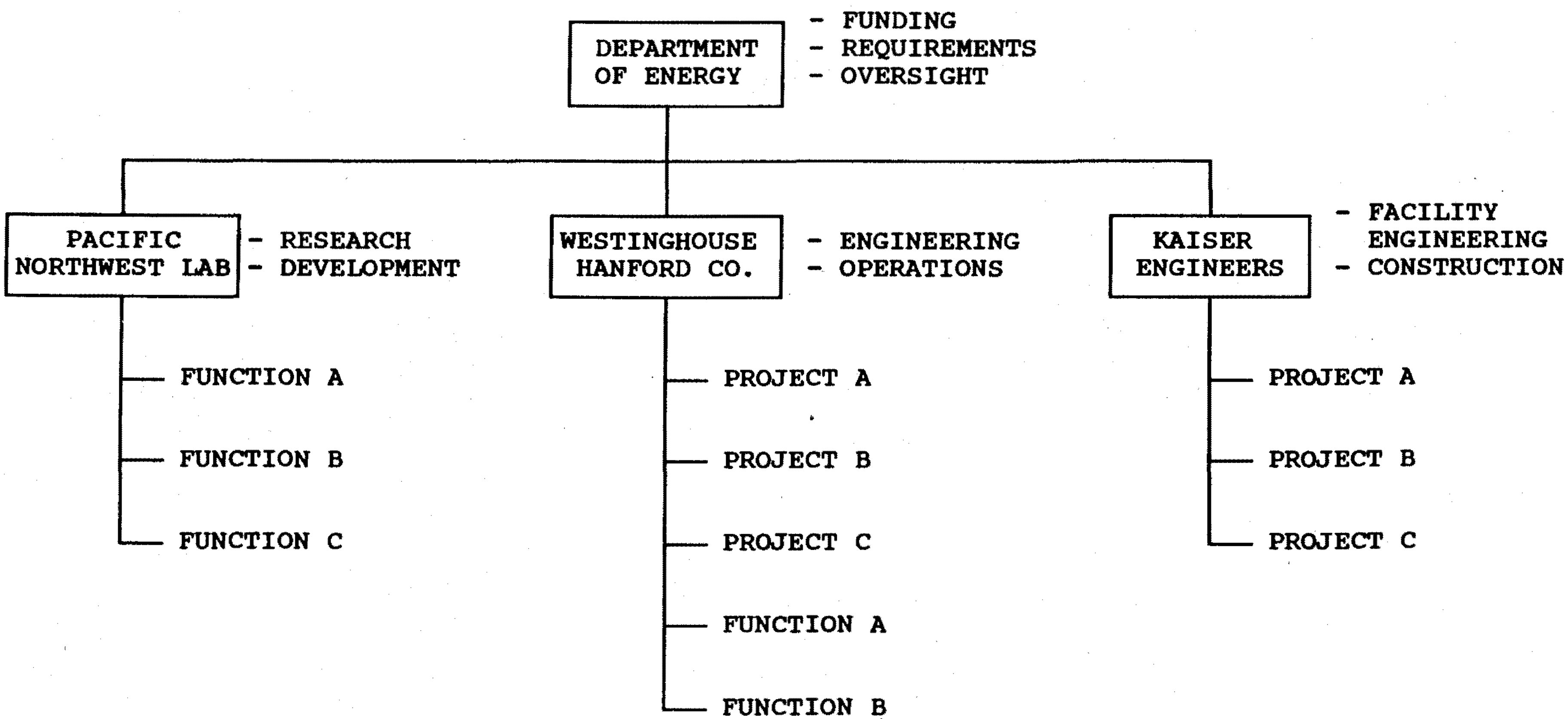


FIGURE 8

a specific DOD or DOE objective and then "retrofitted" for application to industry as opportunities are identified. While transfer of the actual technology can be funded by the government, any further development for application to non-government needs requires funding from the potential user in the private or commercial sector. As part of the DOE's encouragement for technology transfer, license for application of DOE-developed technologies and devices can be granted to sole or limited users in the private sector to encourage their investment. Private industry can also contract with DOE through a "Special Request" to have technology or testing developed and performed to satisfy its own requirements, if this capability is not otherwise available in the private sector.

