SCHEDULING AND RESOURCE ALLOCATION METHODOLOGIES FOR FAST PRODUCT DEVELOPMENT IN A MULTI-PRODUCT ENVIRONMENT

by

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ABSTRACT

Companies that develop products quickly gain many advantages over their competitors: premium prices, valuable market information, leadership reputations with consumers, lower development costs, and accelerated learning. A common characteristic of these companies is a rigorous and disciplined approach to the process of developing products. This research effort analyzes the process of product development at two companies and addresses three opportunities for faster development:

- new scheduling tools and processes at the project team level,
- new analytical techniques to manage inter-schedule conflicts between different product development efforts for finite resources, and
- management's ability to speed the necessary organization and process changes.

An analytical framework for scheduling product development is reported to capitalize on the first opportunity above. The critical path methodology is modified to allow and encourage overlap between successive development activities. A generic product development schedule is created for use across the organization. Task durations and overlap are estimated based on specific project characteristics. Schedules are more reliable and considerably shorter as a result of this systematic and rigorous approach to scheduling.

A new approach relying on queueing network theory is proposed to account for delays in development caused by conflicts among projects for resources. An analytical framework of human, capital, and administrative resources is constructed. Preliminary data for one department is collected and reported. The analysis identifies the resources that seem to be the bottlenecks causing the most schedule slippage in the department. Additional data is required to fully build and qualify the queueing network model. The queueing approach suggests that companies should provide *slack* development resources to reduce product development cycle times.

The implementation of a more disciplined approach to product development is described in a case study format. Employees representing a diagonal slice of the company are interviewed to support the case. The case is analyzed using organizational development tools. The analysis highlights management's crucial role in the implementation stage to recognize and reward successful change. Specific change levers such as corporate goals and incentive systems are proposed to facilitate the change process.

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Polaroid Corporation provided easy access to both people and information. The company thesis supervisor, my mentor, and friend, Walter Byron, opened many doors for me, and taught me a great deal about management, leadership, organizational politics, and change. My steering committee, Dick Collette, Frank Cusack, Peter Scibilia, Keith Shoneman, and Fred Slavitter religiously attended our bi-weekly meetings and ensured I was headed in the right direction. The analysis of the product engineering department would have been impossible without the help of Don Francis, Diego Bettancourt, and Bill Olson. Lih Lih Chang and Carole Uhrich helped me understand the process of product development at Polaroid. Carol Bruno and Joe Kasabula were always willing to provide a helpful hand, and kept me sane on a daily basis. Bill McDonough at Motorola Codex graciously shared his insights into fast product development. John Chap and Jane Allen honestly conveyed their successes and challenges at Bellex Corporation. Many others at Polaroid and Bellex opened their doors to me. I thank you all for being so attentive and candid.

The author also wishes to acknowledge the Leaders for Manufacturing program for its support of this work. The program has been everything it promised to be and more. I look forward to significantly impacting North American manufacturing competitiveness.

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to continue these efforts. Professors Schein and Van Maanen provided helpful feedback on the Bellex case study and its analysis.

Finally, most important of all, I want to thank my wife for her unending encouragement and support through this process. In the end, her PhT is worth far more than a few Masters degrees. I am forever grateful. This thesis is dedicated to Roberta.

TABLE OF CONTENTS

INTRODUCTION

Time to market has emerged as a critical strategic dimension in the nineties. Increased global competition and an increasing rate of innovation have created shorter product life cycles. Shorter life cycles have decreased the window of opportunity for product introductions and increased the risk of introducing products that quickly obsolesce. Competing on time is becoming as important as competing on cost or quality.

While industry dynamics seem to necessitate shorter development cycles, there are also external benefits to being the industry leader in this dimension. Time to market leaders command premium prices and establish market share.[1] The latest technologies can be incorporated in new products and customer needs can be more accurately forecast.

A company can also realize significant internal benefits: decreased development costs, accelerated learning, less waste in development rework, and improved information flows across functions and product areas. The risk of rushing to market is that the product does not fully satisfy customer needs, leaving the door open to followers that do. As life cycles decline, however, the follower strategy becomes much less viable.

This thesis is based on a seven month internship sponsored by Polaroid Corporation in conjunction with the Leaders for Manufacturing program at MIT. Polaroid is aggressively adopting many leading edge changes in order to become a World Class company. In the spirit of Total Quality, Polaroid is examining various processes and how to improve its own change processes. This thesis describes and contributes to elements of this renewal and the self-examination and continuous improvement efforts concerned with product development at Polaroid.

Through a process of benchmarking, Polaroid has recognized a need to shorten its development cycle. A cross-functional group was commissioned to examine internal opportunities to cut lead time out of product development. Our research led us to focus on scheduling issues. Specifically we identified the following issues:

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[1] Stalk, George, and Hout, Thomas M., *Competing against time: How time-based competition is reshaping global markets*, New York, NY: The Free Press, 1990.

- a lack of appropriate scheduling skills, tools, and historic data at the project team level,
- difficulty meeting agreed upon schedules,
- failure to take time out of schedules, and
- conflicts among projects for finite development resources.

The thesis can be divided into three sections which attempt to take advantage of these opportunities to improve time to market performance. The first section (Chapter 3) describes a modified critical path method (CPM) to address the first three issues above. The second section (Chapters 4 through 7) outlines a new approach to account for conflicts among projects for finite resources using queueing network theory, the fourth issue above. The third section analyzes the implementation of a new product development process at a company called Bellex. The focus of this case is management's role in the change process.

Modified Critical Path Method

An analytic framework is constructed to analyze and improve product development at Polaroid. The process of product development is codified into overlapping phases, steps, and tasks. Task durations and the overlap with successive tasks are estimated based on specific project criteria. The result is a matrix of schedules for all the products a company develops. The schedules serve as a realistic benchmark for time to market performance, and a framework for comparison and systematic improvement of the process. The primary contribution of this modification of CPM is to focus attention on two interrelated categories of time: task duration and task overlap.

The analytic framework has been built with a team of company employees. The data to support the scheduling matrix, however, was not available. Future work will attempt to fully implement this methodology at the sponsor company.

Queueing Network Theory Applied to Product Development

A second related problem in product development scheduling is competition among projects for a company's finite resources. Since the advent of CPM and PERT, companies and academics have wrestled with this shortcoming. Various simulation and enumerative methods have been proposed, although they typically require a great deal of analysis to be implemented.

This thesis proposes another approach to this problem based on emerging approximations for fork-join queueing networks. The approach attempts to account for both finite resources, and the stochastic nature of product development. Development projects correspond to the "jobs" arriving at specific "resources" (e.g., mechanical engineers) for processing. An analytic framework is constructed and initial data is collected from one department. This data seems to support the formation of queues in the department. Additional data is being collected, in a follow-on project, to fully qualify the model.

Case Study on Implementing a Time-based Strategy

Time-based strategy and related total quality literature emphasize that companies, managers, and employees all have to change the way they do business. Doing the same things faster does not capitalize on the largest opportunities to take time out of the development cycle. The necessary corporate overhaul requires fundamental changes in processes and organizational culture.

Frequently companies encounter difficulties in the implementation of a time-based strategy versus its design. Organizational resistance, the lack of the proper implementation sequence, and ineffective or uncommitted leadership compromise many efforts.

The final section in this thesis presents a case study at Bellex Corporation (a disguised name) that analyzes the design and implementation of a new process to improve time to market performance. Numerous employees from management, manufacturing, marketing, and research and development were interviewed to support the case, and offered a variety of suggestions to improve the change process. The crucial role of top management as a change agent is emphasized.

The work in this thesis marks the beginning of a major undertaking at Polaroid to significantly reduce its time to market. Success has been realized as a result of the approaches mentioned above and through many other efforts initiated by the company. All those that contributed to this research agree however that, in the spirit of continuous improvement, significant additional opportunities exist. This will be the subject of a follow-on Leaders for Manufacturing project at Polaroid.

CHAPTER 1: SURVEY OF RELEVANT LITERATURE

Research in methods to reduce time to market (TTM) has been relatively scarce until very recently. One reason for this deficiency is the difficulty of comparing development cycle times across different industries. What works in one industry may not be transferable to another. In addition, research in new product development has often been a risky endeavor for junior faculty. The subject cuts across a wide range of academic boundaries, and therefore does not generate the support needed within any one discipline. As a result, many problem definitions have been too narrow to be of much use.

This section surveys a number of related fields for relevant literature to reduce time to market: the popular business press (magazines and books), the management fields (marketing, manufacturing, strategy, management of technology, operations research, operations management, and organizational behavior), and the engineering disciplines. The purpose of this survey is not to summarize the important contributions to this field of thought. Instead we hope to provide a useful roadmap for interested academics and practitioners to help understand the multiple facets of product development and begin integrating the learning that has occurred in different disciplines.

A thorough review of this literature indicates the following general principles, structures, tools, and skills that seem to speed product development:

1) Cross-functional and co-located teams
2) Parallel versus sequential product development
3) Matrix or biased-matrix organizational structures
4) Market-driven development
5) Early vendor involvement and suppliers as designers
6) Evolutionary versus revolutionary technical development
7) Inventions completed off-line
8) Rigorous concept selection and planning in the early development stages

9) An ability to adopt new technologies (e.g., CAD/CAM and stereolithography)
10) A product development strategy
11) Design for manufacturing and assembly, and
12) Multiple competing new product development teams.

Essentially all academics and product development practitioners agree that a cross-functional product development team contributes to superior time to market performance, the quality of design, and lower product costs.[2] Cross-functional teams have replaced a more functional approach in which each team relinquishes project responsibility to a down-stream function (e.g., the engineering team hands-off to the manufacturing team). This new paradigm requires frequent communication between functions represented on the team. Co-location greatly facilitates this process.[3] Henderson and Clark have argued that cross-functional teams avoid missing major architectural changes in product design.[4]

Parallel development is consistent with this new paradigm.[5] Market planning and research, and product and process design occur simultaneously to reduce time to market and enhance information flows between functions.

Organization of the team, and specifically, the power of its leader is critical to development success. Hayes, Clark and Wheelwright find that teams with a Heavyweight Project Manager of a Tiger Team organization

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2 A representative sample includes: Larson, Erik W. and Gobeli, David H.,"Organizing for Product Development Projects," *Journal of Product Innovation Management*, 1988:5:180-190; Hirotaka Takeuchi and Ikujiro Nonaka, "The new new product development game", *Harvard Business Review*, Jan-Feb. 1986; Don Clausing, "Concurrent Engineering," *Proceedings of the Design and Productivity International Conference*, Honolulu, HI, Feb. 1991.

3 See "Research Laboratory Architecture and the Structuring of Communication" in *R&D Management*, Vol. 5, N2, 1975 by T.J. Allen and A.R. Fustfeld for this landmark study on the effect of distance on communication patterns.

4 Henderson, Rebecca M., and Clark, Kim B., "Innovation and the Failure of Established Firms," *MIT Management* , Fall 1990.

5 See Clausing op cit.; Preston G. Smith, "Fast-Cycle Product Development," *Engineering Management Journal*, Vol. 2 No. 2 June 1990; or Robert H. Hayes, Steven C. Wheelwright, and Kim B. Clark, *Dynamic Manufacturing: Creating the Learning Organization*, The Free Press, New York, 1988, Chapters 10 & 11.

tend to exhibit the best time to market performance.[6] Separately, the research of Larson and Gobeli found balanced-matrix or project matrix teams to perform best.[7] Project matrix refers to an arrangement in which the project manager has direct authority to make decisions about personnel and work-flow activities. In a balanced-matrix the project manager shares responsibility and authority with the functional managers.

Market-driven, as opposed to technology-driven development is characteristic of most successful development projects. Cooper assembled empirical evidence of this relationship.[8] Braham chronicles the need for engineering and manufacturing to be active in market research activities.[9]

Clark's studies of the automobile industry have focused on the new relationship between suppliers and buyers in the development process. The most effective development teams involve suppliers in the early stages of development, and frequently rely on suppliers for a large portion of the sub-system design.[10]

Just as continuous improvement is a vital characteristics of the best manufacturing systems, evolutionary technology development seems to provide the best product development results.[11] An evolutionary approach to technology gets products to market faster, provides valuable customer feedback for future development directions, and is much less risky as life-cycles shorten.

Completing inventions off-line is consistent with this approach. The high degree of variability in the time to complete an "invention" does not justify the high cost of a product development team running concurrently.[12] Clausing and Pugh discuss the importance of a rigorous concept selection

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6 Op cit. pg. 302.

7 Op cit.

8 Cooper, Robert G., "The New Product Process: A Decision Guide for Management," *Journal of Marketing Management*, Spring 1988, Vol. 3 No.3, pg. 238.

9 Braham, James, "The Marriage of Marketing and Manufacturing," *Industry Week*, June 1, 1987, pg. 41.

10 Clark, Kim B., and Fujimoto, Takahiro, "Product Development in the World Auto Industry: Strategy, Organization, and Performance," Working Paper, Harvard Business School 1988.

11 Hayes, Wheelwright, and Clark op cit. pg. 339.

12 Clausing, op cit.

process to ensure the best concept is chosen in the early design phases.[13] Hayes, Wheelwright and Clark support a funnelling approach to product development. A wide range of product and process concepts are supported (the mouth of the funnel) in the earliest stages by soliciting creative inputs from a variety of sources. Management then screens these opportunities (the neck of the funnel) so that resources are only committed to the most attractive opportunities.[14]

Firms need to have the capability to adopt new technologies that speed development.[15] CAD/CAM, stereolithography, finite element analysis, and CASE tools are just some of the technologies that significantly impact development cycles.

Hayes, Wheelwright, and Clark suggest that a product development strategy should be integrated with other aspects of the firm's strategy.[16] Crawford found that a charter for product innovation was characteristic of the most successful development firms.[17]

Design for manufacturing and assembly has been popularized by Boothroyd and Dewhurst.[18] Design decisions have a large impact on the manufacturability of a part and its subsequent cost and quality performance. Often slight modification early in the design process can significantly reduce problems in the manufacturing phase of development.

Finally, a less popular but nonetheless compelling strategy for product development management is to establish competing teams in the early stages of development to speed organizational learning.[19] This

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13 Clausing, Don and Pugh, Stuart, "Enhanced Quality Function Deployment," *Proceedings of the Design and Productivity International Conference*, Honolulu, HI, Feb. 1991.

14 Hayes, Wheelwright, and Clark, op cit. pg 296.

15 This characteristic is often implied in many articles. Dr. William Sheeran, Vice President of the Technology Division of GE Appliances discussed this capability in a speech at the Product Development and Management Association's "Speed Conference" on September 25, 1990 in New York.

16 Op cit. pp. 332-335.

17 Crawford, C. Merle, "Defining the Charter for Product Innovation," *Sloan Management Review*, Fall, 1980.

18 Boothroyd, G. and Dewhurst, P., *Product Design for Assembly*, Wakefield, RI: Boothroyd Dewhurst Inc., 1987.

19 Nonaka, Ikujiro, "Redundant, Overlapping Organization: A Japanese Approach to Managing the Innovation Process," *California management Review*, Vol. 32, No. 3, Spring 1990.

redundancy, properly managed, contributes to a more creative and robust design, and faster development cycles.

Popular Business Press

There is a wave of books and articles being released on time-based competition. Time-based competition includes faster development cycles, production cycles, and indeed faster cycle time throughout all the functions of a corporation.

Fortune ran one of the earliest articles on the subject.[20] Stalk and Hout[21] recently published a book summarizing their work with numerous Boston Consulting Group clients. Blackburn sees time-based competition as a logical extension of just-in-time production practises to other parts of the business.[22] Ciampa discusses the CEO's role in time-based competition in the same book. Smith and Reinertsen[23] will release a book which focuses on some tools to hasten product development.

Management Research

Hayes, Wheelwright, and Clark reported the results of a number of on-going studies in their book *Dynamic Manufacturing*.[24] They suggest that a new paradigm of product development is necessary to significantly reduce cycle time. The paradigm is based on four principles:

1. Technical development is evolutionary; progress occurs in small steps.
2 A close interaction between commercial needs and work in the laboratory is essential.
3. Product innovation and process innovation are intimately related; internal development of equipment is imperative for success.

20 "Speeding New Products to Market," *Fortune*, March 2, 1987, pp. 62-66.

21 Op cit.

22 Blackburn, Joseph D. et al, *Time-Based Competition: The Next Battleground in American Manufacturing*, Business One Irwin, Homewood, Illinois, 1990.

23 Smith, Preston G. and Reinertsen, Donald G., *Developing Products in Half the Time*, Florence, KY: Van Nostrand Reinhold, 1991.

24 Op cit., Chapters 10 & 11

4. Progress occurs through organized effort and team work; collaboration across functional boundaries is critical.[25]

Gupta and Wilemon[26] provide an extensive review of available literature. They surveyed managers from 12 high technology companies to determine why product development delays occur, the nature of these delays, and what can be done to avoid them. Cardonne organized specific methods of cycle-time reduction into human, organizational, technological, and strategic accelerators.[27]

Organizational Structure

Organizational structure has been a primary focus of many studies. Larson and Gobeli[28] surveyed managers from 540 development projects and summarized the conflicting results of earlier research. Project management structures were characterized as functional, functional matrix, balanced matrix, project matrix, and project team. The *functional* project is divided into segments and assigned to relevant functional groups within functional areas. The project is coordinated by functional and upper levels of management. Within *functional matrix* projects, a project manager with limited authority is designated to coordinate the project across different functional areas. The functional managers retain responsibility and authority for their specific segments of the project. A *balanced matrix* approach assigns a project manager to oversee the project and shares responsibility and authority for completing the project with functional managers. Project and functional managers jointly direct many work-flow segments and jointly approve many decisions. In a *project matrix*, a project manager has primary responsibility and authority for completing the project. Functional managers assign personnel as needed to provide technical expertise. Finally in the *project team*, a project manager is put in charge of a project team composed of a core group of

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25 Hayes et al., op cit, pg. 339.

26 Gupta, Ashok K. and Wilemon, David L., "Accelerating the Development of Technology-Based New Products," *California Management Review*, Vol. 22:2, Winter 1990.

27 Cardonne, Raymond A., Jr., "Accelerating the New Product Development Life Cycle: Using Time as a Strategic Weapon," Lehigh University Master's Thesis, 1989.

28 Larson, Erik W. and Gobeli, David H.,"Organizing for Product Development Projects," *Journal of Product Innovation Management*, 1988:5:180-190.

personnel from several functional areas assigned on a full-time basis. The functional managers have no formal involvement.

The Larson and Gobeli study indicated that both the balanced matrix and project matrix structures compared favorably with project teams in terms of cost, schedule, and technical performance. This result contradicts the conclusion drawn by Peters and Waterman[29] that project teams are superior to matrix structures for developing new products and services. Larson and Gobeli hypothesize that Peters and Waterman may have used a biased sample in their survey (i.e., only successful companies with extensive resources) and that they did not distinguish between different types of matrix structures.

Clark, Chew and Fujimoto[30] studied 29 auto companies in Europe, the U.S. and Japan. Development teams with heavy-weight project managers had significantly lower development costs (engineering hours) but only moderately shorter lead times. Functionally organized teams performed the worst and teams with light-weight project managers were in the middle. Clark et al. found that while the organizational structure had a significant effect, performance was best explained by a new paradigm of product development which included a high degree of dialogue communication (versus batch communication) and a high degree of overlapping problem solving or parallel development.

Additional formal research in this area has been inconclusive and sometimes contradictory. Cory and Starr,[31] Rubenstein et al.,[32] Marquis and Straight,[33] Katz and Allen,[34] and Keller[35] have conducted much of this

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29 Peters, Thomas J. and Waterman, Robert H., *In Search of Excellence*, New York: Harper & Row, 1982.

30 Clark, Kim B., Chew, W. Bruce, and Fujimoto, Takahiro, "Product Development in the World Auto Industry: Strategy, Organization, and Performance," Harvard Business School Working Paper, 1988, page 30.

31 Corey, E. R. and Starr, S.A., *Organization Strategy: A Marketing Approach*, Boston: Harvard University, 1971.

32 Rubenstein, A. H., Chakrabarti, A. K., O'Keefe, R. D., Souder, R. D. and Young, H. C., "Factors influencing innovation success at the project level," *Research Management*, 19(3):15-20, May 1976.

33 Marquis, Edward F. and Straight, D. M., *Organizational Factors in Project Performance*, Washington, DC: National Aeronautics and Space Administration, 1965.

research. While researchers continue to argue over the effectiveness of matrix, biased-matrix, and strong project leadership structures, very few argue that a functional organization results in faster development cycles.

Marketing

A great deal of research and literature has come out of the marketing field. Important texts include Cooper,[36] Kuczmarski,[37] Souder,[38] and Urban and Hauser.[39] The importance of market-driven product development is typically emphasized in these texts.

Manufacturing

The manufacturing field has also contributed to thought in this area. A representative sample includes Ettlie and Reifeis,[40] Hagel,[41] Stoll,[42] Whitney,[43] Boothroyd and Dewhurst,[44] and Rosenthal and Tatikonda.[45]

Research in this area has focused on design for manufacturability and the impact of many early design decisions on the product cost and quality. Across many industries there is growing evidence to indicate that

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34 Katz, Ralph and Allen, Thomas J.,, "Project performance and the locus of influence in the R&D matrix," *Academy of Management Journal*, 28(1):67-87, March 1985.

35 Keller, Robert T., "Predictors of the performance of project groups in R&D organizations," *Academy of Management Journal*, 29(4):715-726, December 1986.

36 Cooper, Robert G., *Winning at New Products*, Reading, MA: Addison Wesley, 1986.

37 Kuczmarski, Thomas D., *Managing New Products*, Englewood Cliffs, NJ: Prentice Hall, 1988.

38 Souder, William E., *Managing New Product Innovations*, Lexington, MA: Lexington Books, 1987.

39 Urban, Glen L. and Hauser, John R., *Design and Marketing of New Products*, Englewood Cliffs, NJ: Prentice-Hall, 1980.