At Hanford, the transition from development of a technology or device to production applications can be divided into three basic areas as shown in Figure 9.

A) From a government contractor to the private or commercial sector.

B) Across organizations or divisions within a single government contractor.

C) Between different government contractor or entities.

Development/Production Transitions at Hanford

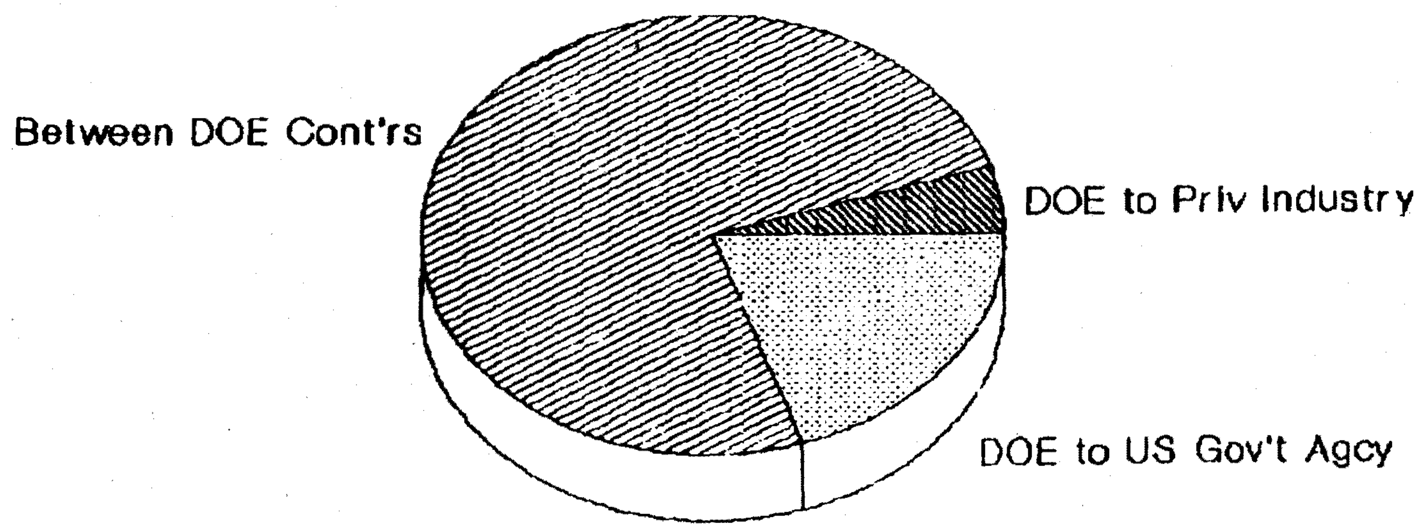


FIGURE 9

DPT FROM THE HANFORD SITE TO THE PRIVATE OR COMMERCIAL SECTOR

Less than 5% of Hanford's total business volume is performed for the private or commercial sector. Prototype products can be developed and produced for external customers upon request. However, since the government cannot compete with private industry and "manufacture" production lots of devices for external customers, a DPT to private industry is often required. The amount of continued government contractor involvement is highly dependent on the complexity of the product, the size of the company which will product it and the expected production volume.

In general, it is quite expensive to do business with DOE contractors so the prospective production company typically desires to "disengage" from the government as soon as possible. Unfortunately, this often means the government contractor does not play a major role on the production transition team, and instead often gets called back in only later, as a "last resort" in crisis situations.

<u>DPT ACROSS ORGANIZATIONS OR WITHIN A SINGLE CONTRACTOR</u>

Transfer of technology or devices within a single contractor is the simplest and therefore usually the easiest form of DPT within the government. This kind of process is usually run like a project, with the production application being the end objective of the work from the beginning. Because everyone works for the same company, the project teams can be close-knit and communication is usually not a problem even when matrix type organizational systems are employed. One of the reasons this is possible is that a single leader is normally selected to manage the project from development to operation of the full production system. This well-focused leadership is also typically supported by a strong upper management commitment, with performance and plans continuously overviewed by the local DOE office.