40 Ettlie, John E., and Reifeis, Stacy A., "Integrating Design and Manufacturing to Deploy Advanced Manufacturing Technology," *Interfaces*, 17:6, Nov/Dec 1987, pp. 63-74.

41 Hagel, John, "Managing Complexity," *McKinsey Quarterly*, Spring 1988, pp. 2-23.

42 Stoll, Henry, "Design for Manufacturing," *Manufacturing Engineering*, January 1988, pp. 68-73.

43 Whitney, Daniel E., "Manufacturing by Design," *Harvard Business Review*, July/August 1988, pp.83-91.

44 Op cit.

45 Rosenthal, Stephen R. and Tatikonda, Mohan V., "Managing the Time Dimension in the New Product Development Cycle," Boston University Manufacturing Roundtable Series, August 1990.

85% of the life cycle costs for a product are determined in the first 15% of the cycle time.[46]

Engineering Research

Numerous academics have studied concurrent engineering and organizational barriers to faster development cycles. Clausing,[47] Nevins and Whitney,[48] and Liker and Hancock[49] provide useful examples.

Quality Function Deployment (QFD) has been recognized as one of the useful tools for quickly translating marketing needs into a product. Clausing and Pugh discuss an enhanced version of QFD that includes rigorous and systematic concept selection.[50] However, Griffin studied the effect of QFD at thirty-five American companies and found a negligible effect on development cycle time.[51] Hauser and Clausing[52] reported a tool named the House of Quality used by Toyota in Japan.

Suh[53] has proposed two axioms which lead to optimal designs. Black, Fine, and Sachs[54] applied a useful tool (the design structure matrix) to help organize complex design tasks (discussed in a later section). Ebert, Majerus, Rude[55] provide a survey of design principles.

Numerous technologies are being applied to speed product development including CAD, CAE, CAM, CIM, CASE, stereolithography,

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46 Nevins, James L, and Daniel E. Whitney, *Concurrent Design of Products and Processes: a strategy for the next generation in manufacturing*, New York: McGraw Hill,1989.

47 Clausing, Don, "Concurrent Engineering," Proceedings of the Design and Productivity International Conference, Honolulu, Hawaii, Feb., 1991 and

48 Op cit.

49 Liker, Jeffrey and Hancock, Walton, "Organizational Systems Barriers to Engineering Effectiveness," *IEEE Transactions on Engineering Management*, May 1986, pp. 82-91.

50 Op cit.

51 Griffin, Abbie, PhD Dissertation, University of Chicago, 1988.

52 Hauser, John R. and Clausing, Don, "House of Quality," *Harvard Business Review*, May-June 1988, No. 3, pp.63-73.

53 Suh, Nam P., *The Principles of Design*, Oxford University Press, New York, 1990.

54 Black, Thomas A., Fine, Charles H., and Sachs, Emanuel, "A Method for Systems Design Using Precedence Relationships: An Application to Automotive Brake Systems," Leaders for Manufacturing Program, MIT, Cambridge, Mass, 1990.

55 Ebert, Ronald, Majerus, Clyde, Rude, Dale, "Product Development: Assessing the Consistency of Engineering Design Policies," *IEEE Transactions on Engineering Management*, May 1989, pp. 140-146.

electronic mail, project management software, word processing, computer simulation, and finite element analysis.

CAD, CAE, computer simulation, and finite element analysis are powerful because one can simulate product performance and optimize design. Stereolithography and CAD/CAM help reduce the time to produce a prototype and often avoid numerous prototyping iterations due to errors. Some companies use electronic mail and various other communication devices to simulate co-location of development teams. Electronic data interchange facilitates a coordinated development effort between suppliers and buyers. Research into common product database structures, primarily being undertaken in Europe, will allow groups in different areas to concurrently develop the same product.

CHAPTER 2: RESEARCH METHODOLOGY

This chapter describes research activities undertaken over a seven month period as part of an internship at Polaroid Corporation. The focus of the effort was to address specific time to market issues at Polaroid. The internship can be divided into six parts, roughly corresponding to the distinct phases of the research:

- Formation of a Cross-functional Team
- KJ Analysis to Speed Problem Identification
- Benchmarking to Identify Best Practice
- Modified Critical Path Analysis
- Queueing Network Analysis of Product Engineering
- Case Study Analysis of Bellex Corporation

Figure 2.1 provides a timeline description of the research progress.

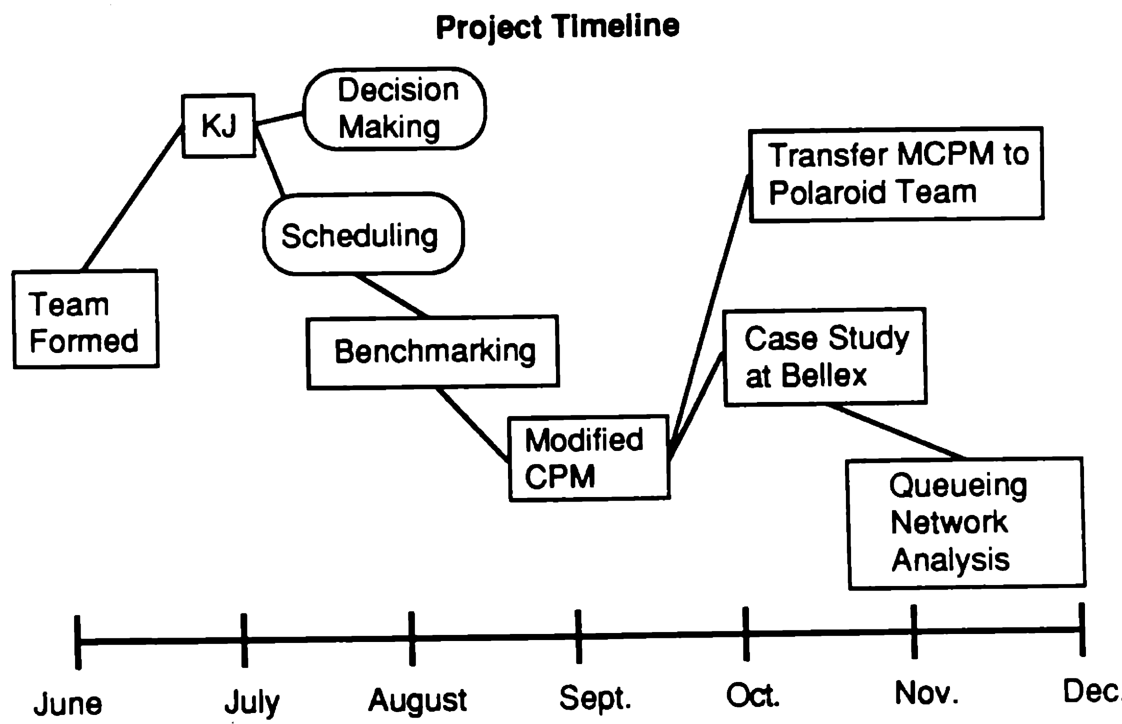

Figure 2.1

Formation of a Cross-functional Team

Planning for this thesis research began in February 1990 when thesis advisors and a company supervisor were selected based on a proposed thesis topic. Based on discussions within Polaroid, the company supervisor (a manager from the manufacturing strategy group), determined that the most useful research from Polaroid's perspective would be in the area of new product development. A cross-functional steering committee was formed to ensure an integrated and comprehensive approach to the issue. Company representatives included three managers with manufacturing backgrounds, and one each from marketing, product engineering, and program management. The team met on a bi-weekly basis to discuss progress, share information, and plan future work.

Various thesis topics were discussed for approximately one month before final topic selection. Although this sounds like a long time, the time was well spent in the author's opinion. The author met individually with all the team members a number of times to understand the company's product development process from their functional perspectives. Bi-weekly meetings were used to bridge the gaps between different functional areas, and pursue root causes of inter-functional problems. This initial period was critical for the team building and ensured that all members sufficiently subscribed to the research goals.

After this initial period the project mission included the following components:

- study a cross-functional issue in product development
- look within Polaroid and outside Polaroid for solutions and "best practices"
- begin implementation of an improvement before December 1990.

By the end of June, we were focusing specifically on the issue of time in the development cycle.

KJ Analysis to Speed Problem Identification

Since one of the goals of this project was to begin implementing an improvement within six months, we needed to reduce the time to identify major opportunities. One tool for this purpose, found in the total quality literature, is called the KJ method.[1] This method, although common in Japan, is just gaining acceptance in the U.S. Polaroid, and many other Leaders for Manufacturing companies, have found this approach to be very efficient when dealing with complex issues.

The KJ Method (coined from the inventor's initials) is a practical method for recognizing and formulating problems. A group of knowledgeable people is assembled to address a *what* question. The output of the session is a well structured answer to the question showing causal relationships and the most important opportunities for improvement.

The KJ Method

There are four basic steps in the KJ[2]:

1. note card making
2. note card grouping and title making
3. chart making
4. explanation

In the note card making phase, each person in the KJ group answers the *what* question with as many ideas, thoughts, and information as they can think of. Next, each individual reads their cards and explains them as necessary. Similar cards are grouped in topics and each group is then titled. Groups of cards are then grouped and these super groups are also titled until the group feels comfortable with the structure. Chart making describes the process of defining relationships between groups of note cards. Relationships include *cause* or *result* and *contradiction*. Finally, the group begins a process of explaining the chart created. It is typical in this stage to vote for the most critical answers to the question. The group then comes to a consensus about the conclusion of the session.

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1 Kawakita, Jiro, *The Original KJ Method*, Kawakita Research Institute, Tokyo, Japan.

2 This section is based on an unpublished paper by Shoji Shiba and Dirk A. Bettendorf called "The KJ Method: A Scientific Approach to Problem Solving."

The July 3rd KJ

On July 3, 1990, we brought together two groups of six people each to run two separate KJ sessions addressing the same question: *What prevents Polaroid from successfully bringing new products to market faster?* Our scope was very broad at this point. We wanted to identify opportunities that had wide applicability across Polaroid. Participants were chosen to represent a diagonal slice through the complete organization. Four people were from manufacturing, two from engineering, one from marketing, two from program management, and three from a corporate product development task force. The level of the participants ranged from senior managers (e.g., Plant Manager) to non-managers. In addition, there were representatives from both the media and hardware businesses. Although the teams were fairly well balanced, the author had difficulty attracting marketing representatives and to a certain extent engineering representatives. The media organization (2 people) was not as well represented as hardware (8 people). The results, therefore, may be less indicative of how people from these groups would answer the question.

The output from the sessions is shown in Figures A.2a-d and A.3a-d in Appendix A. There was surprising agreement between the groups on the two most important opportunities to improve Polaroid's time to market performance. Both teams cited decision making as the most important area for improvement. Group A stated, "Senior management is not making timely, focused decisions nor following through when made." Group B wrote, "The decision making process is inadequately defined and controlled." The second most important opportunity concerned scheduling issues. Group A wrote, "We need to deliver what has been promised to an agreed upon schedule." Group B stated, "Right or wrong we must meet the schedule."

Critique of the KJ

Overall the KJ was good for focusing our research on key opportunities at Polaroid. Careful analysis of the charts shows surprising agreement between the two groups which gives us some confidence that the methodology was effective in identifying key areas for focus.

An optimally-run KJ session will force participants to state only clear facts on their labels. This requires significant work and experience with KJ. Unfortunately, many of the note cards contained statements that were rather vague. For example: "Senior managers are not following through on the decisions made." This begs the question: what decisions specifically? Although the participants may have been specific in their verbal descriptions of the cards, many failed to transfer these clarifications to the written cards. The author and KJ facilitator also deserve blame for this weakness. Since the sessions were being run concurrently, they were unable to force precision. In addition, it was suggested that the *what* question may have been too broad, and consequently encouraged broad and vague answers.

The decision making issue is problematic; to a certain extent it appeared that the groups were pointing fingers at whomever was not represented, that is top management. Additionally, this issue is extremely difficult to address with a research project! Instead we decided to focus on the second most important issue, that is, opportunities to improve product development schedules.

Addressing the Schedule Issue

Further research into scheduling issues was conducted by interviewing those involved in past and present product development efforts. A few common scheduling issues were revealed. At the product development *team level*, different functional areas (e.g., marketing and engineering) often used different scheduling tools. Consequently, these areas often worked from schedules that were not well integrated and sometimes might conflict. In addition, it often appeared that new product development teams "reinvented the wheel" by scheduling based on their own best guesses. No database of past schedule performance existed to shorten the time to produce a schedule, or help improve schedule accuracy from one project to another.

At the *corporate level*, many people commented that scheduled resource utilization often exceeded capacity. When conflicts for resources did exist, resolution was slow since projects had never been prioritized.

Our response to these opportunities developed in two directions: at the *team level* we began developing a tool that helps project managers to schedule; at the *corporate level*, we started developing a model that simulates the consumption of human, capital, and administrative resources. To a certain degree, the output of the scheduling tool facilitates corporate modeling. Our goal at the corporate level, is to identify bottlenecks and unnecessary waiting at key resources, and to simulate changes before implementing in order to better understand the impact of the changes on the corporate system.

After identifying these two responses, we began looking outside Polaroid to identify solutions or "best practices".

Benchmarking to Identify Best Practice

Benchmarking describes the process whereby a company (or person) scans the environment to identify what it believes is "best practice" for a particular function or process.[3] The firm then compares its own performance to a "benchmark" performer, and then endeavors to eliminate the gap between performance levels. Benchmarking is quickly gaining acceptance among American firms who often focused their attention inward, believing that they were necessarily best in class (or at least good enough). Polaroid has adopted this process throughout the corporation and has witnessed a variety of improvements as a result.

For the purposes of this project our "benchmarking" took two forms. Company representatives from some Leaders for Manufacturing sponsor companies were polled to see if they had addressed similar issues in product development. In addition the author attended a conference entitled "Speeding New Products to Market" and sponsored by the Product Development Management Association on September 25, 1990 in New York City. Both exercises revealed a large number of companies with very similar problems. At the same time however, some companies have been able to make very dramatic improvements in a wide range of industries. Chapters 1 and 8 touch on some of the results of these surveys.

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3 For an excellent book on benchmarking read Robert C. Camp, *Benchmarking: the search for industry best practices that lead to superior performance*, ASQL Quality Press: Milwaukee, WI., 1989.

Modified Critical Path Analysis

Benchmarking led to the discovery at Motorola Codex of what we term here as a modified critical path methodology (CPM). Codex had faced circumstances similar to those at Polaroid: difficulty meeting product development schedules, and slow or poor decision making. Using this methodology, Codex has been able to reduce time to market performance by 45% over a period of two years. Chapter 3 discusses this methodology at length.

Queueing Network Analysis of Product Engineering

One of our goals was to develop a model that simulates the consumption of resources needed to support product development so that the impact of decisions on time to market could be reasonably predicted. A new approach to this problem relies on queueing network theory to model corporate resources. Chapters 4 through 7 describe this novel approach at length.

Case Study Analysis of Bellex Corporation

The modified CPM and queueing network analysis focus on tools to help improve time to market performance. The author, and indeed most industry practitioners, believe that organizational change is required to ensure these tools become adopted and fully utilized. Chapter 8 attempts to address this issue by analyzing a case study of Bellex Corporation (a disguised name) in Appendix C. The author prepared this case study by interviewing a variety of people at the company studied. The focus of this chapter is on management's role in this (and any other) change and improvement process.

CHAPTER 3: A MODIFIED CRITICAL PATH METHOD

This chapter reviews traditional project management tools and describes a modified critical path method (MCPM) to help reduce time to market. Project tasks are allowed to overlap and thus parallel development can be managed more accurately. The product development cycle is viewed as a hierarchy of phases, steps, tasks, and activities. After identifying the critical tasks, task times are predicted based on specific complexity criteria. Successful implementation at other companies has resulted in significantly faster time to market, and lower variability in product development schedule performance.

Review of Traditional Project Management Tools

The most popular methods for project management are the *critical path method* (CPM) and the closely related *project evaluation and review technique* (PERT). CPM assumes task times are deterministic while PERT allows variability in the activity times. *Precedence Diagramming* is a relatively new extension of CPM that allows overlapping between activities. This section relies heavily on a book by Moder, Phillips and Davis.[1]

CPM

The Critical Path Method grew out of a joint effort conducted between 1956 and 1959 by the duPont Company and Remington Rand Univac.[2] The technique evolved from a study aimed at reducing the time required to perform plant overhaul, maintenance, and construction. In essence, the group was interested in determining the optimum tradeoff of time (project duration) and total project cost. Since there was relatively little variation in the duration of the tasks being modeled, CPM treats the activity performance times as deterministic. Projects are organized into networks and the critical path is determined to predict lead time and to schedule tasks.

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1 Moder, Joseph J., Cecil R. Phillips, and Edward W. Davis, *Project Management with CPM, PERT and Precedence Diagramming*, Van Nostrand Reinhold, New York, NY 1983.

2 Walker, M.R., and Sayer, J.S., "Project Planning and Scheduling," Report 6959, E.I. du Pont de Nemours & Co., Inc., Wilmington, Del., March 1959.

For the sake of consistency, we will adopt definitions and rules described by Moder et al.[3] An *activity* is any portion of a project which consumes time or resources and has a definable beginning and ending. A *network* is a graphical representation of a project plan, showing the interrelationships of the various activities. The basic rules of network logic are as follows:

1. Before any activity may begin, all activities preceding it must be completed. (Activities with no predecessors are self-actuating when the project begins.)
2. Arrows imply logical precedence only. Neither the length of the arrow nor its "compass" direction on the drawing have any significance.

Both CPM and PERT emphasize the construction of a network based on logical or technical dependencies among activities. That is, the activity "approve shop drawings" must be preceded by the activity "prepare shop drawings". A common error in this regard is to introduce activities into the network on the basis of a sense of time, or a "feel" for appropriate sequencing. *Subjective* networks result which can lead to embarrassing situations for the planner when activities begin before the network says it's possible, or are delayed for activities that were supposed to be independent.

After preparing a network diagram of the project, and predicting activity times, the critical path through the network is determined. The scheduler or computer program computes *earliest start and finish times* for each activity by doing *forward pass* calculations. The *backward pass* computes the *latest allowable start and finish times* for each activity. These calculations reveal a *critical path* of activities through the network representing the path with the least *path float* or *slack*. This path determines the longest path through the network and facilitates the scheduling of all activities in the network.

After all activities have been scheduled the project begins. Actual task durations are recorded and charted in Gantt form against predicted task times. The schedule becomes a benchmark by which the project team measures its time performance.

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[3] Op cit., pp. 23-27.

PERT

PERT was developed separately as a result of the Polaris Weapons System program undertaken by the Navy in 1958.[4] Lockheed Aircraft Corporation, the Navy Special Projects Office, and the consulting firm of Booz, Allen, and Hamilton jointly created the technique. The advantage of PERT over CPM is that it allows variability in the activity times. This seems especially appropriate for scheduling and controlling research and development projects, or others comprised primarily of activities whose actual duration times are subject to considerable chance variation. It is because of this variability that for projects of this type, the time element of project performance is of paramount importance.

"Conventional" PERT calculates the earliest and latest activity start and finish times in the same way as CPM, however *expected activity times* are used instead of a deterministic *activity times*. Measures of variability for each activity are then used to calculate PERT probabilities. Since the methodology only considers the most probable critical path, PERT event times (milestones) are biased slightly, always on the low side, and the PERT probabilities considerably on the high side. These biases however can be circumvented using either Monte Carlo simulations or a simply method called PNET which considers not only the critical path but also a "sufficient" set of near critical paths.[5]

While the PERT methodology seems to be a more accurate representation of product development, in practice it has many shortcomings. Typically, a PERT chart will show expected and best and worst case activity times. Project managers often find team members use the expected or worst schedule as their true schedule goals. From an incentive perspective this suggests that a CPM schedule should be used for project management *in process*.

Limitations of CPM and PERT

CPM and PERT have a number of limitations including the following:

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4 "PERT: Program Evaluation Research Task," Phase I Summary Report, Special Projects Office, Bureau of Ordnance, Department of the Navy, Washington, D.C., July 1958.

5 Moder et al, pp. 269-311.

- difficulty in representing *divisible tasks and overlapping activities*
- inability to represent *simultaneous activities*, and
- no account for delays caused by *finite resources*.

Divisible tasks and Overlapping Activities

Strictly speaking CPM requires that projects are broken down into indivisible tasks. This has many weaknesses. According to most industry sources, roughly one to ten thousand indivisible tasks are necessary to develop a new to the world product.[6] Predicting these tasks at the outset would be both time consuming and highly inaccurate. The result would be an ungainly schedule that would be too detailed to serve anyone's needs. More importantly, the exercise would not capitalize on an important opportunity to cut time out of a schedule, that is, by overlapping activities. *Precedence Diagramming* was developed to address this issue and is discussed below.

Simultaneous Activities

A related shortcoming of traditional CPM is the difficulty of determining exactly how to divide projects into tasks. The procedure described below uses a hierarchical approach which does not attempt to represent all of the simultaneity explicitly.

Another approach has been used by Black, Fine, and Sachs,[7] who applied Steward's[8] Design Structure Matrix to the design of an automotive brake system. The procedure orders and organizes design activities on the basis of the information flows involved. Design decisions that can be made independent of other decisions are separated from those that constitute a simultaneous subsystem. The technique is useful for indicating which design tasks must be done simultaneously. Design tasks are ordered to minimize the number of simultaneous tasks and streamline the development process. This technique could be used prior to a CPM

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6 The sponsor company listed 2,000 tasks necessary to design a medium complexity electro-mechanical device.

7 Black, Thomas A., Fine, Charles H., and Sachs, Emanuel, "A Method for Systems Design Using Precedence Relationships: An Application to Automotive Brake Systems," Leaders for Manufacturing Program, MIT, Cambridge, Mass, 1990.

8 Steward, Donald V., *System Analysis and Management: Structure, Strategy, and Design*, New York: Petrocelli, 1981.

analysis, with simultaneous tasks grouped into one activity for the purposes of CPM. This methodology seems to apply very well when the system design or architecture is relatively static and specific informational needs can be described in advance.

Finite Resources

Another important shortcoming of CPM is its inability to account for finite resources. When different product development projects use the same resources the true activity times are equal to both the actual time performing the activity, and the time spent waiting for a resource. Chapters 4 through 7 discuss a queueing network model that tries to take this into account when scheduling a portfolio of product development efforts.

Precedence Diagramming

Precedence diagramming describes a scheme whereby activities are allowed to "lag" one another. This extension of an activity-on-node network representation was first mentioned in J. W. Fondahl's 1961 report.[9] The method received further notice in the user's manual for an IBM 1440 computer program for network processing, published around 1964. One of the principle authors of that manual was J. David Craig.

Figure 3.1 illustrates possible precedence relationships and their representation.[10] The first relationship in Figure 3.1a is the only one allowed in PERT and CPM. Borrowing an example from Moder et al, the *start* of "concrete forms stripping", might have to lag 5 days after the *finish* of "pour concrete". The lag of 5 days may be required to allow the concrete to cure and strengthen before the forms are removed.

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9 Fondahl, J. W., "A Noncomputer Approach to the Critical Path Method for the Construction Industry," Dept. of Civil Engineering, Stanford University, Stanford, Ca, 1st Edition 1961, 2nd Edition, 1962.

10 Moder et al, pg. 40.

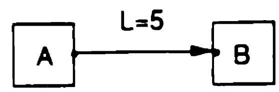


Figure 3.1a Finish-to-start relationship

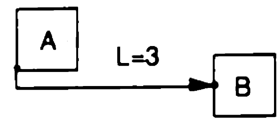


Figure 3.1b Start-to-start relationship

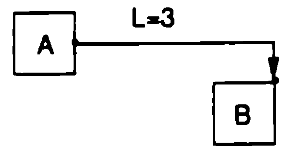


Figure 3.1c Finish-to finish relationship

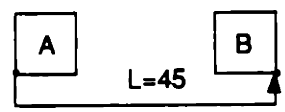


Figure 3.1d Start-to finish relationship

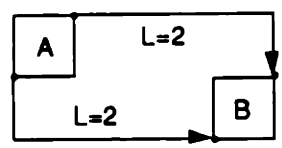


Figure 3.1e Composite start-to-start and finish-to-finish relationships.

Figure 3.1b illustrates a start-to-start relationship which is also very common in practice. For example, the *start* of a part design may precede the *start* of building a prototype part by 3 days. The prototype builder can procure materials and begin rough modeling before the part is completely designed.

Figure 3.1c illustrates a finish-to finish relationship. For example using a construction example, suppose activity A is "place electrical" (5 days) and activity B is "complete walls" (15 days). Note it takes 3 days of activity B work to complete the output from one day of activity A. Therefore the finish of "complete walls-B" must lag behind the *finish* of "place electrical-A" by 3 days because it will take 3 days of wall completion work to handle the last day of electrical work.

The fourth relationship shown in Figure 3.1d, start-to-finish, is less frequently used. Using an automotive design example, suppose activity A is "design power train" (40 days) and activity B is "design chassis" (30 days). The dependency relationship between A and B might be that the *last* 20 days of chassis design work depends on the results that will be obtained from the *first* 25 days of power train design work.

The fifth relationship shown in Figure 3.1e is required whenever a series of activities must follow each other. For example, if activity A is "design parts", and activity B is "draw parts", it may be that activity B "draw parts" cannot start until 2 days after A has started, and similarly, B cannot finish until 2 days after A has finished.

Advocates of precedence diagramming feel that it is easier to understand and less confusing then the alternative of splitting an activity into separate activities using traditional CPM. However, the method introduces some complexities of its own due to connecting arrows with several different definitions. Project time calculations are not quite as straightforward as in traditional network representations. Moder et al discuss these anomalies at length.[11]

A Conceptual Approach to Overlapping Activities

The decision process of when to overlap activities is not an intuitive one and deserves some attention. Traditionally the decision was made purely on a cost basis (similar to the way economic order quantity decisions were made on the manufacturing floor). Schedulers learned that the most efficient way from a cost standpoint was to do activities sequentially, thus minimizing the time any one person took to do a job. This approach has many weaknesses. First, it ignores the value of time in product development. Consumers are willing to pay more for products that hit the market early. Secondly, it ignores the potential revenue gains associated with more efficient *information flows* between upstream and downstream activities. Much the same way as just-in-time forces communication from the start of a product process to its end, overlapping activities in the development cycle force information transfers between upstream and downstream activities. These information flows help to expose

[11] Moder et al, pp.94-100.

inefficiencies and refine the process, and ultimately can be reflected in higher quality and lower cost products.

A simple project can be represented as a network of four activities as shown in Figure 3.2.

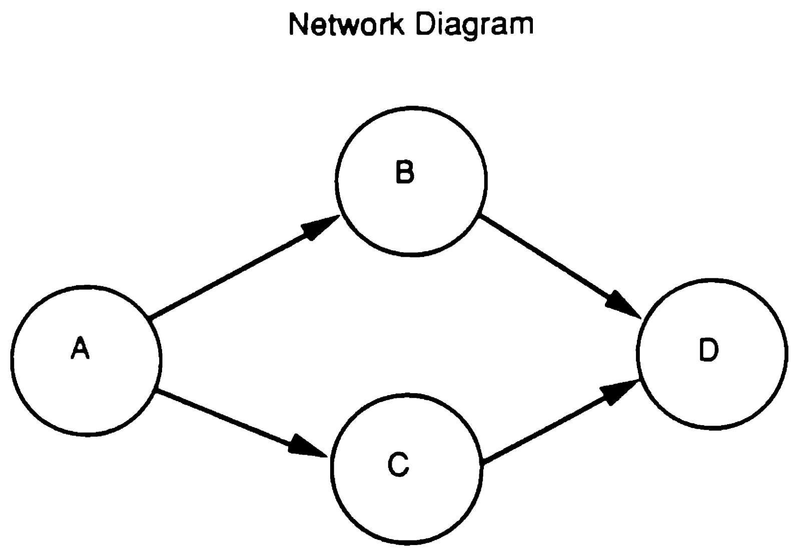


Figure 3.2

In traditional CPM, activities A, B, C, and D are indivisible, and activity A must precede activity B, which must precede activity D and so on. In Gantt chart form, this project might look as follows in Figure 3.3.

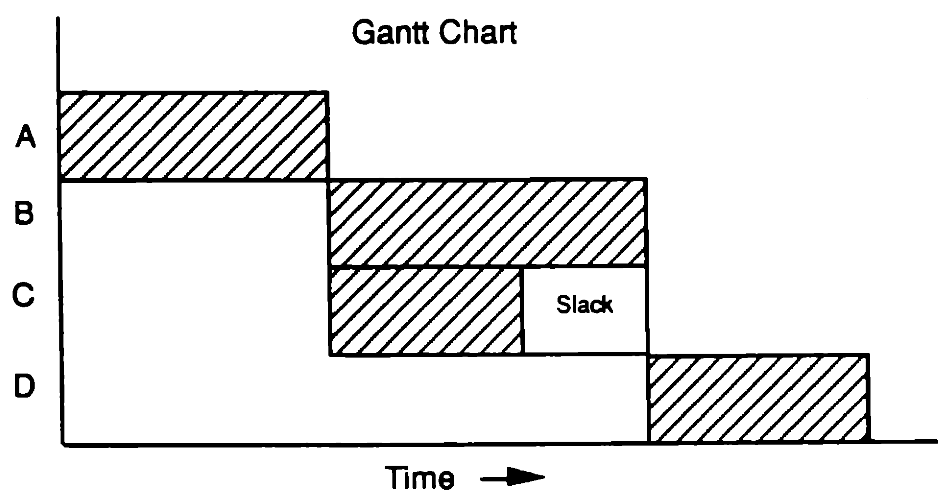


Figure 3.3

The problem with this representation is that there are many cases when a downstream activity can overlap its upstream activity. An example would be the design of a part, and the subsequent model building, or the design of a molecule and its subsequent synthesis.

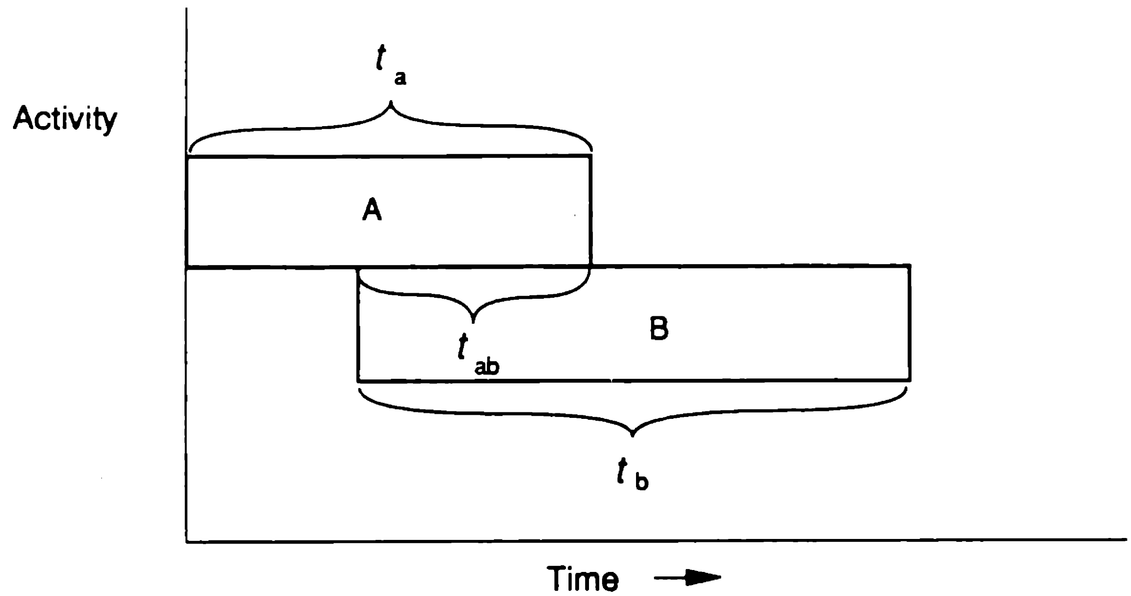


Figure 3.4

In Figure 3.4 above, t_a and t_b are the time to complete activities A and B respectively. Let t_{ab} be the amount of overlap between the start of activity B and the end of activity A. Define the lead time as

$$l_{ab} = t_a + t_b - t_{ab}$$

In terms of total lead time (total elapsed time from the start of A to the end of B), it makes sense to increase the overlap as long as

$$\partial l_{ab}/\partial t < 0 \text{ or,}$$
$$\partial t_a/\partial t + \partial t_b/\partial t - \partial t_{ab}/\partial t < 0 \text{ or,}$$
$$\partial t_a/\partial t + \partial t_b/\partial t < \partial t_{ab}/\partial t.$$

Thus, one should continue to overlap activities as long as the rate of increase in the total time to do activity A and B is less than the rate of increase in the overlap time. Put another way, activities A and B should be overlapped more if the expected total extra time to do A and B is less than the amount of extra time overlapped.

Define

$$t_a = t_{a'} + t_{a''} \text{ and}$$
$$t_b = t_{b'} + t_{b''} \text{ where}$$

$t_{a'}$ and $t_{b'}$ are constants representing the activity times for A and B with no overlap, and $t_{a''}$ and $t_{b''}$ are variables representing the extra time it takes to do A and B with overlap t_{ab}.

The variable $t_{a''}$ can be thought of as the extra time to communicate and react to the changes resulting from the overlap with the downstream activity B. Likewise $t_{b''}$ is the extra time to communicate and react to changes from the overlap with the upstream activity A. For example, the downstream activity may have to do some rework because initial information is incomplete. Thus, if one is focusing solely on lead time, one should continue to overlap the activities A and B as long as the rate of increase in $t_{a''}$ and $t_{b''}$ is less than the rate of increase in t_{ab} (the time of overlap).

Of course, this does not take into account either the advantages (e.g., in product cost, performance, or quality) of changes in design made in activity A due to communication from activity B, or the disadvantage in terms of increased development costs (i.e. $C_a t_{a}''$ and $C_b t_b''$ where C_a and C_b are the cost for resources to do activities A and B respectively). In order to accurately make this tradeoff one needs a value for reducing cycle time, and the relationship of product cost, performance and quality to total return.

This analysis makes more sense for activities on the critical path of a project. If the activities A and B are not on the critical path than the total value of overlapping is determined by the relationship between the extra development costs ($C_a t_a''$ and $C_b t_b''$) and the incremental income from increases (or decreases) in product performance, quality, or manufacturing costs. However, as companies continually work to shrink the development cycle and do more work in parallel, the number of potential critical paths is likely increase.

The result of this simple analysis is that if one is focusing solely on lead time, the overlap of tasks should be increased as long as the sum of the increases in time to complete the two tasks is less than the increase in the overlap. The procedure described below relaxes the rule that CPM tasks must be indivisible. Tasks are allowed to overlap, and these overlapping times are predicted. This hybrid CPM methodology still allows one to calculate the critical path, while taking lead time out of the development schedule.

A Modified CPM

This section describes a modified critical path method (MCPM) which allows and encourages overlapping activities.[12] The product of this analysis is a matrix of product development schedules that can be used for a variety of product development projects. The process of product development is analyzed and systematized by a cross-functional company team. The specific tasks and the times to complete the tasks are made explicit. Figures 3.5 and 3.6 show hypothetical output from this analysis.

The method of producing a generic schedule that all projects can use requires a top down approach. Product development is analyzed at the highest level (often called the phase level), and then disaggregated into smaller and smaller activities until it is appropriate to predict task times. Product development is viewed as a hierarchy of phases, steps, tasks and activities (see Figure 3.7). The following is an outline of the major steps in the analysis:

1. Determine the phases of product development, major milestones, and the major steps in each phase.
2. Analyze each major step and disaggregate them into tasks.
3. Determine the critical determinants of cycle time for each major step.
4. Create categories based on the determinants that cover the whole range of products developed.
5. Assign task time and overlap time estimates to each task for each category of complexity.

[12] This methodology largely follows that used by Motorola Codex in Canton, Mass. For more information contact Mr. Bill McDonough.

A Modified CPM Methodology

Time to Complete (Overlap Time)

Determinants of Time: No. of piece parts	New Architecture	In-house Materials	HW Subsystem Design: Design	Draw	Check	HW Subsystem Build: Procure Mat'ls	Build Prototype	HW Subsystem Test: Develop Test	Build Test	Test
<5	N	Y	4(2)	4(3)	4(5)	2(0)	4(4)	1(0)	4(0)	1(0)
5-10	N	Y	6(3)	6(4)	4(5)	2(0)	6(5)	2(0)	4(0)	2(0)
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮

Figure 3.5

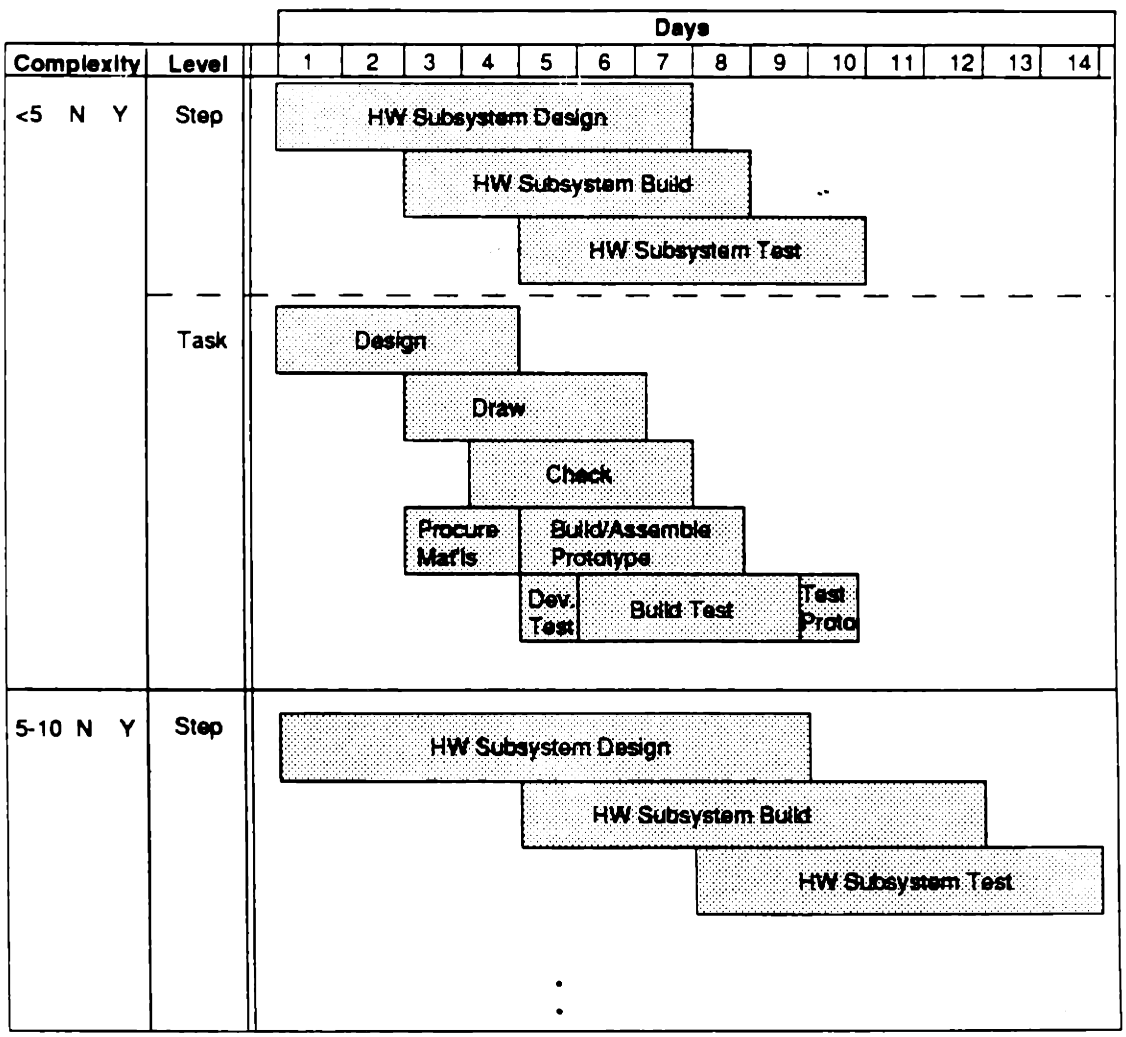
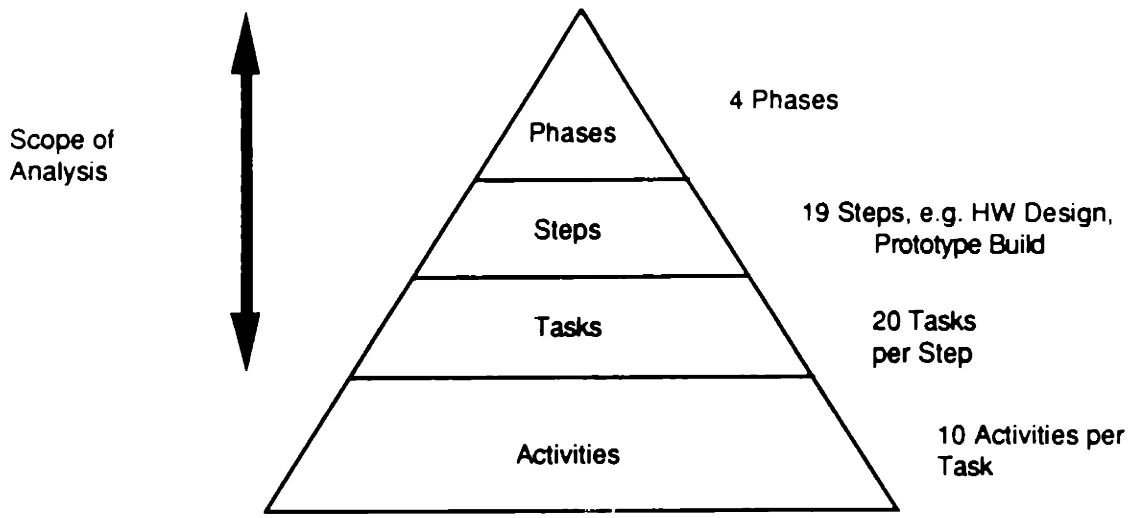


Figure 3.6

Conceptual Model for Product Development



Source: Motorola Codex, Canton, MA

Figure 3.7

Advantages of the MCPM

The advantages of producing a generic schedule for product development are numerous and wide ranging. The method is consistent with Total Quality Management's focus on process and process improvement. The process of product development is analyzed and waste is eliminated from the system. In addition the analysis provides:

- a baseline for setting time to market goals,
- a framework for capturing experience and learning,
- a top level view to identify areas for major cycle time improvements, and
- critical information for portfolio management.

These benefits are described below.

A critical starting point for any improvement process is to define the gap between present performance and the goal. As a precursor to the MCPM analysis a company should determine its own time to market performance (possible metrics include time to market, or breakeven time). Next the time to market goal should be set based on the product development strategy and careful analysis (or benchmarking) of one's competitors. The MCPM analysis follows and attempts to be specific how the time to market (TTM) goals will be achieved. In effect, MCPM breaks down the corporate TTM goals into sections that those developing products can relate to. People have a baseline, upon which to measure their own performance.

The second major advantage of this analysis relates to organizational learning. Because the method is not static and requires constant upgrading and improvement, it serves as a framework for comparison between different product development teams. The performance of each product development effort is recorded and a database of experience is produced. This database serves a number of purposes. Major advances and mistakes are recorded and shared throughout the organization. Improvements become more widely adopted, and mistakes are not made more than once. The database increases the confidence of the organization in its schedules. The amount of *scheduled safety slack* diminishes as a result.

A third advantage relates to taking a systematic approach to product development. By understanding the total process of product development one can prioritize improvement efforts, focusing only on those areas of major opportunity that lie frequently on the critical path.

Finally this methodology produces information useful for the effective management of product development resources. The data collection necessary to begin and sustain the system can be used to more effectively to make tradeoff decisions between different product development projects.