DPT within a single contractor is also relatively rare at the Hanford site, however, as DOE has purposefully divided R&D operations and constructions activities between the three contractors.

DPT BETWEEN CONTRACTORS AT THE HANFORD SITE

The majority of research and development work at the Hanford site is performed in pursuit of DOE's objectives for use by the government. As previously indicated, Pacific Northwest Laboratory has the charter to perform R&D activities for Hanford. One of its stated corporate objectives (Reference - PNL Business Plan) is to accomplish the transfer of internally developed technology and devices to other government contractors as quickly and efficiently as possible. While there is no set way to perform DPT between PNL and WHC, a project team is usually formed following successful development of the technology or device. This team is typically led by the operations or production people rather than the developers, with the original "developers" retained as consultants. In many cases, PNL continues to be contracted/funded to build the prototype unit for installation, checkout and modification by WHC in a WHC facility. Depending on the size of the production job, the "prototype" unit may become the production unit after this checkout and modification phase, or it may be scaled up and rebuilt by WHC to ensure production reliability. Even in cases where a completely new unit is fabricated, PNL usually stays involved on at least a consultation and review basis.

The relative success of DPT between contractors at Hanford appears to be quite dependent on the size of the project, specific individuals involved, their experience and history of cooperation/teaming across contractor boundaries. The following section describes the transition process for major projects (>$20 million) at WHC.

THE FOUR PHASES OF A PROJECT AT WESTINGHOUSE HANFORD COMPANY

As the Operations contractor for the Hanford Site, WHC manages all the major projects at the site, including their DPT processes. Figure 10 describes the four phases of each major project at WHC: development, readiness, operations and transition (13).

The development phase includes strategic planning and marketing of the project as well as technology development. As previously described, the lead responsibility for technology development activities is most often subcontracted to PNL, with close WHC interaction from project inception to ensure the objectives of the project are met. "Marketing" activities within the development phase are focused on gaining political support and becoming the recognized national leader by the