Disadvantages of the MCPM

The MCPM is not without its difficulties and challenges. It can be very difficult to define tasks such that the network is simple while the important precedence relationships are represented. The procedure is also very time-consuming. An analysis that can represent all the products that a mid-sized company develops takes from two to six man-years of work, and requires significant resources to maintain and improve even after start-up.

Additionally, the analysis can also be risky from an organizational perspective. The procedure asks those developing products to examine exactly what they do and then do it faster. Resistance from many areas can be expected.

Implementation Suggestions

Deciding to produce a generic product development schedule is only one of a number of hurdles towards reducing time to market. A few important implementation principles should be heeded in order to make the analysis and the subsequent adoption a success. These can be separated into three areas: 1) Goals and incentives; 2) Analysis team composition; and 3) Continuous improvement.

It is critical to any major change process that the company has committed to a clear goal, and is confident that goal can be achieved. Successful use of this procedure was preceded by very explicit time to market goals which the organization believed were necessary and possible. Stating the goal is only the first part however. To truly get the organization aligned one must incorporate the goal into the incentive systems for the key facilitators. Typically this will involve paying managers based on time to market performance, or incorporating the analysis baseline into product development teams' goal structure and incentives.

The skills, seniority, and organizational respect of analysis team members is critical to the success of this procedure. The analysis team is attempting to tell product development people how long it should take to do their jobs. The results of the analysis will only be accepted if this team is comprised of people well respected in their discipline.

Finally there is the issue of support and improvement after the initial analysis period. A process for debriefing project performance will ensure learning is shared among teams. A project champion is necessary to update and sell the results.

Application of the Modified CPM

As discussed in Chapter 2, the modified CPM was discovered at Motorola, Codex as part of the thesis project benchmarking phase. Codex has reportedly reduced their development cycle by 45% over a two to three year period using the system. The cross-functional project team began the first phase of a similar analysis at the sponsor company. The results of this first phase (code named Project Pluto) are included in Appendix B. The team is currently in the process of selling this procedure to others at the sponsor company in the hopes that a full time Analysis Team is formed to continue the analysis. Aside from the time to market gains expected to result from this analysis, we intend to use output from the analysis to help create the corporate resource allocation model described in Chapter 4.

Project Pluto: A Generic Product Development Schedule

Project Pluto is an effort to begin the first phase of the modified CPM described above. The author and the six person steering committee worked approximately one and a half months to produce the generic product development schedule shown in Appendix B. Information to support this analysis came primarily from two sources: experience of the steering committee members, and interviews with members of five current or recently completed product development efforts.

Our intent was to try to incorporate what should happen to develop a new to the world product that incorporates both a media system (e.g. film) and a hardware system (e.g. a camera). These are the most complex systems developed by the sponsor company and represent a formidable product development task.

The analysis also tries to build on previous work to systemize product development at the firm. This system uses a phase review system to manage product development and encourages the use of cross-functional product development teams. Review meetings are represented by milestone indicators in the network diagram.

The network was created using MacProject II. This software package is very easy to learn and has numerous desirable features such as master and subprojects, resource leveling capabilities, and start to start and finish to start lags. Currently the sponsor company uses three different platforms for project management: MacProject for the Apple Macintoshes, an IBM PC based system, and a mainframe based package. Different functional areas tend to use one of these systems exclusively.

MacProject II does have a few limitations. The program does not allow other precedence diagramming relationships such as start to finish or finish to finish. From a presentation perspective, the program does not allow milestones or tasks to exist at multiple master or subproject levels.

Instead these relationships have to be implied (see "Pre-Production Pilot" and subproject #10 in Appendix B).

Initial Results of Analysis

Although most of the benefits of this analysis are realized after completing all of the procedures, the first phase revealed a number of potential delays in the product development process due to control mechanisms. "Institutionalized delays" discovered were as follows:

1. Feasibility Review officially releases funds for vendors yet vendors are needed to aid in development prior to the review to support early vendor involvement;
2. Test marketing cannot precede until product identification codes (PIDs) have been issued, which in turn cannot be issued until after the AFS Review, thus delaying vital market research;
3. Full market research cannot be funded until after Feasibility Review but is most beneficial immediately following the Concept Review.

Next Steps

The sponsor company is in the process of forming an Analysis Team to continue this procedure. The next step is to explode the current analysis (largely at the step level) down to the task level. The team will then determine the specific project criteria that determine task durations and overlap times. A matrix of task durations and task overlaps will be created for all the possible new product configurations (similar to that in Figures 3.5 and 3.6). Due to the magnitude of this task, it is likely that the analysis will be done for one business unit on a pilot basis in the near term.

CHAPTER 4: AN APPLICATION OF QUEUEING NETWORK THEORY TO PRODUCT DEVELOPMENT

This chapter presents a conceptual model of product development as a network of queues through which product development "jobs" travel. Using this mental model, we hope to better understand and manage the relationship between resources that support product development, and the total development time. This work represents an initial exploration and feasibility study into the application of queueing network theory to product development. Our intent is to gain a better understanding of the challenges to building such a model.

A model is proposed of one section of the sponsor company's product development resources in this chapter. Empirical data is collected and analyzed, and indicators of queues are proposed in Chapter 5. Chapter 6 analyzes the actual performance of specific product development projects and compares this to the characterization of Chapter 5. Chapter 7 describes alternate model formulations and next steps in this research.

Motivation

It has long been recognized that CPM/PERT does not work well when activities within a project or a number of projects compete for the same resources. The basic CPM/PERT procedures produce a detailed project schedule which is limited in the sense that resource availabilities do not enter into the scheduling process. The procedures implicitly assume that resources are unlimited and that only technological (i.e. precedence) requirements constrain job start/finish times. One consequence of this is that schedules produced may not be realistic when resource constraints are considered.

CPM/PERT assumes that the activity times are independent of any other project. In reality, however, there are a number of situations when multiple projects use the same finite resources. In engineering this might be a fixed supply of electrical engineers, or some other *human* resource. Similarly all projects might use a supply of CAD systems, or some *capital* resource. Finally, work could be delayed as a result of some *administrative* resource such as waiting for a decision or approval.

If the use of these resources is low relative to capacity, we expect few inter-schedule delays. However, as resource utilization increases, delays in one project tend to delay all the projects using the central resource. An example will help illustrate this point.[1]

Example of Multiproject Scheduling Interactions

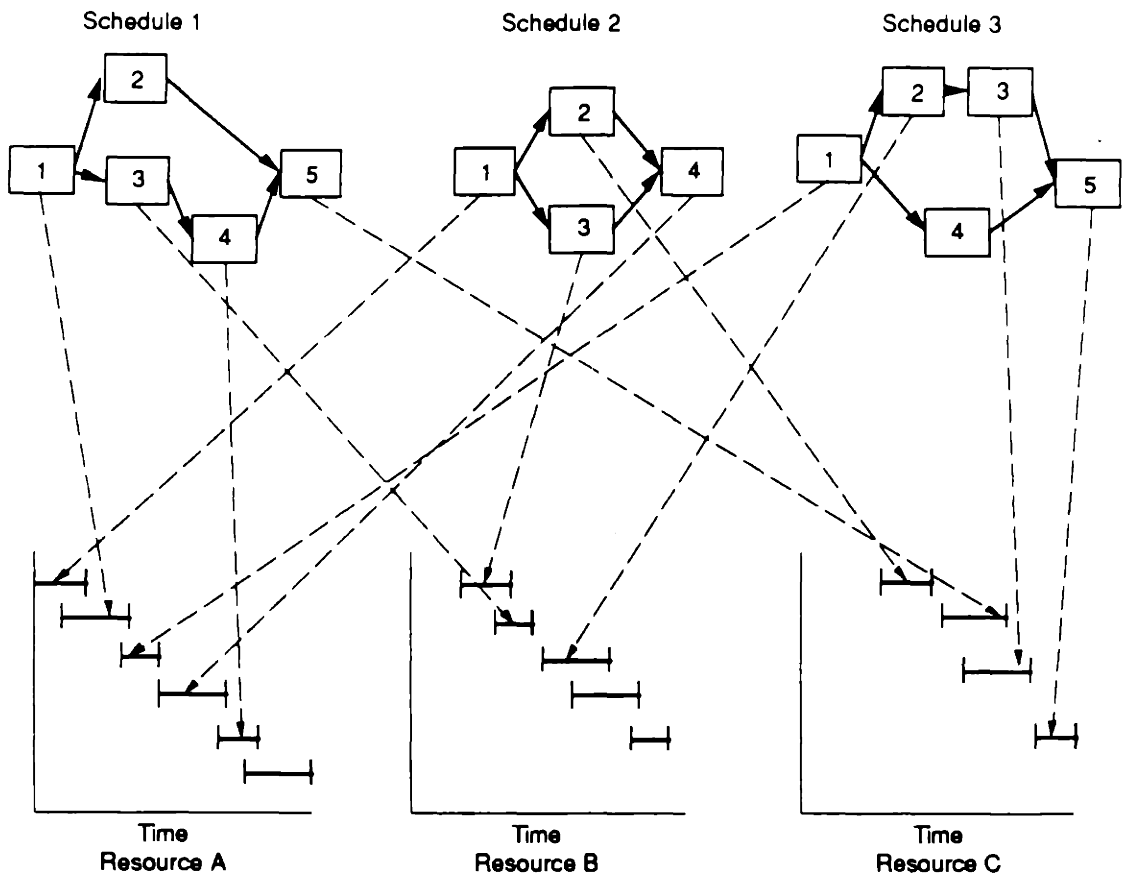


Figure 4.1

Figure 4.1 shows three hypothetical product development schedules (1-3) using three different resources (A-C). To simplify the example suppose that all activities use only one unit of any one of the resource types at a time, and that only one unit of any resource is available. The figure above shows all the activities as if they had been scheduled using typical

[1] This example resembles one from page 195 of Moder, J.J., Phillips, C. R., and Davis, E. W., *Project Management with CPM, PERT, and Precedence Diagramming*, 3rd ed. New York: Van Nostrand Reinhold, 1983.

CPM/PERT. That is, activities are scheduled on a project by project basis without regard to other projects.

The first step to create a feasible schedule is to eliminate the overlap. A domino effect occurs as one delays activities to resolve particular resource conflicts. For example, if activity 1 of project 1 is delayed to resolve the conflict with activity 1 of project 2 for resource A then the following might happen:

a. delays in successor activities 3, 4 and 5 of project 1;
b. as a result of (a), the creation of additional resource conflicts among activities requiring resources B and C;
c. as a result of (b), additional delays in projects 2 and 3, and possibly even project 1 again.

A feasible schedule is likely to significantly increase the lead time for each project over its theoretical minimum. Slack time will exist between activities but not at the resource level. Now if for some reason an activity for project 1 is delayed (e.g., the task duration is underestimated), successor activities will be delayed, causing activities for other projects at other resources to be delayed. For resource constrained networks, schedule delays ripple through all development projects causing all development projects to be late to market.

Queueing network theory provides one way to try to account for delays caused by finite resources and thus manage resources and the development cycle more effectively. The advantage of queueing theory is that the analysis can be relatively simple compared to a detailed computer simulation. Frequently one needs only determine the first and second moments of the arrival and service rates to estimate critical model performance measures. The disadvantage however is that the theory can be restrictive in terms of the arrival and service rate distributions that can be represented, the type of queueing disciplines, and the specific routing constraints.

Review of Applicable Theory

Application of Queueing Network Theory to Manufacturing Systems

Queueing network theory is increasingly being applied to many manufacturing systems. For example, Chen, Harrison, Mandelbaum, Van Ackere, and Wein[2] modeled the performance of a semiconductor wafer fabrication facility using queueing network models. Baskett, Chandy, Muntz, and Palacios[3] provide the necessary queueing theory to support these applications.

Resource-constrained Networks

Since the advent of CPM/PERT, researchers have proposed numerous procedures to calculate optimal or near optimal schedules under resource constraints for both single project and multiproject problems. This work can be categorized according to the type of resource constraint problem, or the solution technique used.[4]

There are two major types of resource constraint problems. *Resource leveling* describes the situation when the pattern of resource usage must be improved by leveling. This condition may arise when frequent changes in the amount of a particular manpower category required lead to undesirable human resource policies (e.g., boom and bust hiring and firing). Procedures use heuristics and graphical techniques to juggle schedules within the limits of available schedule slack. *Fixed resource limits scheduling* describes the situation when there are definite limitations on the amount of resources available to carry out the project (or projects) under consideration. This category includes the multiproject scheduling problem addressed here. The category can be further segregated to those problems when the fixed limits are constant and those when the limits are allowed to vary from one period to the next.

There are two major categories of solution techniques being applied to these problems: Heuristic approaches have been used successfully for many medium sized problems although they are not guaranteed to provide an optimal schedule; Optimization techniques are increasingly being

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2 Chen, Hong, Harrison, J. Michael, Mandelbaum, Avi, Van Ackere, Ann, and Wein, Lawrence M., "Empirical Evaluation of a Queuing Network Model for Semiconductor Wafer Fabrication," *Operations Research* Vol.36, No. 2, March-April 1988.

3 Baskett, F., Chandy, K.M., Muntz, R.R., Palacios, F.G., "Open, Closed, and Mixed Networks of Queues with Different Classes of Customers," *Journal of the Association of Computing Machinery* Vol.22, 1971, pp. 248-260.

4 Moder, J.J., Phillips, C. R., and Davis, E. W., *Project Management with CPM, PERT, and Precedence Diagramming*, 3rd ed. New York: Van Nostrand Reinhold, 1983, Chapter 7.

applied although they are still limited to relatively small scheduling problems due to computing constraints. A survey of heuristic approaches is provided by Davis and Patterson.[5]

Optimization approaches include both linear programming (LP) methods and enumerative or other mathematical techniques. LP methods do not seem to work well for the large, complex problems easily handled by heuristic approaches. In addition, the effectiveness of these methods is largely unpredictable. Enumerative techniques have shown some promise recently. In a comparison of these methods, Patterson found different approaches to perform better on different project types.[6] Stinson's branch and bound procedure was found to perform the best for problems with high resource constrainedness and a large number of precedence feasible subsets.[7]

The above approaches are oriented towards deterministic representations of project schedules. A few researchers have attempted to simulate stochastic networks. Sullivan, Hayya, and Schaul[8] have focused on developing efficient simulations to account for networks with random activity times using the antithetic variate method instead of Monte Carlo simulation.

Application of Queueing Network Theory to Product Development

A few authors have identified the similarity between a job shop model of manufacturing systems and development processes. Hayes, Wheelwright, and Clark state that "the right starting point for product development and process development capacity planning is never to allocate 100 percent of engineering capacity to known project needs."[9] The right

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5 Davis, E.W, and James H Patterson, "A Comparison of Heuristic and Optimum Solutions in Resource Constrained Project Scheduling," *Management Science*, 21, 8 (April 1975), 944-955.

6 Patterson, J.H., " A Comparison of Exact Approaches for Solving the Multiple Constrained Resource Project Scheduling Problem," *Management Science*, 30, 1984, pp. 854-867.

7 Stinson, Joel P., E. W. Davis, and B Khumawala, "Multiple Resource-Constrained Scheduling using Branch and Bound," *AIIE Transactions*, September 1978.

8 Sullivan, R. S., Hayya, J. C., and Schaul, R., "Efficiency of the Antithetic Variate Method for Simulating Stochastic Networks", *Management Science* 28, 1982, pp. 563-72.

9 Op cit, pg 302.

starting point is always less than 100% utilization and should be lower as the uncertainty in activity times increases within projects and across a portfolio of projects. Smith and Reinertsen[10] discuss the risk of "project overload" in which a firm takes on enough projects to fully utilize its product development resources. They use a simple analysis to show that additional projects can often increase the cycle time for a number of projects, and thereby reduce their profitability significantly.

To the author's knowledge, queueing network theory has never been applied to product development. There are a number of reasons why this is the case:

- In traditional queueing theory, a customer (or job) can only be in one place at a time. In product development one customer (or product to be developed) can be in many places at any one time, that is, electrical engineers probably design an electrical subsystem at the same time mechanical engineers design a mechanical subsystem.
- In traditional queueing theory different resources can have different queueing disciplines. In product development, the queueing discipline is often dependent on the customer type, not the resource type.
- Queueing theory assumes finite or infinite capacity. In product development it is often the case that a company can outsource work, that is, capacity can be variable, especially over longer periods. An additional complication occurs if the pace of work varies according to the size of the queue.

The third issue above has been partially addressed by relaxing the condition of a fixed work rate. Fine and Graves[11] describe such an application of "nontraditional" queueing network theory to the

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10 Smith, Preston G. and Reinertsen, Donald G., *Developing Products in Half the Time*, Florence, KY: Van Nostrand Reinhold, forthcoming, Chapter 11.

11 Fine, Charlie and Graves, Steven, "A Tactical Planning Model for Manufacturing Subcomponents of Mainframe Computers," *J. Manufacturing Operations Management*, 2, 4-34, 1989.

manufacture of thermal conduction modules, a subcomponent for mainframe computers.

Recently there has been some landmark work done to address the first issue above. In queueing theory terms, the situation of being in two or more places at once is called a fork/join queueing network. Jobs split or fork into more than one job and then join together later in the network. It is often the case in product development that a split job must come fully together in order to precede through the next station. This can be described as a joining or a synchronization constraint. A number of sub-jobs must all arrive before the master job precedes. A simple example is the case when two subassemblies must be completed before the assembly can be made. Varma[12] and Nguyen[13] have recently submitted dissertations on this field of queueing networks. These dissertations are discussed below.

Queues with Synchronization Constraints and Parallel Tasks

Varma and Nguyen have each recently completed research independently on non-standard queueing systems which exhibit synchronization constraints. These systems have assumed increased importance in recent years due to their applicability to modeling multi-processor architectures and distributed systems.

Varma develops approximations to performance measures for fork-join queues with resequencing constraints using limit theorems for both heavy traffic systems operating close to full capacity and light traffic systems. The approximation can be used for fork-join queues with general distributions but is limited to symmetric queues, that is, systems in which service times are identically distributed at all queues.

Heavy traffic limit theorems are obtained by means of diffusion approximations. This corresponds to replacing the discrete state or discrete time stochastic process under consideration by a diffusion process, with the understanding that in heavy traffic a scaled version of the original stochastic process behaves similarly to a diffusion process. Light traffic approximations are obtained using theory developed by Reiman and

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12 Varma, Subir, "Heavy and Light Traffic Approximations for Queues with Synchronization Constraints," Phd. Dissertation, University of Maryland, 1990.

13 Nguyen, V. "Heavy Traffic Analysis at Processing Networks with Parallel and Sequential Tasks," Phd. Dissertation, Stanford University, 1990.

Simon.[14] The combination of the two approximations allows one to extrapolate between them to obtain performance measure approximations for all traffic conditions.

Nguyen[15] provides a heavy traffic approximation and steady-state analysis for fork-join queues. The approximation method can handle any distributional assumptions, including systems whose service times have different distributions at each station. However, customers (or jobs) must be homogeneous, routing deterministic feed-forward (acyclic), and the queueing discipline must be first-in-first-out (FIFO).

Nguyen shows that under certain regularity conditions the total job count process converges weakly to a multi-dimensional *reflected Brownian motion* (RBM) whose state space is a *polyhedral cone* in the nonnegative orthant. Weak limits of workload levels and throughput times are shown to be simple transformations of the RBM. A numerical algorithm for calculating the stationary density of the RBM is provided. This representation is particularly useful since the "steady-state throughput time" (a random variable) can be expressed in terms of workload levels and processing times via the "longest path functional" of classical CPM/PERT analysis.

In her dissertation, Nguyen suggests that in heavy traffic the approximation will work fairly well for multi-server queues by scaling queue capacities appropriately. She also suggests that the extension to networks with heterogeneous customers and general routing will be significantly more difficult.

We suspect that a model of multiple product development projects will operate very close to full capacity and thus future efforts will focus attention on diffusion approximations of the performance measures. Kleinrock provides a good summary of this approach.[16]

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14 Reiman, M.I., and B. Simon, "Open queueing systems in light traffic," *Maths. of Oper. Res.*, Vol 14, No 1, pp. 26-59 (1989).

15 Nguyen, Viên, "Processing Networks with Parallel and Sequential Tasks: Heavy Traffic Approximation and Steady-State Analysis," unpublished paper, Stanford School of Business, Stanford University, Stanford, CA 1990.

16 Kleinrock, Leonard, *Queueing Systems, Volume II: Computer Applications*, John Wiley & Sons, NY, NY 1976, pp.62-105.

Research Methodology

This section describes the methods used to examine the feasibility of applying queueing network theory to product development. Our ultimate goal, if it is possible, is to create a decision-making tool that effectively models the future performance of a corporation's product development efforts. This work represents the preliminary work toward that end.

We began by defining what our ultimate goal would be: a software program to simulate the consumption of product development resources as a function of the number and types of product development efforts on-going at any one time. The model would allow one to evaluate the effect of starting or stopping a product development effort on all the other product development efforts in terms of their time to market and cost performance.

The next step was to begin searching for the data that would be necessary for such a model. From a queueing perspective, we wanted to be able to calculate utilization rates (demand/supply), service rates, arrival rates, and queueing disciplines. Ideally, this data would be available for all the resources that support product development, that is, *human* resources such as marketing, engineering, research, and manufacturing, and *capital* and *administrative* resources. Unfortunately however, since this is a novel way to approach this area, very little data was currently being collected.

Two departments within the sponsor company currently collect some of the data we need to understand how *human* resources are being consumed: Product Engineering (PE), and Engineering, Research and Development (ER&D). The database, called the Electronic Timecard System, is used as a management information and financial accounting system. On a weekly basis, all engineers, technicians, and support personnel fill out cards that indicate what they worked on over the last week. Codes indicate whether individuals worked on specific product development efforts, core technology or support projects, or were absent for various reasons.

Although this database indicated how each person spent their time each month, it did not classify employees by specific skills. A new field was added to the personal records to allow for skill codes and we attempted to classify each person. Current employees were relatively easy since the sponsor company already had another information system that contained a skill classification system. Information for employees who had since left the company was more difficult to collect. Most of these past employees were classified by interviewing department supervisors.

The next step was to analyze the database for evidence of queueing effects. This analysis is described in Chapter 5. There is some indication that queues are forming at some resources.

We began analyzing the data on a product by product basis to try to determine a reasonable network structure and link the queueing data to other schedule and anecdotal data. The results of this analysis are described in Chapter 6.

Based on these results, alternate formulations of a queueing network model are proposed in Chapter 7. Future work is also discussed.

A Conceptual Queueing Network Model of Product Engineering

Product Engineering is one of the eight organizations that support product development in some way at the sponsor company (see Figure 7.1 for others). Most of the development work, however, occurs in ER&D and Product Engineering. Using the Electronic Timecard database, the Product Engineering department is described conceptually as a queueing network. The model consists of an open network of ten different human resources (skill bases). Customers or jobs are the specific products to be developed. Jobs arrive at each resource with a certain amount of development work necessary. The time for a job to pass completely through the network is a function of the resource capacity (headcount and productivity) and the number of other jobs "competing" for the resources.

Figure 4.2 provides a graphical representation of a potential model structure. We present it here by way of example only. The arrows represent the progression of sub-projects through various resource centers. Sub-projects may be passed back to the originating resources due to rework or additional qualification. Associated with each arrow would be some routing probability. This may or may not vary with job type.

A Conceptual Queueing Network Model of the Product Engineering Department

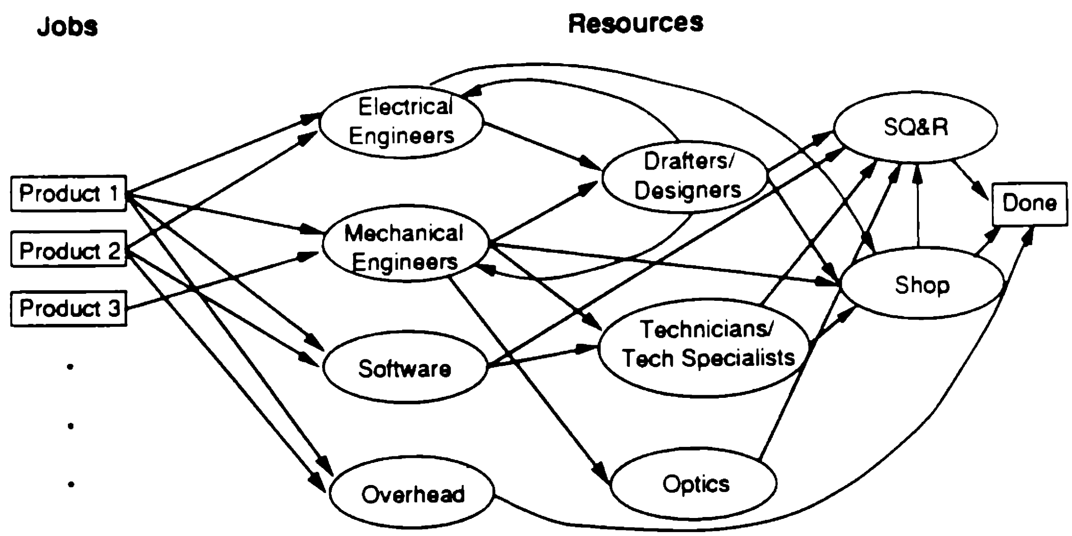

Figure 4.2

As presented, the model indicates three stages roughly corresponding to the usual progression of development. Development begins with engineers laying out a system design and developing sub-systems and parts. Electrical and mechanical engineers transfer work to technicians, and drafters and designers to fully specify designs. These groups in turn transfer work to the shop to build prototypes and models, and System, Quality and Reliability (SQ&R) to design tests and comment on quality issues. The product is fully developed after final prototypes have been built and qualified.

Note that the network described in Figure 4.2 is acyclic and routing was not necessarily deterministic. The same job may flow through the same resource more than once. This precludes the use of Nguyen's heavy traffic approximation discussed earlier.

The following describes various characteristics of the model more fully.

Resources

The conceptual model consists of the following ten human resources:

1) Electrical Engineers (EE)

2) Mechanical Engineers (ME)
3) Drafters and Designers (DFTR/DES)
4) System Quality and Reliability Engineers (SQ&R-ENG)[17]
5) System Quality and Reliability Technicians (SQ&R-TECH)
6) Software Architects, Designers, and Coders (SOFT)
7) Optics Engineers and Technicians and Opticians (OPTICS)
8) Technicians and Technical Specialists (TECH)
9) Shop Personnel, Modelers, and Machinists (SHOP)
10) Administrative and Support Personnel (OH)

Each of these human resources can be viewed as a multi-server resource with the number of servers equal to the number of people in each resource. That is, we assume as a first approximation that people are roughly identical. (Note: future formulations may adjust for experience level.)

Some people work on only one project for years. Here the arrival rate is very low as is the corresponding service or work rate. For example, one project may arrive every three years (an arrival rate of .33 projects per year), and be completed in 2.9 years. Here the service rate is 1 project per 2.9 years, or .34 projects/year.

Other people work on a number of product development teams simultaneously. There are a few ways to represent this behavior from a queueing perspective. The first is to subdivide jobs into subjobs (projects into subprojects) so that each server only works on one subjob at a time. This would be equivalent to a high arrival rate for the specific subjob type, and a corresponding high service or work rate for the server. Another possibility is to maintain the standard job definition and represent some servers as *shared processors*. Borrowing from traditional queueing theory, shared processing represents a server that works an equivalent amount of time on all the jobs in the queue.

Neither of these representations is ideal however. In the first case the routing of subjobs, and the number of different customer types becomes very complex. The second representation does not allow different priorities

[17] SQ&R engineers and technicians are treated as one resource sometimes.

for different projects. It does however accurately capture the effect that too many projects have on throughput. That is, the service rate for each project becomes slower as more projects are added.

An extra complexity in this model is the use of outside resources. The sponsor company typically hires temporary workers, called "per diems," to handle overload situations. Per diems may be modeled as separate resources that are only used when queues reach a threshold. Another possibility is to allow the capacity (or the work rates) of resources to vary according to the demand for them. In both cases there are limits to how much capacity can be added and over what time frame. For example, overtime can only be added up to some fixed limit of hours per week, and is not feasible over extended periods of time. There are also limits to the number of contract workers that can be hired, and their productivity in the initial period of employment is low as they come up the learning curve.

Customers or Jobs

It is not clear how many customer types are needed to accurately represent reality. There are at least two types of customers: the large, corporate sponsored projects, and the smaller development projects. Typically the first get priority over the second, take five to seven years to complete, and use more fully dedicated resources. The second type are completed in one to four years and are staffed by people serving multiple projects at once. As discussed earlier, accurate representation of this subtlety will be difficult.

Queueing Disciplines

Because queueing theory has been born out of computing research, there are typically only four types of queueing disciplines described:

1) First-in-first-out
2) Last-in-first-out
3) Shared processing, and
4) Preemptive priorities.

One of the challenges of this research is to capture the effective queueing disciplines at the sponsor company. Certain projects have priority. When these projects need more resources (e.g., electrical engineers), resources are borrowed from other projects. One way to model this may be to view the extra work discovered as a second related project (or forked project) with preemptive status.

As discussed earlier, it is typical for a resource to be working on a number of different projects at once. In some respects this corresponds to shared processing, however the dedication of resources is not necessarily equal (as it is for traditional queueing theory) for all customer types.

Network Structure

Figure 4.2 presented a potential network structure but is incomplete in many respects. The network structure should become more apparent after an analysis of a combined activity and resource network representation of product development similar to the generic schedule discussed in Chapter 3. Further research will attempt to determine the network structure. This is discussed more fully in Chapter 7.

The Electronic Database

As discussed early, the raw data for the following analysis comes from the electronic timecard system. Historical data is stored in monthly buckets by employee clock number. Contract workers are indicated by a clock number that begins with "999." Stored data includes the number of regular hours and overtime hours worked, and the number of "person equivalents." "Person equivalents" is the total number of hours worked multiplied by a factor. This factor (called the Full Time Equivalent or FTE) is calculated based on the ratio of total absence in the department to the number of regular hours available each month. The use of "person equivalents" helps smooth resource reporting for seasonal absence effects.

The time data is further subdivided by subgroups and trunk codes. Subgroups represent a particular program (technology program) or use of time (e.g., *absence* is one subgroup). Trunk codes divide subgroups into specific products or subsystems (e.g., *customer visit* might be a specific trunk code within the subgroup *overhead*). The following analysis works with data at the subgroup level.

Limitations of the Data

This data is not completely consistent with a CPM or queueing network representation of activity times. The data is seen by top management and used for budgeting purposes so there is a strong incentive for engineers to ensure that forty hours are accounted for every week. In a naive formulation of the model, this implies 100% utilization of every person! From a queueing perspective, this would imply infinitely long queues.

The accuracy of the time period for this data is also circumspect in many cases. Frequently it appears that groups of people forget to file their time cards one month, only to file two months worth the next month. Where necessary, it is possible to use smoothing functions (moving averages) to filter this effect.

Approximately 600 people have worked in the area to be analyzed, of which only 300 are still employed. Resource classifications for all the people who have since left the company were not available. In most cases uncoded people represent less than 5% of total resources.

Finally, segmentation of employees into skills was not ideal. For example, there are drafters that specialize in mechanical work and others that specialize in electrical. The nature of the work done by drafters and designers, and technicians and technical specialists is not identical. Additionally there are some drafters skilled in the use of CAD systems and others who are not. Future work may try to enhance the skill coding system. Chapter 7 discusses some of these model formulation alternatives.

CHAPTER 5: ANALYSIS OF AGGREGATE DATA

This chapter describes the initial analysis of the electronic timecard database from the product engineering department. Aggregate data for each skill category was analyzed to detect evidence of queues forming, and identify potential bottlenecks in the department. Time series data is available for the period from November 1987 to October of 1990.

Queueing Effects

As discussed above, it is difficult to verify that a queueing model accurately describes performance since all the corporate resources are not being modelled (largely because the empirical data does not exist in these other areas) and thus, the actual product development schedule slippage cannot be compared to model predictions. Instead, the desire is to identify other manifestations of queueing effects and try to evaluate what the cost of these queues may be in terms of lost time to market, extra development costs, and additional complexity.

The following queueing effects are hypothesized:

- overtime hours
- use of contract workers (per diems).

As more work queues at a resource, the percentage of work done on overtime and by per diems is expected to rise. That is, we make the assumption that managers and employees recognize that queues are forming and begin working overtime and/or hiring per diems to handle the extra work.

Another indication that queues are being observed will be their relationship to indications of underutilization of resources, that is, those periods when it appears there are sufficient resources to do the work at hand. The following underutilization effects are hypothesized:

- hours of absence
- hours of work on non-product related projects (core technology).

As the size of the queue diminishes, the percentage of absence and the time spent working on core technologies is expected to rise. We assume that as the amount of work in the queue decreases employees begin taking

Statistics for Monthly Timecard Data by Skill
36 Months - November 1987 to October 1990

		EE	ME	SW	Dftr/ Des	Shop	SQR Eng	SQR Tch	Tech/ TSpec*	Optics	Ohd	Oth	Dept
People Months	Average	29.30	37.71	11.76	47.04	58.10	24.26	11.80	25.59	15.51	35.82	3.12	300.00
	% of Dept	9.8%	12.6%	3.9%	15.7%	19.4%	8.1%	3.9%	8.5%	5.2%	11.9%	1.0%	100.0%
	Std. Dev	3.91	4.44	6.00	5.67	3.76	1.87	1.22	5.08	1.14	2.64	1.02	
	StdDv/Avg	0.13	0.12	0.51	0.12	0.06	0.08	0.10	0.20	0.07	0.07	0.33	
Absence	Average	11.6%	11.7%	6.6%	12.2%	12.7%	12.6%	17.2%	12.7%	11.8%	13.3%	13.1%	12.1%
	Std. Dev	6.8%	6.5%	5.8%	7.4%	5.7%	8.1%	6.7%	6.8%	6.7%	6.8%	8.8%	
Core	Average	3.3%	1.7%	0.0%	0.2%	5.1%	0.1%	4.5%	1.6%	30.3%	0.2%	0.0%	2.3%
	Std. Dev	2.4%	1.5%	0.0%	0.4%	2.2%	0.2%	1.1%	1.3%	8.5%	0.4%	0.0%	
Overhead	Average	4.9%	8.2%	8.5%	7.0%	6.1%	12.6%	12.0%	5.8%	10.2%	67.6%	4.1%	14.6%
	Std. Dev	6.7%	5.9%	6.3%	5.8%	6.4%	8.3%	7.4%	7.3%	7.1%	7.6%	6.8%	
Per Diems	Average	0.4%	4.1%	58.6%	17.5%	8.1%	0.0%	0.0%	10.8%	2.4%	3.5%	0.0%	8.6%
	Std. Dev	1.1%	7.9%	29.8%	6.2%	3.0%	0.0%	0.0%	7.5%	2.3%	1.8%	0.0%	
Overtime	Average	0.5%	0.6%	2.0%	4.2%	10.9%	0.8%	3.6%	2.1%	0.2%	1.0%	0.3%	3.5%
	Std. Dev	0.7%	1.5%	1.2%	3.1%	1.2%	1.2%	2.5%	1.4%	0.4%	0.4%	1.0%	

* Data for 11/88 is omitted for Technicians and Technical Specialists due to data error.
Data has been disguised for proprietary reasons.

Table 5.1

previously delayed vacations or begin working on new technologies, unrelated to any specific product.

Some aggregate statistics for the time series data collected are reported in Table 5.1 below. In addition to the four proposed queueing effects mentioned above, the table includes statistics for the number of people months entered in each skill group, and the percentage of time spent working on "overhead" projects for each resource. Overhead allocations include education, safety or scientific meetings, clerical activities, instrumentation development, shop support, competitive product analysis, and CAD library support.

"Absence" is the number of hours a skill group was absent divided by the total number of hours accounted for that month. The subgroup "absence" includes a variety of trunk codes such as authorized and unauthorized absence, vacation, family emergency, family death, civic obligation, scheduled holidays, seniority vacation, personal illness, industrial accidents, and personal conviction. The variation in average absence between skill groups is believed to result from differing seniority among different skill groups.

"Core" and "overhead" are the ratio of hours worked on core technology and overhead projects, respectively, to total hours accounted for (work & absence). "Per Diems" is the ratio of hours worked by contract workers to company employees. Finally, "overtime" is the ratio of overtime hours worked to total hours accounted for.

The largest resources in the Product Engineering department are shop personnel and drafters and designers (an average of 58 and 47 people, respectively). Software resources have been growing rapidly over the period studied and thus show the highest ratio of standard deviation to average people months (.51). The "other" resource (OTH) includes people with specialty skills (e.g., information systems analyst) and individuals we were unable to classify.

The statistics indicate stark differences in average levels and the monthly variability of these queueing effects across different resources. The hypothesized queueing effects are analyzed and reported individually below.

Overtime

The percentage of time a group works overtime seems to be a good indication of whether or not the group is under pressure to deliver a product. Overtime can result from at least three cases: 1) a group underestimated the time needed to complete a task; or 2) the group committed to more tasks than it can complete in a given time period; or 3) a group actually planned to work overtime in order to allow a dependent task to start earlier.

In the first case we would expect the overtime to be localized within a subgroup of people committed to the project, that is, if the group is working on multiple projects at once. In the second case we would expect the overtime to be distributed among everyone in the group. In the third case, either result is possible.

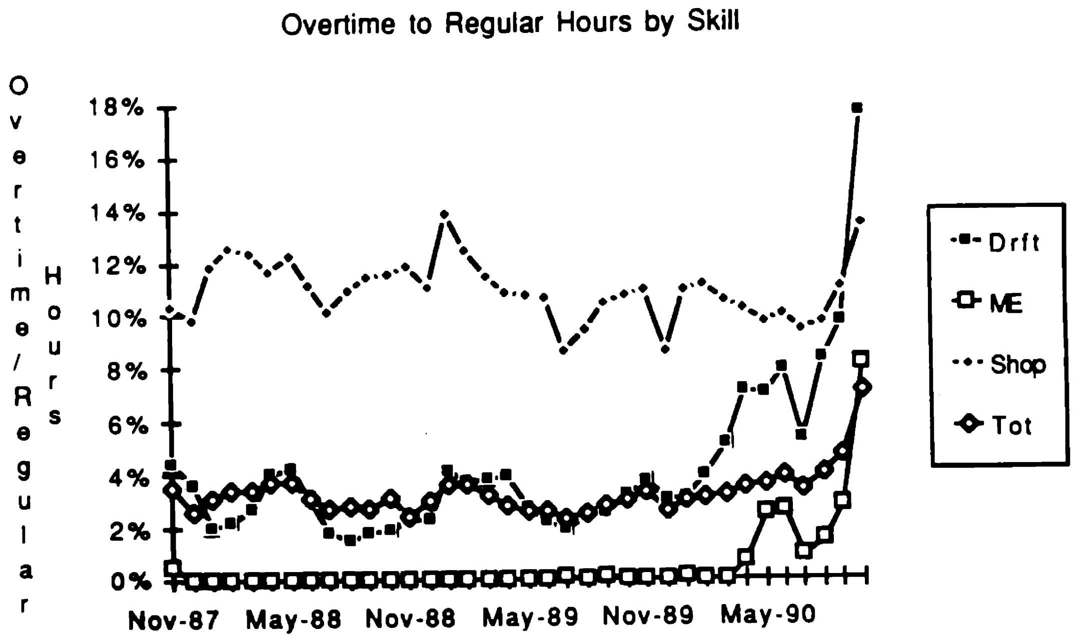

Figure 5.1

Overtime to Regular Hours by Skill

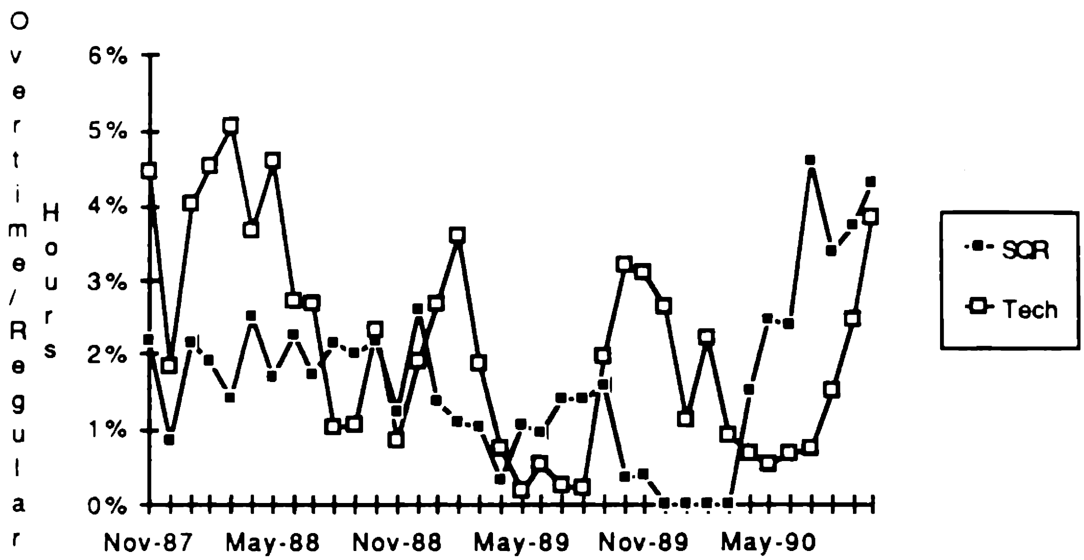

Figure 5.2

Overtime to Regular Hours by Skill

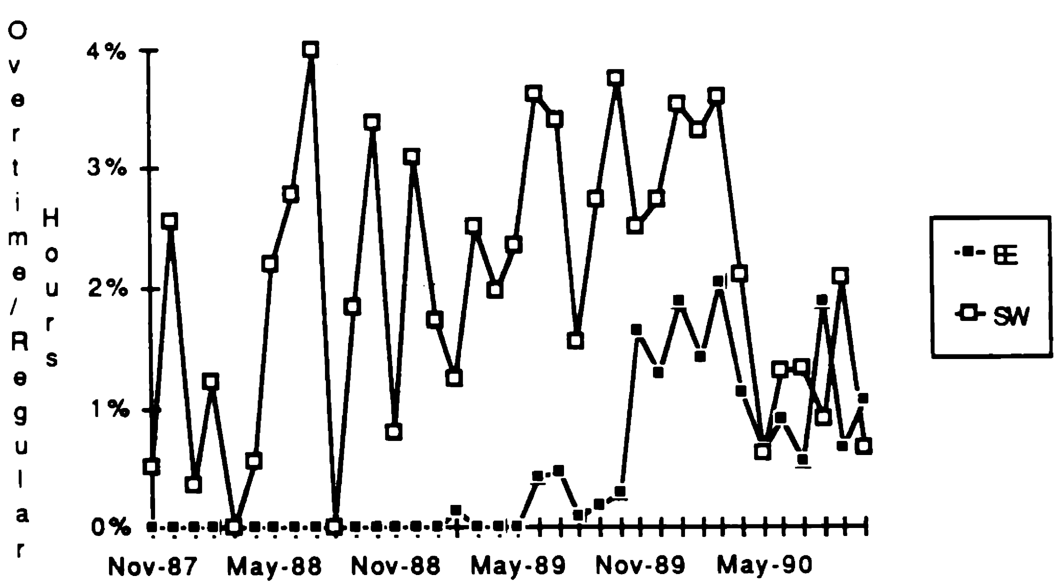

Figure 5.3

Unfortunately, the overtime data is incomplete since only workers in some salary grades have a financial incentive to record overtime hours. (Others do not get paid for the extra hours.) Drafters, designers, and shop workers show the highest percentage of overtime because they are dominated by employees that do earn overtime pay (see Figures 5.1, 5.2, and 5.3).