Four Phases Of Business At WHC

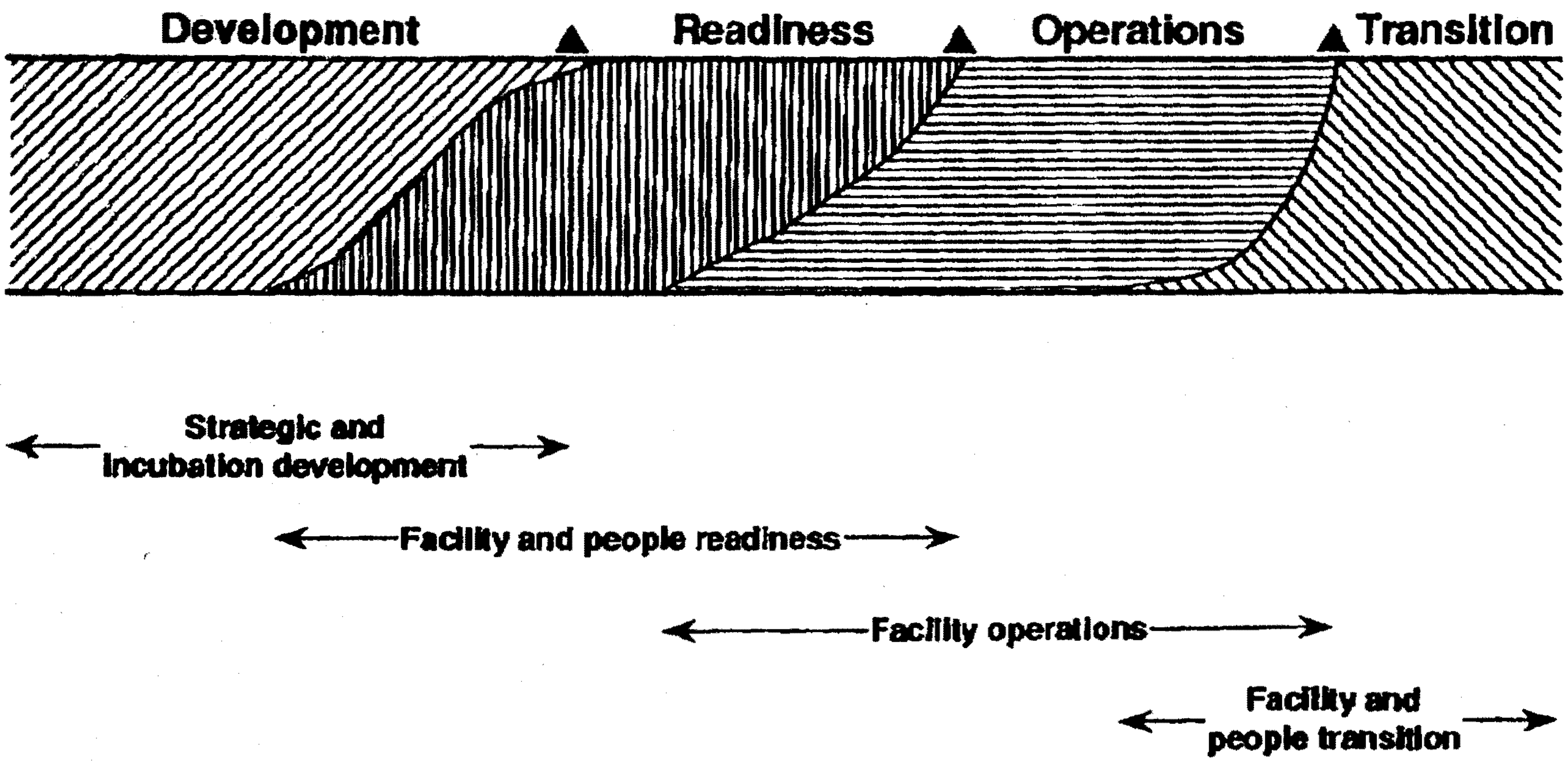


FIGURE 10

Department of Energy and Congress to perform the project. Unlike most other business sectors in the country, any large-scale project at WHC requires several levels of government approval before any funds are appropriated to begin. One of the requirements of performing a major project for DOE is to have an approved Project Management Plan in place which describes in detail the total life cycle plan over the four phases of the project. This plan specifies the organizational framework and relative responsibilities for the project and also includes cost and schedule estimates for all phases. Although DPT is not specifically addressed as such in this plan, the technological transition from R&D is discussed in terms of remaining unknown and risks to the project. In terms of the four project phases, the technological aspects of DPT are envisioned to primarily occur at the overlap between development and readiness phases, although some interaction with the "developer" typically occurs throughout the whole life of the project.

The readiness phase includes design, construction and fabrication of the required facilities and processes, as well as preparation and approval of all required safety and environmental documentation and operating procedures. For chemically or radioactive hazardous materials work, the safety and environmental activities are usually the time-controlling steps for completion of the readiness phase. Depending on the scope of the project, Environmental Assessments and Environmental Impact Statements may take more than two years to prepare and receive the required public and government reviews and approvals. The purpose of the safety and environmental documentation process is to force a detailed evaluation of any potential impacts on the public and environment which could result from both normal and off-normal conditions of the proposed project. Part of this process involves assessments to ensure total compliance with the growing number of state and federal regulations. Over the last two decades, the apparent "bureaucracy" and lack of control over external factors, coupled with swings in national political policy, have caused many major DOE projects to be terminated during the readiness phase.

During the operations phase, the facility is operated to satisfy the government's objectives. This phase continues as long as there is a national need for the "product" and necessary funding is available through congressional appropriation. The objective of the transition phase at the end of the project's life is a controlled shutdown of full facility operation. This phase may include many different stages, such as "hot standby", cold standby", "dry lay-up", etc., depending on national needs. Transition can also include identification of a new mission for an existing facility, as well as transfer of the skilled workforce to another project.

DISCUSSION OF PROJECT PROCESS AT WHC AND RELATIVE IMPORTANCE OF DPT

While the length of each of these four phases and degree of overlap varies from project to project, it seems clear that the readiness phase has undergone the most radical changes over the last two decades. The level of government and public oversight and approval required during this phase has increased dramatically in recent years, to the point where the "paperwork and approval process" has become the rate controlling factor in accomplishing the overall DPT. This is believed to be one of the significant differences between DPT in the private sector and in major projects for DOE. Within DOE, new technology implementation and transition to production now appears to be controlled to a great extent by external factors, due to the numerous reviews and approvals required outside of the company during the early stages of the project. Although the level of scrutiny and continual struggle to retain funding continues through all four phases of WHC projects, the readiness phase is the most critical to the continued life and success of the project. Unlike most new product or process developments in the commercial sector, the ability and total time required for WHC to technically accomplish full scale engineering implementation of some new development is not the most critical success factor. In fact, there are those that would argue the system has become so distorted that the relative incentive and efforts of the contractor to successfully achieve full operation of a new process are significantly lower than the contractor's motives to just maintain funding and support during the readiness phase. Basically, in today's changing political climate, the "life cycle" of the country's objectives and funding to accomplish them is often shorter than the time required to complete the "readiness" phase.

CRITICAL FACTORS FOR SUCCESSFUL DEVELOPMENT TO PRODUCTION TRANSITIONS

The case studies highlighted DPT in three very different distinct industries, and displayed the disparity of DPT definition, emphasis and methods due to the varied products and marketplaces of each company. However, some general DPT critical factors have been revealed from research of available literature, and are applicable to the case studies to varying degrees. The following discussion separates the critical success factors into six major categories:

1) Strategic
2) Technological
3) Operational/Resource
4) Organizational
5) Cultural
6) Environmental

Before further description of these categories, it is useful to note that their relative importance changes over the life of a single transition process, from transition to transition within a given company, and from company to company (14)(15)(16).

STRATEGIC FACTORS - MARKET FIT

Clearly the most important strategic factor in achieving successful production of a new product is how well the product answers a market need. Nearly 90% of respondents in a recent survey indicated that product fit to market needs was key to a product's success (17). As presented in the case studies, Intel possesses a strong market fit due to the high demand for new-improved and more powerful computer chips. Intel is driven by internal technology push and external market pull factors. TBO also, by nature of its business, is in a amiable position. The aerospace market, for instance, is demanding more and more complex light weight titanium alloy castings for military and commercial use. TBO's ability to produce them has created a market niche and a strong market fit. WHC, for the most part, is at the mercy of the federal government, therefore their market fit is determined by primary external factors. Corporate capabilities should be matched to a known market which is based on fact, not emotion. An analysis should be performed prior to start of the DPT to determine market potential, specific target market segments, product life cycle and degree of maturity of the proposed product. A detailed analysis of the competition should also be completed, including competing products, features, relative strength and weaknesses, barriers to market entry, price and the anticipated strategy and tactics of the competition (15)(18)(19). These analyses should lead to an emphasis on product differentiation, detailed sales forecasts in selected market segments, plans for ancillary and next generation products as well as required specifications and target price levels for the proposed new product (5)(20)(21). In Davidow's view, engineering creates great devices but marketing has the real responsibility to create great products (20). The importance of the marketing strategy to product success cannot be over-emphasized. In many industries, especially high technology businesses, the price of the product is dominated by the cost of marketing, rather than manufacturing. Manufacturing technology has succeeded in driving costs down on complex devices to the point where further improvements in this area may not be as important as a clearer focus on efficient sales and marketing operations (20)(22). According to Davidow, the objective of any company in bringing a new product to market should be to "invent complete products and drive them to commanding positions in defensible market segments: (20).

Many products have failed due to false perceptions of market potential (19). Companies must continue to be careful to ensure that some consumer need has not been compromised through changes proposed during DPT to improve manufacturability or other aspects of the new project.