The data does exhibit some macro trends. There are seasonal effects; overtime seems to drop in July and August (a popular vacation time) and during the holiday periods in November and December.

The rise in overtime for drafters and designers since January 1990 suggests that there may be queues forming at these resources. Also note that the average overtime for the whole department was at an all time high in October 1990 ("Tot" is the department average in Figure 5.1). This increase seems largely due to the fact that two large projects (Jason and Icarus) are at about the same point of development (i.e., the design stage).

Contract Labor

The use of contract labor is another good indication that the demand for a specific skill exceeds supply. As in the above case, the use of contract workers can result from at least three cases: 1) a group underestimated the time needed to complete a task; or 2) the group committed to more tasks than it could complete in a given time period (i.e., a result of interschedule conflicts); or 3) a group actually planned to hire per diems in order to allow a dependent task to start earlier.

Of course, contract labor can be a very efficient way of managing the variability in demand for certain resources. A new product may require specific skills that are not available in-house, and will not be needed after a product is launched. The use of contract labor also allows one to screen new employees before hiring them as permanent employees.

The trade-off, however, can be delays in the time to market. Contract workers may be less efficient in the short run because they are unfamiliar with a company's systems, culture, and organization. If workers are brought in late in the development process, they will not have the benefit of understanding why certain product decisions were made, and may start to question those decisions. Apart from not being fully productive, contract workers may hamper the productivity of others on the product team who are needed to bring them up to speed. Because they are not full time employees who must live with their mistakes, the quality of their work may also be sub-standard.

Figures 5.4, 5.5, and 5.6 show the ratio of hours worked by contract workers to regular company employees. The use of per diems has been rising gradually on average over the period studied as shown in Figure 5.4 ("Tot" is the average for the department in Figure 5.4). In late 1987, the ratio of per diems to regular employees averaged about 6%. This ratio had risen to about 10% by the end of 1990.

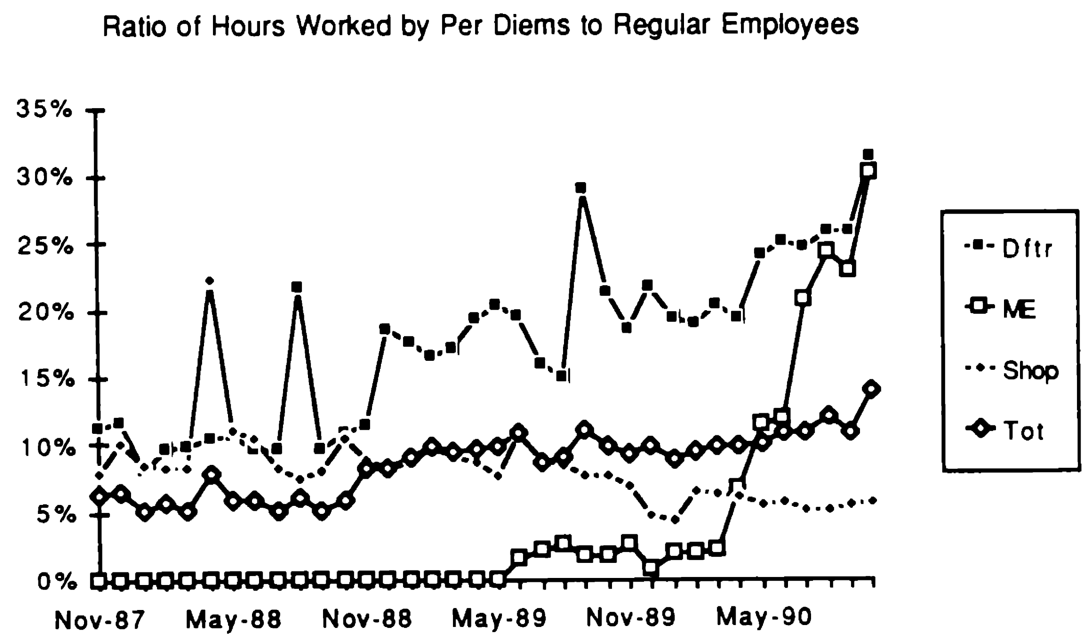

Figure 5.4

Ratio of Hours Worked by Per Diems to Regular Employees

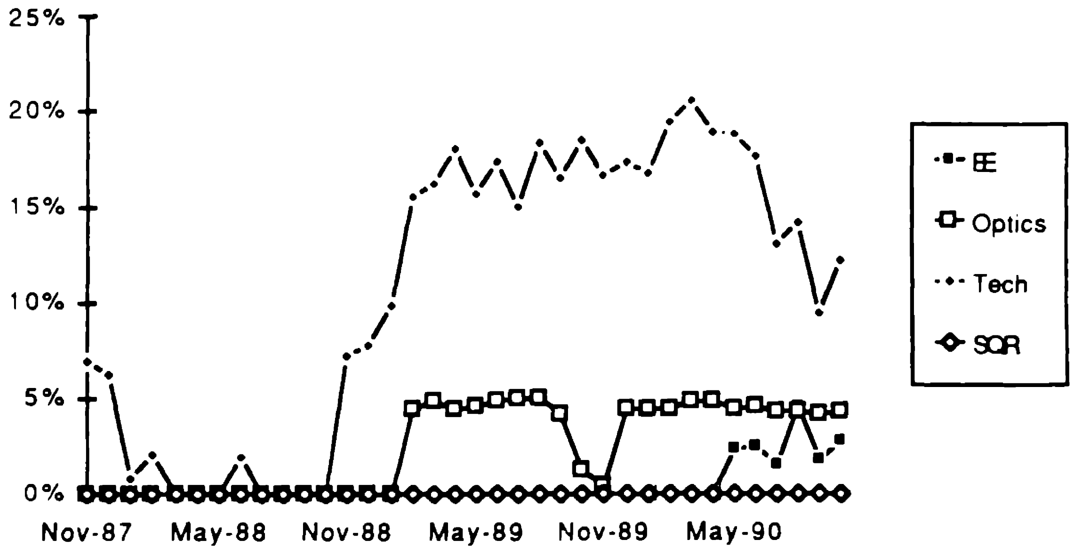

Figure 5.5

Ratio of Hours Worked by Software Per Diems to Regular Software Employees

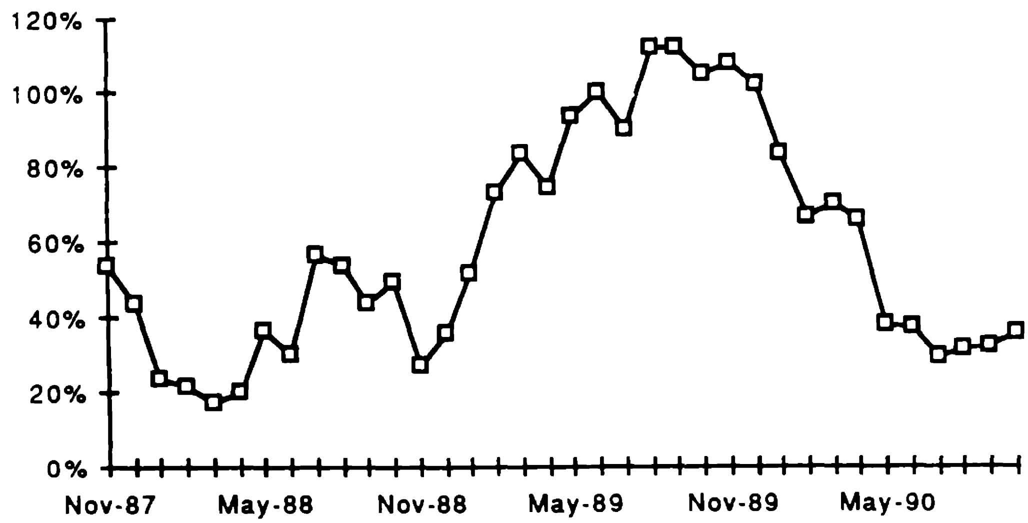

Figure 5.6

The use of contract software workers has traditionally been much higher than any other skill base. In mid-1989, over half of the hours spent producing software were by non-company employees. This appears to have been both a demand and supply issue. The software content in the company's products has been rising rapidly. Figure 5.7 shows the total demand for software development in man months, and the total headcount of company employees with software expertise over time. In spite of this constant increase there has been a large lag between the need for software expertise and the subsequent full time hires. The graph indicates that since 1988, it took five to ten months for the company to hire enough full time employees to meet demand, although this lag seems to be diminishing lately.

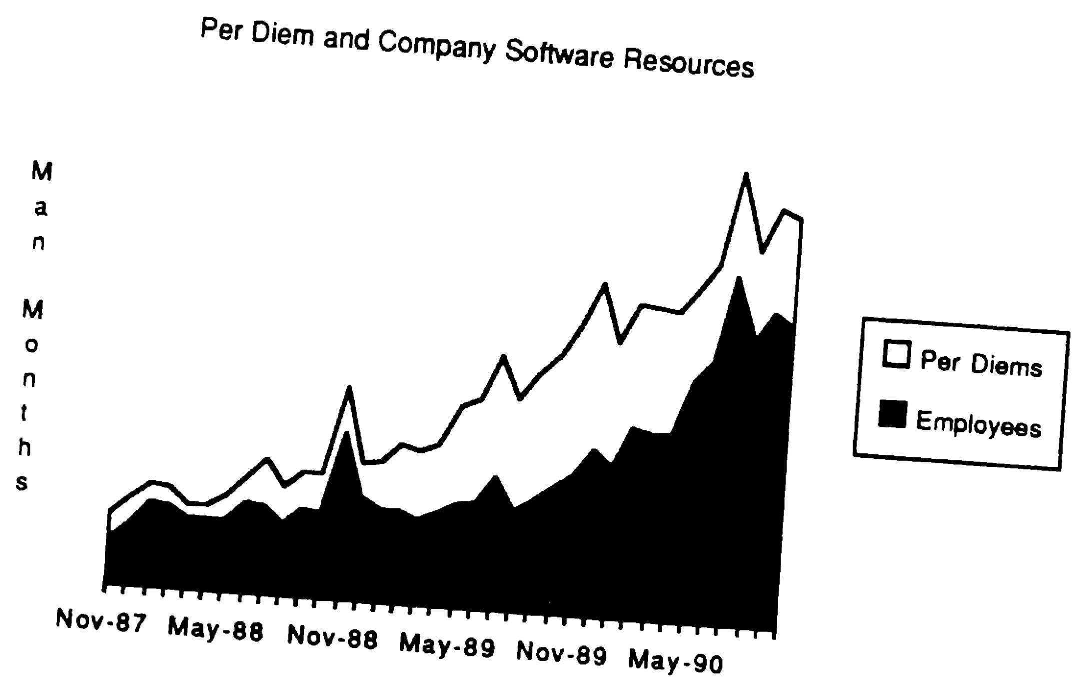

Figure 5.7

Absence

Just as the use of overtime or contract labor suggests that a queue may be forming at a resource, a rise in absence is speculated to indicate underutilization of a resource. Conversely, a decrease in absence indicates that a queue may be forming. There is a strong seasonal effect in the summer months (July and August) and during November and December, although this effect seems to vary according to skill type. Figure 5.8 shows a representative graph of this data. To understand the relative pressure to remain at work, a seasonally adjusted absence is calculated by subtracting the average monthly absence for each resource from the raw data. Figures 5.9 through 5.13 graphically display this data. Absence is adjusted by seasonal resource averages because different skill groups tend to vacation at different times during the year.

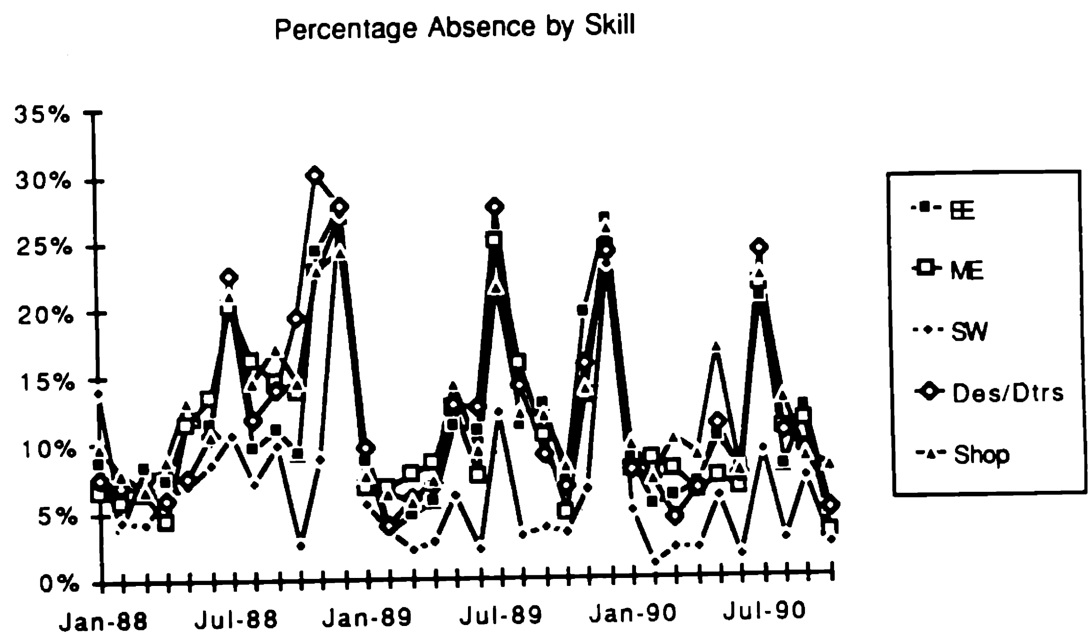

Figure 5.8

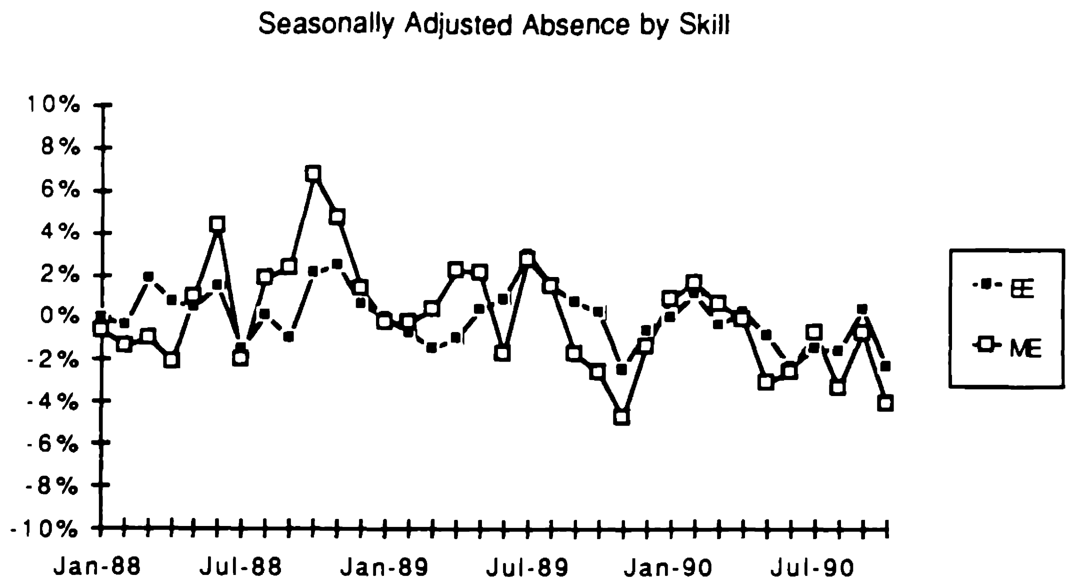

Figure 5.9

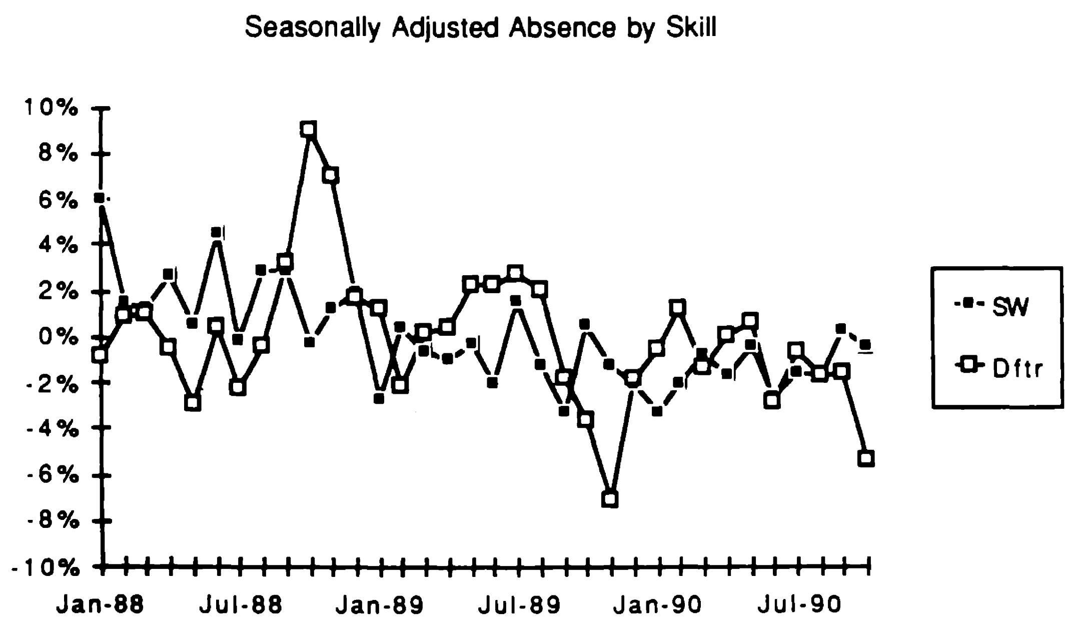

Figure 5.10

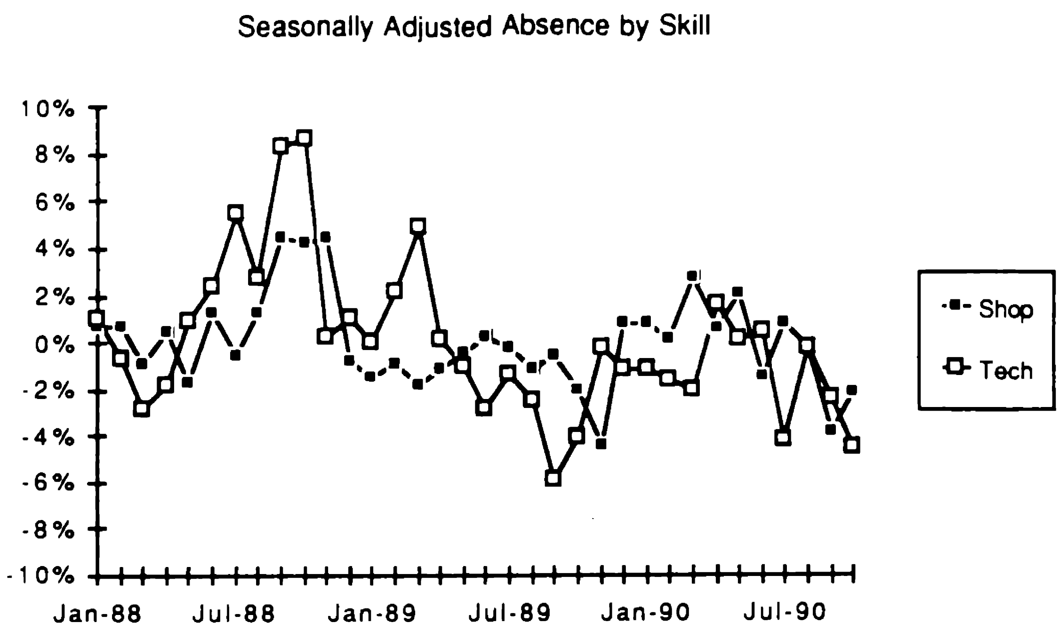

Figure 5.11

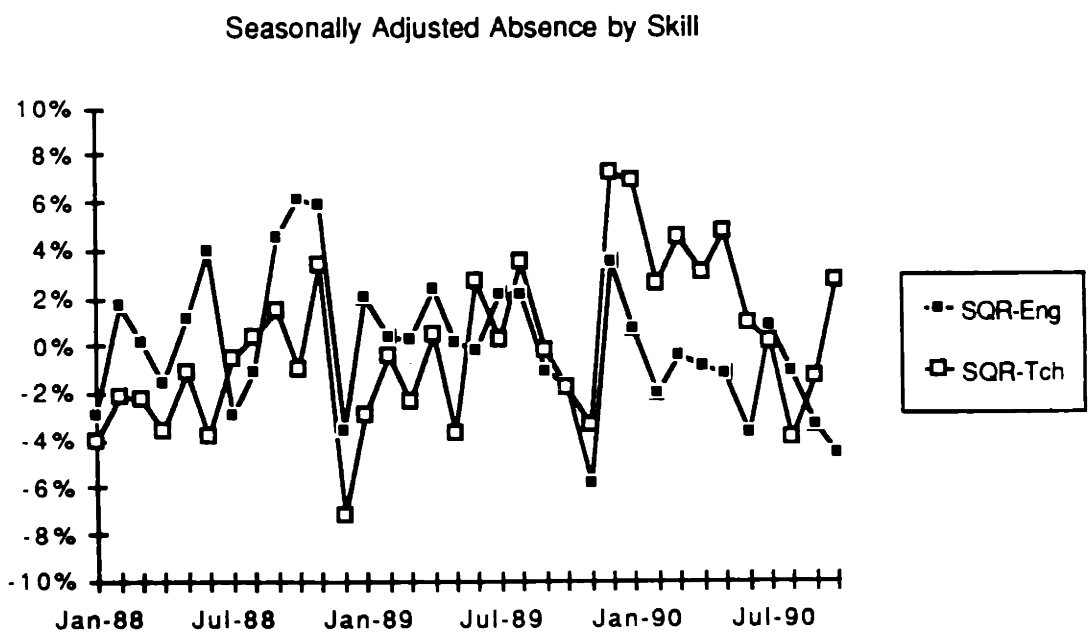

Figure 5.12

Seasonally Adjusted Absence by Skill

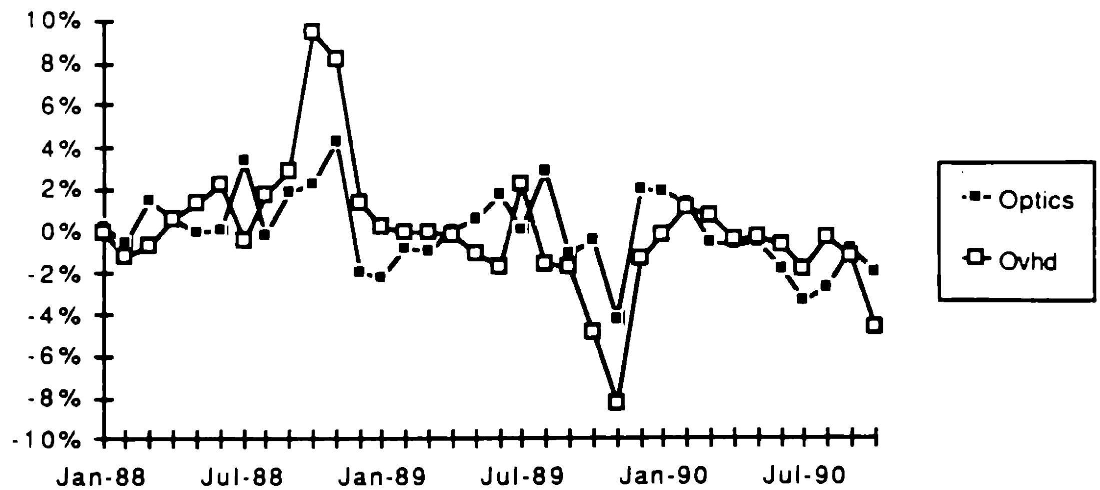

Figure 5.13

Core Technology

It was hypothesized that the transfer of people from product development related projects to core technology projects may also signal excess resources or underutilization. Figures 5.14, 5.15 and 5.16 show this data. The correlation analysis shown below does not support this hypothesis.