STRATEGIC FACTORS - COMPANY FIT

The product fit to the company's capabilities and objectives is believed to be second in importance to market fit, as supported by 60% of the respondents in a recent survey (17). There is significant evidence that the further a potential new product is from the mainline business of a firm, the greater chance for failure of the product. Radical departures from a firm's mainline business are risky and more costly due to the corresponding changes in operations, new equipment investments, different customer markets and new styles of doing business (7). All three case study companies exemplify the need to excel in a particular market niche and not delve into unfamiliar territory. Intel is a world leader in computer chips, but has not ventured into further computer applications. TBO could potentially profit from machining their raw castings into finished products, but have backed away due to the extreme learning curve inherent to a new manufacturing technique. Furthermore, WHC has found a profitable market as an operations contractor for the Department of Energy. The common motto is "why change a good thing?"

Corporate objectives also generally define the importance of new product development to the firm and provide the framework regarding which new products can be pursued (i.e. inventive, innovative, productivity improvement, market expansion, new technology). Corporate strategy often defines whether the firm will be a market leader, imitator or follower in its field and provides the relative focus between research, development and manufacturing objectives for the firm (6). The corporate strategy regarding new product sales goals, R&D budgets, expected product life cycles and overall financial objectives of the firm also have a significant impact on how DPTs are accomplished (18).

TECHNOLOGICAL FACTORS

Technological factors include the availability of skills, tools and expertise to perform the tasks which are necessary for transition from development of a product to full-scale production. A technical risk assessment should be performed prior to initiation of the DPT process (22). This includes how much new technology must be developed by the firm as well as how much of the available technology the firm has access to and experience with. All three companies presented in the case studies are leaders in their prospective fields due to aggressively pursuing market needs and applying the most advanced technological tools available.

One of the relatively new capabilities available to industry today is computer aided design and computer aided manufacturing (CAD/CAM) equipment. It is widely held that the use of CAD/CAM systems can significantly enhance the DPT process of most firms (23). Possible design changes can be worked as simulations,. allowing problems to be found and avoided much earlier in the production design process. CAD/CAM systems also offer a more disciplined design process, where interfacing systems, design standards and preferred materials and parts can be tracked and verified during design.

OPERATIONAL/RESOURCE FACTORS

The most important operational factors relate to making sure the company has the resources required to achieve success with the proposed new product (19). According to Leiva and Obermayer, a frequently fatal flaw in developing new products is companies undertaking projects far beyond their technical and financial resources (19). The annual and total budget required for the project must be well defined early in the conceptual stages of product development (21). Sufficient budget must be established and committed to the product to accomplish the stages between product definition and full market entry. Further cost escalations must be well controlled. The resources of the company and importance of meeting product entry schedules also have a great effect on the emphasis individual firms place on DPT. Other operational considerations include the importance of meeting interim cost and schedule objectives during the DPT and the impact of this performance on continued company (or customer) support of the project (14).

If a product is critical to the continued health and growth of the firm, then a strong focus on DPT is typical. A good example of this is the high technology industry, where survival depends on continuous introduction and success of new products. The commitment to successful DPT in these types of companies is evident in their dedication of resources, people and corporate structure to perform the task. Very often, several editions of a "prototype" are designed, built and tested prior to production. The idea during the prototype stage is not to alter any functional requirements, but to optimize the quality and manufacturability of the new product and make sure it meets all functional requirements before it goes to production (19)(24). Intel is a model example here as evidenced by their prototype facility to bridge the gap between R&D and full production. They spare no expense to guarantee the best manufacturing process in the quickest possible time frame.

ORGANIZATIONAL FACTORS

Recent studies have emphasized the importance of organizational factors on influencing the technical and commercial success of new products (16). Organizational factors are important both within the project and the overall organization. The size of the overall firm, relative size and importance of each group and the number of projects going on at once are important considerations in DPT. For example, if conflicting priorities between competing projects are expected, then a mechanism or method must be in place to resolve them. Poor cooperation and communication between organizations or lack of clarity and definition of project goals can create serious problems which threaten the product's success (16). The TBO case study highlighted how poor communication inherent to the functional organization structure adversely affected DPT.

Most of the literature on new product development and innovation suggests the need to have the new product group led by a strong leader, reporting to a management level directly responsible for success of new projects (18)(20)(21). In high technology industries, there is evidence that the project transition leader should be production, rather than development, oriented (24). In other industries, the specific background of the person is not seen to be as important as his/her commitment to the project and personal power within the company (14)(18).