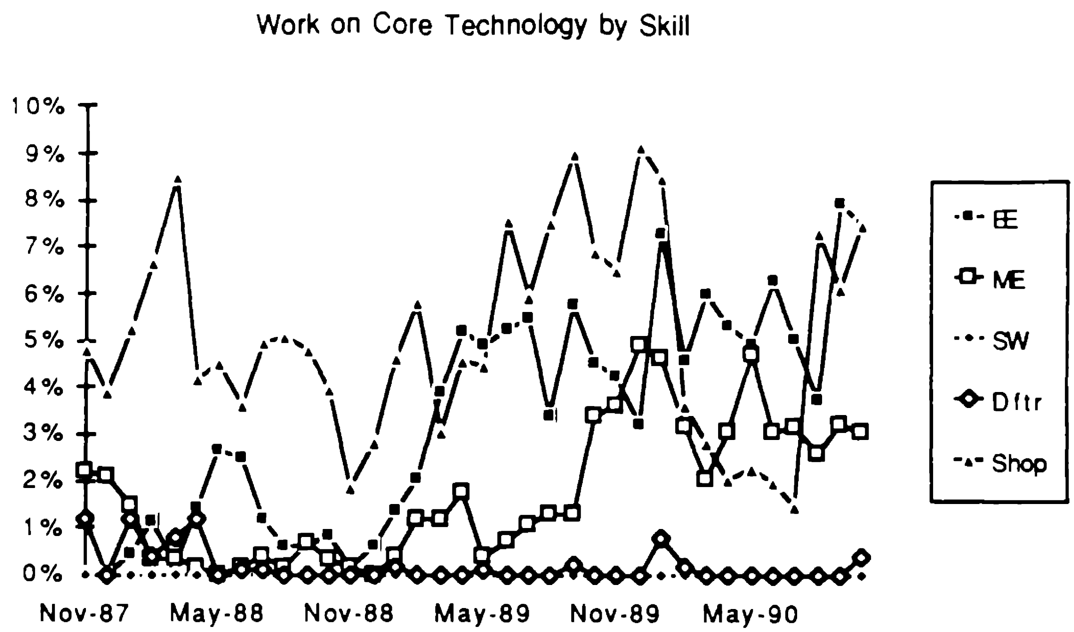

Figure 5.14

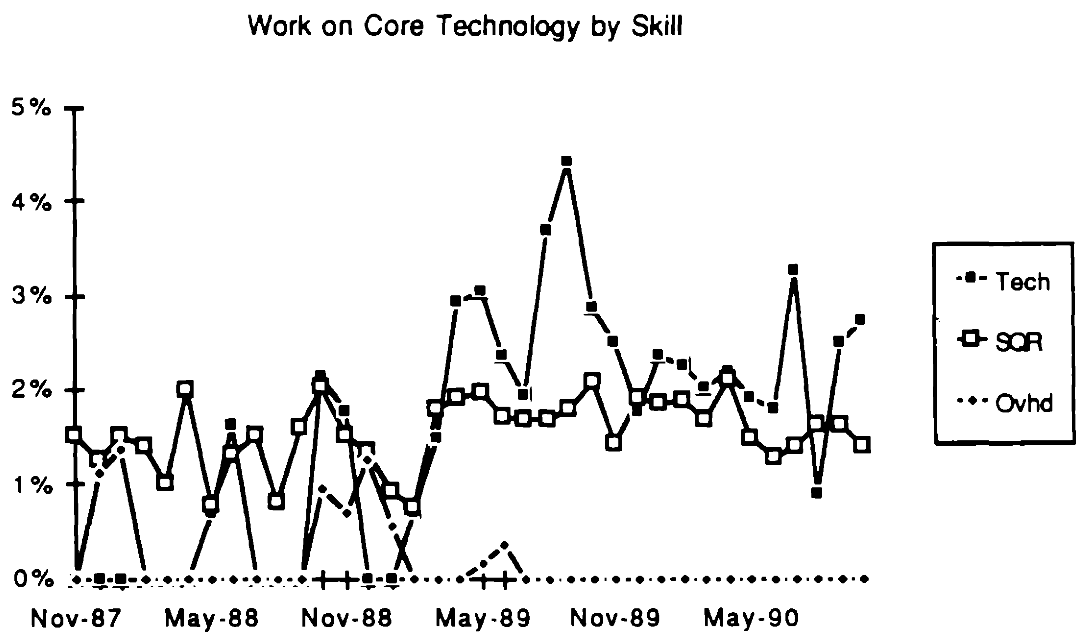

Figure 5.15

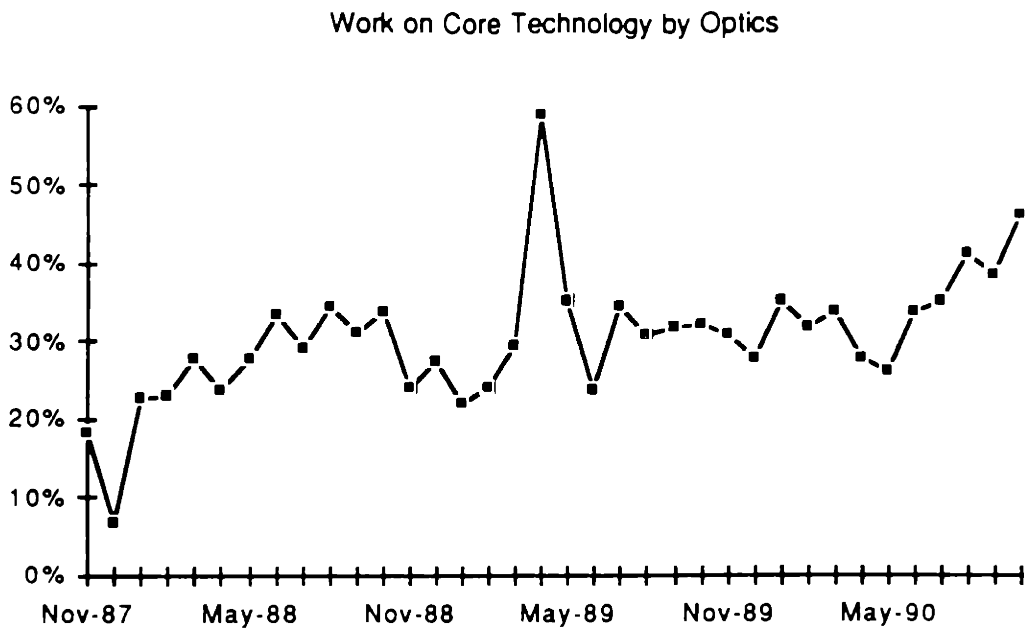

Figure 5.16

Correlation of Queueing Effects

In order to build some confidence in the hypothesized queueing effects, the correlations among the four factors mentioned above were calculated. A priori the use of overtime and per diems are expected to be positively correlated to one another, and both negatively correlated with absence and work on core technology. Table 5.2 summarizes this analysis.

The correlation analysis is somewhat supportive of the proposed hypotheses, except for the relationship between core technology work and the other factors. The use of overtime and per diems is negatively correlated with absence (an average across skills of -.335 and -.325, respectively), and positively correlated with each other (.306). Overtime is negatively correlated with absence for the nine resource types shown. Per diems are negatively correlated with absence for six of the seven resources where data is meaningful (SQ&R has never hired a per diem). Overtime is positively correlated with per diems in six out of the seven cases. Interestingly, the two exceptions above were for the shop, and technician and technical specialist resources, respectively. Both of these resources have a higher percentage of hourly workers compared to the other resources. For shop personnel this implies that absence increases as per diems are added. For technicians, overtime decreases as per diems are hired.

The hypothesis that employees tend to work on core technology when they have slack periods is not supported at all. In fact as work on core technology increases, absence goes down, and the percentage of work by per diems and on overtime rises, although these correlations are weaker on average and more mixed than the above results. This relationship suggests that core technology should not be viewed as a place to work when there is insufficient product development work. Instead it should be treated as similar to any other product development efforts. This will be discussed in Chapter 7.

Correlation of Queueing Effects

		Seasonally Adjusted Absence	Core Technology	Per Diems	Overtime
Electrical Engineers	SeasAdjAbs	1.000			
	CoreTech	-0.258	1.000		
	PerDiems	-0.478	0.394	1.000	
	Overtime	-0.350	0.610	0.425	1.000
Mechanical Engineers	SeasAdjAbs	1.000			
	CoreTech	-0.485	1.000		
	PerDiems	-0.454	0.479	1.000	
	Overtime	-0.424	0.380	0.834	1.000
Software	SeasAdjAbs	1.000			
	CoreTech	•	1.000		
	PerDiems	-0.490	•	1.000	
	Overtime	-0.314	•	0.552	1.000
Drafters/ Designers	SeasAdjAbs	1.000			
	CoreTech	-0.070	1.000		
	PerDiems	-0.415	-0.357	1.000	
	Overtime	-0.455	-0.035	0.615	1.000
Shop	SeasAdjAbs	1.000			
	CoreTech	-0.327	1.000		
	PerDiems	0.087	-0.112	1.000	
	Overtime	-0.082	0.023	0.270	1.000
SQ&R Engineers	SeasAdjAbs	1.000			
	CoreTech	-0.156	1.000		
	PerDiems	•	•	1.000	
	Overtime	-0.419	0.253	•	1.000
SQ&R Technicians	SeasAdjAbs	1.000			
	CoreTech	0.322	1.000		
	PerDiems	•	•	1.000	
	Overtime	-0.496	-0.421	•	1.000
Technicians/ Technical Specialists *	SeasAdjAbs	1.000			
	CoreTech	-0.476	1.000		
	PerDiems	-0.458	0.695	1.000	
	Overtime	-0.038	-0.470	-0.514	1.000
Optics	SeasAdjAbs	1.000			
	CoreTech	-0.161	1.000		
	PerDiems	-0.135	0.445	1.000	
	Overtime	-0.345	0.500	0.208	1.000

Average Correlations	SeasAdjAbs	1.000			
	CoreTech	-0.201	1.000		
	PerDiems	-0.335	0.257	1.000	
	Overtime	-0.325	0.105	0.306	1.000

* Time series data excludes bad data in 11/88

Table 5.2

Evidence of Queues

Three factors (overtime, absence, and contract work) seem to be reasonable indicators of queueing effects in that they seem to change over time as would be expected if queues were forming. This section analyzes each resource or skill base individually to determine where queues seem to be forming most frequently.

Electrical Engineers

There is relatively little evidence of queues forming among electrical engineers. Figures 5.3, 5.5, and 5.9 show little overtime or contract work, and a rather stable pattern of absence. Table 5.1 indicates that electrical engineers work slightly more than average on core technologies. This may be an indication of future product development efforts.

Mechanical Engineers

There is evidence of queues forming among mechanical engineers since March of 1990. The dramatic increase in the use of contract labor in Figure 5.4 provides the best evidence of a potential queue forming. Since March 1990, the percentage of work by per diems has risen from 2% to 30%. Figure 5.1 shows a sharp rise in overtime in October, and average absence has been below normal for the year according to Figure 5.9.

Software

It seems likely that queues are significantly slowing products that require software development. Table 5.1 highlights the abnormally higher percentage of per diems, lower absence, and nonexistent work on core technology. Because the company has been growing its manpower rapidly, the low absence may in fact be related to the low average seniority of those with software skills.

Drafters and Designers

Since early 1990, it appears that queues have been forming among drafters and designers. Figure 5.1 shows the jump in overtime from about 4% to 18% of regular hours worked with a major increase since March 1990. Figure 5.4 also indicates a rise in per diems first in December 1988 and again in May of 1990. Figure 5.10 displays a low level of absence between September and December 1989, and again between June and October 1990. Drafters and designers have the second highest percentage of per diems overall as shown in Table 5.1.

Shop

It is unclear whether queues are forming among shop workers (machinists, modelers, and others). The group works a high amount of overtime relative to other resources, but this is probably related to the predominance of employees that earn overtime pay. The low and declining level of per diems may also indicate that there is sufficient capacity. Finally, the low variability in the number of per diems suggests that they are not being used in response to changing demand conditions.

System Quality and Reliability

This resource does not seem to be experiencing queueing effects. Table 5.1 indicates the use of per diems is nil, overtime work is average to low, and absence is relatively high although this is probably due to the seniority of those in the group.

Technicians and Technical Specialists

This resource may also be experiencing moderate queueing effects, although the results are inconclusive. Figure 5.5 shows the high percentage of per diems used in 1989 and early 1990. Absence was lower during the latter half of 1989 and overtime did rise in the last quarter of 1989 as shown in Figures 5.11 and 5.2 respectively. The data for this resource seems suspect for the first half of the period studied; headcounts vary widely from one month to another. The high ratio of standard deviation to the average number of people months in Table 5.1 highlights this problem.

Optics

This rather small resource does not appear to be a bottleneck. The use of per diems and overtime is well below the average, and the work on core technology is the highest. Interviews seem to indicate that optical design can often be done quite quickly relative to other subsystems.

Overhead and Support

This resource includes both administrative managers and assistants. The low level of per diems and overtime, and relatively high absence indicate that this is probably not a bottleneck.

Formation of Queues in Product Engineering

Resource	Evidence of Queues	Period of Queues
Electrical Engineers	low	
Mechanical Engineers	medium	3/90 - 10/90
Software Engineers	high	11/88 - 10/90
Drafters & Designers	medium - high	medium 9/89 - 3/90 high 3/90 - 10/90
Shop	low - medium	1/88 - 5/88 1/89 - 2/89 9/90 - 10/90
SQR	low	
Techs. & Tech. Spec	inconclusive	
Optics	low	
Overhead	low	

Table 5.3

Table 5.3 above summarizes the results of this analysis. It appears that significant queues are forming among software, drafters and designers, mechanical engineers and shop personnel in declining order of intensity. Chapter 6 attempts to verify these results by focusing on specific product development efforts and some anecdotal information about schedule slippage.

CHAPTER 6: ANALYSIS OF SPECIFIC DEVELOPMENT PROJECTS

The previous chapter focused on aggregate data for each skill code and attempted to find indications of queueing effects. This chapter describes the analysis of the timecard database sorted according to product development programs. The purpose of this analysis is threefold: first, we want to observe the resource usage of specific product development efforts and relate this data to anecdotal information about schedule performance; second, we want to compare resource allocation budget data to the hypothesized queues to build confidence in our queue indicators; and third, we want to make observations about the possible structure of a queueing network to represent the department.

Management Policies at the Sponsor Company

Management policies for research and development resource allocation and project prioritization affect how the product development projects *move* through the Product Engineering department. These policies are described here because they give us some insight into what the data mean.

Similar to most companies, the company relies primarily on an annual budgeting process to make resource allocation decisions. This provides a rough cut estimation of headcounts for each project. Resource allocation is fine tuned throughout the year to react to changes in customer market conditions, or over or under-estimated resource needs. Some projects may be slowed down or stopped to free up resources for another more critical project. Alternatively, resources may be added to speed up a development effort. While this process has worked relatively well in the past, the company is attempting to improve the process as life cycles shorten, and the number of potential new products increases. A decision-making tool to predict where conflicts are likely to occur is one aspect of the improvement efforts.

Annual Budgeting Process

Research and development resources are allocated annually through a budgeting process. Current and potential program managers submit resource requirements in the form of headcounts. Functional managers and corporate officers aggregate the data. Typically the resources demanded exceed existing supply. The sponsor company never seems to be short of good product ideas. A process of negotiation begins with some programs being cancelled or delayed, others receiving fewer resources than demanded, and others receiving all the required resources. In the past, there was some indication that in spite of this process, scheduled resource usage often exceeded existing supply. The company is currently taking steps to avoid this in the future.

Project Prioritization

Programs are categorized into category 1 and category 2 programs: category 1 programs are typically large, corporate sponsored programs that theoretically receive whatever resources they require; category 2 programs are smaller projects and often lose resources to category 1 programs as their needs change.

Recently management has proposed a new process of project prioritization. Using agreed upon criteria, all potential projects will be prioritized annually. Resource requirements are added up until they meet capacity and the extra projects are delayed or cancelled. When conflicts between projects for resources occur during the year, the prioritization will be used to decide who gets the resources. This process should significantly improve time to market performance.

Dedication of Resources

The sponsor company typically dedicates a certain number of people to one project while others may work on a number of different projects. In the past, 30% of the resources were dedicated and 70% shared. Recently there has been a move to reverse this ratio to hasten product development.

Resource dedication avoids queueing problems resulting from inter-project conflicts. If a project receives all the resources it needs, and they are fully dedicated, one need not worry about losing resources to other projects. We would expect that the more resources dedicated to a project the lower the queueing time, and thus the faster time to market.

Even with fully dedicated resources, there is potential for intra-project queueing effects. That is, typically resource usage is not level over the period of a project. Instead work arrives for each person according to some stochastic process. Again, we would expect to see queueing effects at the piece part level of analysis. Future work may attempt to analyze the department at this level.

Resource Allocation Over the Period Studied

Figure 6.1 below shows the allocation of resources over the three years studied from November 1987 to October 1990. Jason (JAS), Icarus (ICA) and Thomas (THO) are the three largest products being developed in the department, and all three are rated category 1. Work on overhead projects (OHD), absence (ABS), and work cross-charged (X/C) to other departments also consume large amounts of capacity. (Note that accounting for absence changed in January 1988 from an overhead allocation to its own code.) Together these top six projects account for between 55% and 75% of the department resources. DIL, DEL, PHO, and OTHER are other category 2 projects. Work on non-product related projects (NON) or core technology completes the list of the largest individual projects.

It is interesting to note that since January 1989, Jason and Icarus have been consuming a significant portion of the department's resources. These two projects are at about the same stage in the development cycle. Because of their large resource requirements, we question whether the start of these projects should not have been more staggered to level resource usage. We suspect that in spite of the fact that both projects have a large proportion of "dedicated resources", the two projects are experiencing inter-project conflicts for other resources (capital or administrative). A model that simulates the consumption of resources should help the sponsor manage these conflicts more effectively in the future.

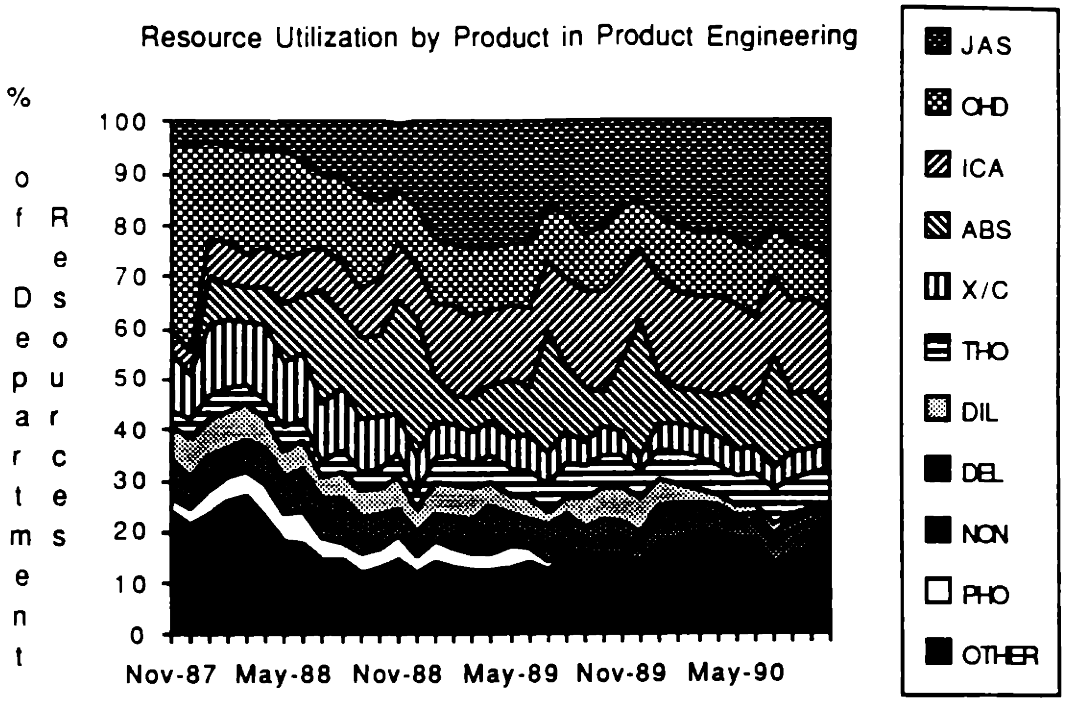

Figure 6.1

Linking Actual Schedule Performance to the Queueing Analysis

This section attempts to link the queue search of the previous chapter to observations gleaned from company interviews about actual project schedule performance. We are forced to rely on this circumstantial evidence since we do not have a good objective measure of the output of the department. Additionally, the available time series data does not break the data perfectly according to product development projects as discussed below. Future work will attempt to collect information that provides a better indication of department output, and better describes specific product development efforts, thus helping to validate the proposed model.