Whenever possible, the new product development transition group should be cross-functional, consisting of members from the development, marketing, engineering, operations and quality control disciplines (15)(18)(23)(25). The creation of a "project team" helps break through the natural barriers between these groups and promotes a teamwork environment where ideas and concerns can be integrated and resolved (19). For these reasons, both WHC and Intel have benefitted immensely from these multi-faceted project teams.

Responsibilities and commitments should be clearly identified and agreed upon between management and the transition team members. A formal transition plan, as practiced by Intel and WHC, should be written and updated as needed, with performance reviews held regularly to assess progress against plans (23)(25). The plan should include specific targets for technical, cost and schedule performance (18)(22)(24). The functional requirements of the product should also be written down with subsequent revisions well-controlled and documented (19). Specific functional requirements to be covered include customer serviceability, reliability and performance requirements. Management should have the overall responsibility for planning, coordination and review of performance during the DPT process (8)(16).

Management must also have the ultimate responsibility for managing the technical risks of the project and any necessary tradeoffs in quality, reliability, producibility, cost and schedule.

CULTURAL FACTORS

Cultural factors affecting DPT are derived from the corporate and individual's values within the firm. Companies who value close customer interaction, well-planned product developments and teamwork are more likely to have successful DPT's (8). Individual and group motivational levels, desired degree of control, and reward and "punishment" systems can also affect the success and quality of DPT (18). The degree of management support and commitment to the new product and relative influence of project leaders are believed to significantly impact the potential for a smooth DPT (14)(20). Flexibility or adaptability of organizations and individuals within the firm is also believed to be a key factor in successful DPT's (18). One of the most significant challenges of any DPT is good communication and cooperation between team members. Good, open communication is essential to accomplish integration and teamwork between the developers, various functional areas, and the production people (16). Organizational factors can promote or discourage inter-group communication and teamwork, but the overall culture of the company may have a more significant impact on success in these areas (15). Intel's case study presents a prime example of a culture created specifically to perform DPT's smoothly and quickly to meet short time-to-market objectives. TBO's culture is focused more on customer satisfaction at the expense of a smooth transition.

ENVIRONMENTAL FACTORS

Environmental factors include those items that are important to new product success but are not under the control of the firm that is developing the new product. Government regulations, politics, effect of outside interest groups, patents, standards and other factors are included in this group. Both known and potential environmental factors should be understood, analyzed and documented as part of the marketing, business and transition planning process both prior and during the DPT. Potential problems and barriers to full-scale market entry should be anticipated and bounded. "If - then" scenarios should be developed wherever possible so management can identify and agree on courses of action if certain external factors present themselves. These scenarios should also include a clear understanding of conditions where the project would be terminated or put on hold. The Westinghouse Hanford Company is especially vulnerable to environmental factors due to their very long projects and direct government support.

In addition, the often volatile nuclear industry can be devastated by ever-changing public sentiment, as evidenced by strong support during the energy shortage in the early seventies to resentment following the Three Mile Island incident.

The technological environment and degree of development of the technological infrastructure also must be understood when developing a DPT strategy (6). As products become more complex and sophisticated, they are increasingly built upon layers of existing technical and scientific knowledge that become the infrastructure for the industry. In many industries, as this infrastructure becomes more highly developed, the non-technological aspects become more critical to product success (17).

CONCLUSION:

This paper has defined and emphasized the importance of a smooth development-to-production transition in high technology firms. Shorter product life cycles, rapidly changing technology, increased R&D expenses and fewer successful products reaching the marketplace have made a successful transition to production critical.

The three case studies highlight practical applications of the DPT process as theorized in the available literature. From this information, six critical factors have been found and compared with the three cases. Although some generalities are common to all cases, it would be naive to use these findings to synthesize into a single successful DPT method for all companies. In fact, the cases underscore the individual nature of DPT.

This report is intended to provide a beneficial framework for analysis of a firm's relative strengths and weaknesses of the DPT process. Identifying and understanding the critical factors prior to entering the transition phase provides an opportunity to change, add or control those aspects not typically associated with successful DPT's.