Three product development efforts (Dillon, Jason, and Cyclone) are analyzed below. Project participants were originally interviewed to investigate potential scheduling problems following the July 3rd KJ session described in Chapter 2. As a result, some of this information is not as detailed as we would like.

In all three cases, the product development efforts have or are experiencing schedule slippage. Table 6.1 shows an estimate of the relative slippage in all these projects. "Zeus" was a large project completed a few years ago and is listed for informational purposes. Notice that Jason and Cyclone were not completed when this data was assembled. The actual time to market is an estimate.

Typical Time to Market Performance

			TTM (weeks)		
Project	Start Criteria	End Criteria	Actual	Forecast	Slippage
Dillon	Concept Fin.	Pdtn. Start	120	81	48%
Zeus	Beg.Styling	Pdtn. Start	102	80	28%
Jason	Concept Fin.	Hi Vol. Pdtn.	**171**	142	**20%**
Cyclone	Design Start	Pdtn. Start	**54**	38	**30%**

Note: Bold figures are projected as of 8/90. TTM = time to market

Table 6.1

Dillon

Actual Schedule Performance

The beginning of the Dillon product development project can be traced back to the first quarter of 1986. At that time the intent was to introduce an enhanced version of the Yates, a previous product in the same product family, Poet products. By the first quarter of 1987 the project team had defined a new product called the Dillon. The project was a priority 2 program and therefore could be subject to "resource stealing."

Engineering drawings were scheduled to be competed in the third quarter of 1987. Instead, drawings were issued through to the end of the third quarter of 1988 as the team realized the program scope was larger than planned. Engineering prototypes originally scheduled for the fourth quarter were available in the second quarter of 1988. Pre-production was scheduled for the third quarter of 1988 and began in the fourth quarter. Production was scheduled to begin in the third quarter of 1988 and actually began in the second quarter of 1989. Quality problems hampered production start-up and production stopped for a few months in the third quarter of 1989 and then resumed in the fourth quarter.

In the post program review the Dillon team identified a number of reasons for the poor time to market performance and divided these into categories of program management, technical, schedule, and testing/quality. Those related to this analysis are reported here:

Program Management

- the scope of the project in terms of resources and complexity was underestimated
- the team lacked a dedicated project leader and electronics leader
- the project priority conflicted with the Zeus and Athena-pro product development projects

Technical

- the resources required, both manning and skill level, were underestimated

Schedule

- the project was compressed at the end leading to quality problems
- the rigid schedule did not allow time for the change in the scope of design.

A summary of key learnings included a need for a core of 100% dedicated people with skills appropriate to do the job.

Timecard Data

A review of the electronic timecard data is difficult since data for Dillon is combined with five other Poet projects. Future work will attempt to disaggregate these numbers. In the meantime we will analyze the data as is, since it is believed that the majority of work on these other Poet projects occurred after the Dillon project.

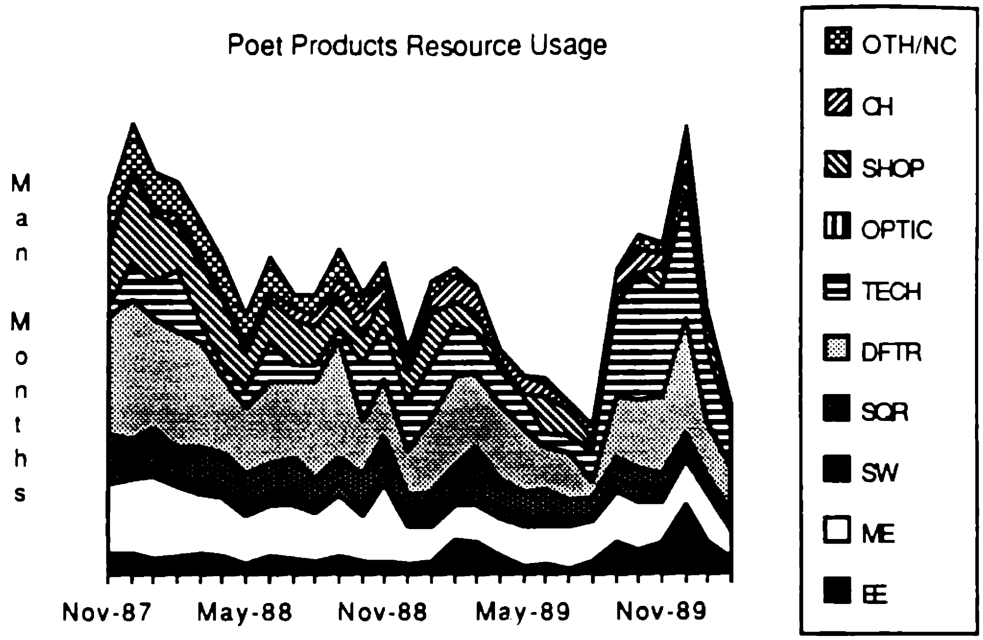

Figure 6.2

Figure 6.2 above shows the manpower usage by resource for all Poet products during the period of Dillon design, development, and production start-up. The second build up in manpower seems to correspond with the redesign effort needed to correct for quality problems encountered in product start-up during the fourth quarter of 1989. The heavy use of drafters and designers up until the third quarter of 1988 corresponds to the time that drawings were issued for pre-production (August 1988). This spike also corresponds to an increase in the use of contract drafters as shown previously in Figure 5.4. Interviews with project participants confirmed that, because of resource constraints, the team had to hire non-company employees to complete the design work. The project debriefing seems to attribute part of the schedule slippage and quality problems to a lack of resources with the correct skills. Future work will verify that these resources were in fact contract workers.

Jason

Actual Schedule Performance

Jason is the code name for a priority one product development effort at the sponsor company and represents one of five large programs in progress during the period studied. Unlike the Dillon program, Jason tends to get the resources it requires, although there is some indication that this does not always happen due to scarce resources throughout the corporation.

Comparison of the planned and actual schedule performance is difficult for Jason because the project was put on hold a few times early in the development cycle. The first schedule available (May 1988) showed concept development beginning in July 1988, engineering pilots beginning by mid-December 1990, manufacturing pilots beginning July 1990, low volume production beginning mid-December 1990, and high volume production beginning July 1991.

The second schedule (October 15, 1988) showed concept development beginning in August 1988, layout between October 1988 and mid-May 1989, detail design between mid-May 1989 and September 1989, low volume production still beginning in mid-December 1990, but high volume production beginning in September 1991.

The product was controversial within the company and thus corporate commitment unclear for most of 1988. In the Fall of 1988 the firm made a public commitment to the project. A new program manager was assigned and design proceeded. In May of 1989 it became clear that the product was not going to be able to meet some product specifications. At the same time an alternate product concept was proposed. The program was stalled except for some electrical subsystem design, and the next eight to nine months were spent doing market research to confirm and compare sales projections for the two different approaches. By January of 1990 there was a firm commitment to proceed with the original design, and development was restarted.

Current schedules run about ten months behind the October 1988 estimates. Detailed design began in May 1990, and low volume production is scheduled for around October 1991. Unit production milestones are about eleven months later than predicted in October 1988.

Discussions with those managing this development effort recognize they are about one and a half to two months behind their revised schedule. Managers attribute this delay to a combination of poor decision making (freezing the concept too late in the process), underestimated product complexity, technical difficulties for two subsystems, and some resource constraints. In an interview on July 24, 1990, manager in the program expressed a need for more people from the product engineering people. At that point, it was unclear whether the people would be available.

Timecard Data

As with Dillon there are a few products being developed simultaneously under the code name Jason, although to the author's knowledge they are almost identical high and low end models of the same product. Therefore, the timecard data should be more representative of development of one particular product line.

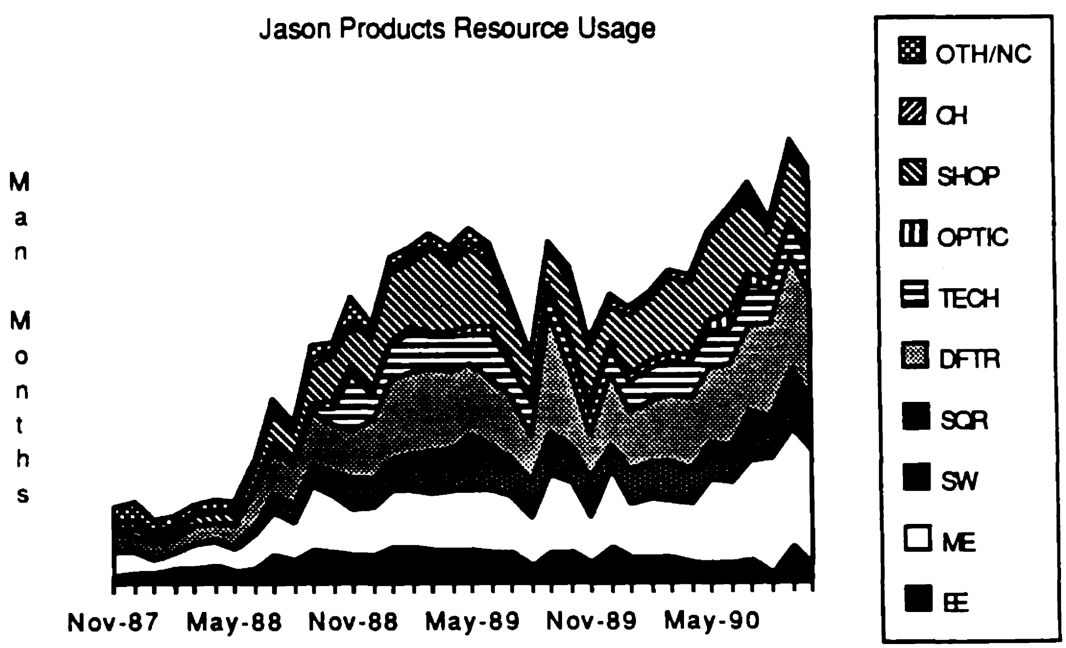

Figure 6.3

Figure 6.3 shows the manpower usage by skill for Jason. The chart clearly shows the lull in activity beginning in July of 1990. Total manpower does not reach its May 1989 level until May of 1990. The inconsistency between when the managers said development was halted and restarted and this data is probably explained by the inertia in the system. A lag of two months seems reasonable for those on the program to find new work. The fact that manpower did not reach historical levels until May of 1990 indicates that many people probably got involved in other projects which they could not leave immediately.

It is also interesting to note that development did not stop completely according to this data. In fact the total man months of work per month only fell about 30% from May 1988 to August of 1988. We propose two reasons for this. First, development may have continued in spite of manager's orders to halt work. Second, many people may have had difficulty finding other development projects to work on, and thus charged their spare time to the Jason account.

It is difficult to link schedule slippage for this project to resource constraints. The only indication that this may be an issue was one manager's opinion that the project needed more people in July, 1990. A look at Figure 6.3 shows that in fact the program received more people in September of 1990, about two months later.

On the other hand, it is quite probable that the increase in resource usage for this project from February 1990 onwards greatly contributed to the hypothesized queues forming among mechanical engineers and drafters and designers from March to October 1990. Jason was the largest user of both of these resources over the three years studied.

Cyclone

Actual Schedule Performance

The Cyclone project is somewhat of an anomaly at the sponsor company; originally the product was developed for use in house to support another line of business. When the decision was made to develop a saleable product, much of the development was already complete, although the design had to be altered for commercial use. Nonetheless, the project still experienced development delays. These delays primarily resulted from delays in the decision to proceed with the project. The project was a relatively low priority and received a category 2 rating.

The original schedule in March 1990 called for pre-baseline drawings the fourth week in March, and production to begin the third week in December (38 weeks). Design was delayed and pre-baseline drawings were supposed to be available the first week in May. By June 1990, production was scheduled to start in March 1991. By late June, schedules indicated pre-baseline drawings would be done by the first week in June, and production was scheduled to start in the second week of June 1991. The extension to a 54 week cycle seems to have resulted primarily from a longer beta test period.

Project team members spoke of the corporation's hesitancy to release funds for the project. There was also some indication that market research had not been completed to justify the project.

Mechanical and SQ&R engineers also spoke of insufficient resources. A request by mechanical engineers for more people (detailers) resulted in a few additional people at various times over the next three months. Engineers complained that this was inefficient since new people had to be retrained on three separate occasions. Senior designers were brought in after many key design decisions were completed and tended to challenge previous decisions. The delay caused in design meant the team had to re-enter the queue at a vendor for tooling. Company employees believed this resulted in a one month delay. SQ&R also had an outstanding request for an individual.

The group made heavy use of contract workers. In general, company employees felt per diems were just as good as in-company resources. Typically it took 3 days to get drafters and designers acclimated to company systems.

Timecard Data

Figure 6.4 shows the timecard data for the Cyclone project. Interviews revealed that the project also used resources in the ER&D department, so this data should not be taken as complete.

The graph shows the ramping up of resources in February and March 1990. Shop and drafting and designing personnel accounted for the majority of the resources used. The steep drop in manpower in August probably resulted from a delayed decision to proceed with the project as explained previously. A review in September released funds, and development proceeded.

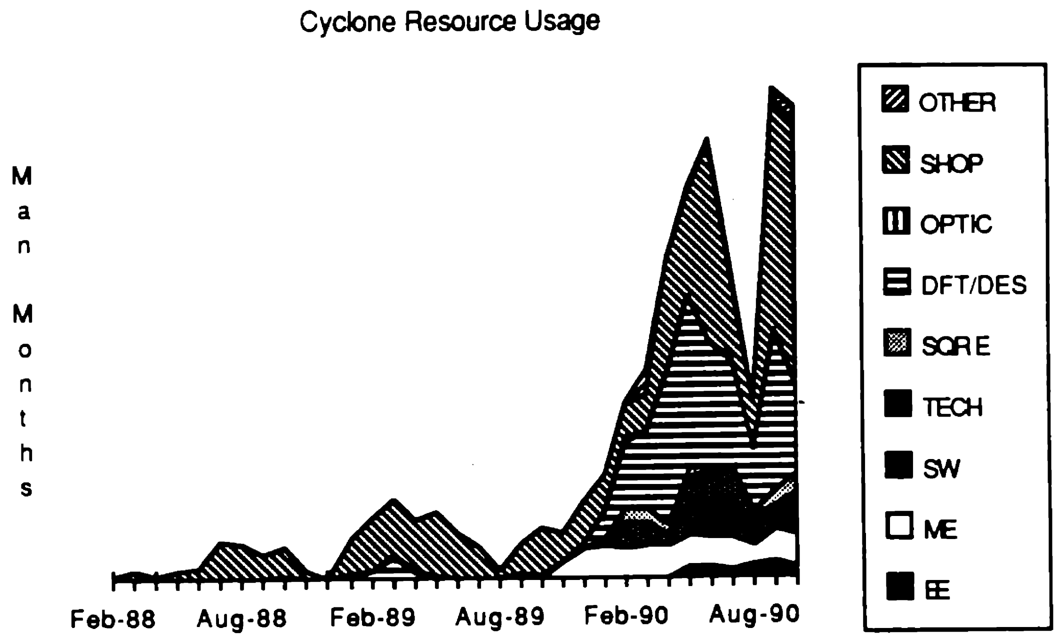

Figure 6.4

There is some correlation between the shortage in resources for this project and the hypothesized queues in Chapter 5. Electrical engineers did not complain about manpower shortages. Mechanical engineers did complain about shortages in both engineers and drafter and designers. Both these correspond with shortages identified in Table 5.3. The shortage of SQ&R engineers is not consistent with previous results.

<u>Comparison of Resource Allocation Budget to Queueing Analysis</u>

Another benchmark for the queueing analysis in Chapter 5 is data from the annual resource budgeting process for the department. Table 6.2 below shows the budgeted headcounts by skill for 1990 including actuals for the first quarter. Note that many resources are budgeted over capacity.

This difference is made up by hiring contract workers, or in some cases, projects are slowed down or cancelled due to resource limitations.

The largest resource deficiencies in 1990 are in software and drafting which agrees with our analysis of the timecard data. These are the resources that are most likely to use per diems, work high overtime, and maintain low absence levels. SQ&R also seems to be severely under-

Total Demand for Resources in Product Engineering

	EE	ME	DFTR	SHOP	SOFT	SQR	TECH	OPTIC
Q1(actual)	31.2	40.9	42.5	52.3	17.8	38.6	26.7	19.4
Q2	31.1	41.1	53.2	47.7	22.9	47.8	26.3	17.4
Q3	34.6	43.0	55.7	47.0	25.0	47.5	32.1	17.4
Q4	34.4	40.7	49.4	45.3	25.3	46.0	31.6	17.4

Company In-House Capacity 1990

	EE	ME	DFTR	SHOP	SOFT	SQR	TECH	OPTIC
Q1(actual)	32	36	35	45	9	34	30	16
Q2	32	36	35	45	13	34	30	16
Q3	32	36	35	45	15	34	30	16
Q4	32	36	35	45	15	34	30	16

Budgeted Resource Utilization 1990
(<100%=slack, >100%=shortage)

	EE	ME	DFTR	SHOP	SOFT	SQR	TECH	OPTIC
Q1(actual)	98%	113%	120%	116%	197%	113%	90%	122%
Q2	97%	114%	150%	106%	174%	140%	88%	109%
Q3	108%	119%	157%	104%	164%	140%	108%	109%
Q4	108%	113%	140%	100%	166%	135%	106%	109%

Number of Projects Using Resource

	EE	ME	DFTR	SHOP	SOFT	SQR	TECH	OPTIC	TOTAL
Q1(actual)	17	23	21	19	5	21	13	7	39
Q2	16	24	21	14	7	25	15	12	43
Q3	16	22	20	14	7	23	15	12	43
Q4	17	19	19	14	7	22	14	12	43

Table 6.2

capacity which was not indicated in our analysis. It is possible that this deficiency has not showed up yet in the timecard data. A look at Figure 5.2 indicates that overtime among SQ&R has been at its highest level ever since

June of 1990. Mechanical engineering is also under-capacity which agrees with the queueing analysis.

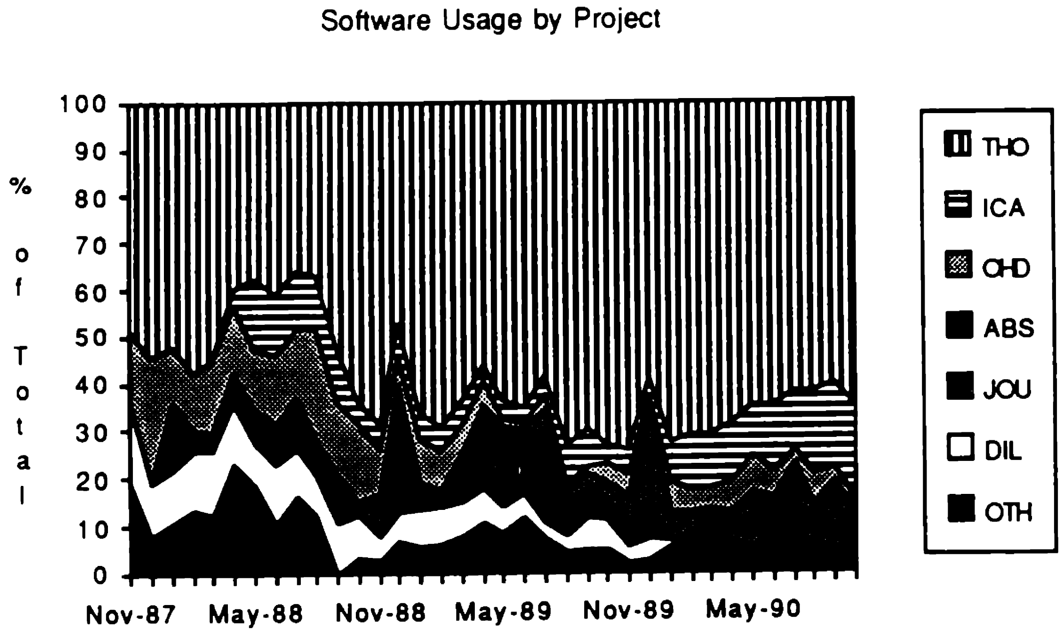

Figure 6.5

Table 6.2 also shows the number of development projects using each resource. Note that software is only working on a few projects. Figure 6.5 shows software resource usage by project. One project, Thomas (THO) consumes the vast majority of software resources. As a result, an increase in software capacity would have a limited effect on many other projects that do not require software development.

An Investigation of Network Structure

So far in this chapter we have been using the project data to link actual schedule performance with the bottlenecks hypothesized in Chapter 5. The project data collected can also give us some idea of the *structure* of the queueing network. A priori we suspect that in the early stages of a project we observe the majority of work in design oriented resources such as electrical and mechanical engineers. Later in the process we suspect to see work passed to resources more oriented towards implementation such as drafters, model builders and possibly technicians.

To test this hypothesis we present data for the two largest projects in the department, Jason and Icarus. Figures 6.6 and 6.7 show representative manpower data for these two projects. The data has been smoothed using a first-order exponential to filter out "noise" in the system from input errors and seasonal effects.[1] The horizontal axis indicates months over the 36 month period from November 1987 to October 1990.

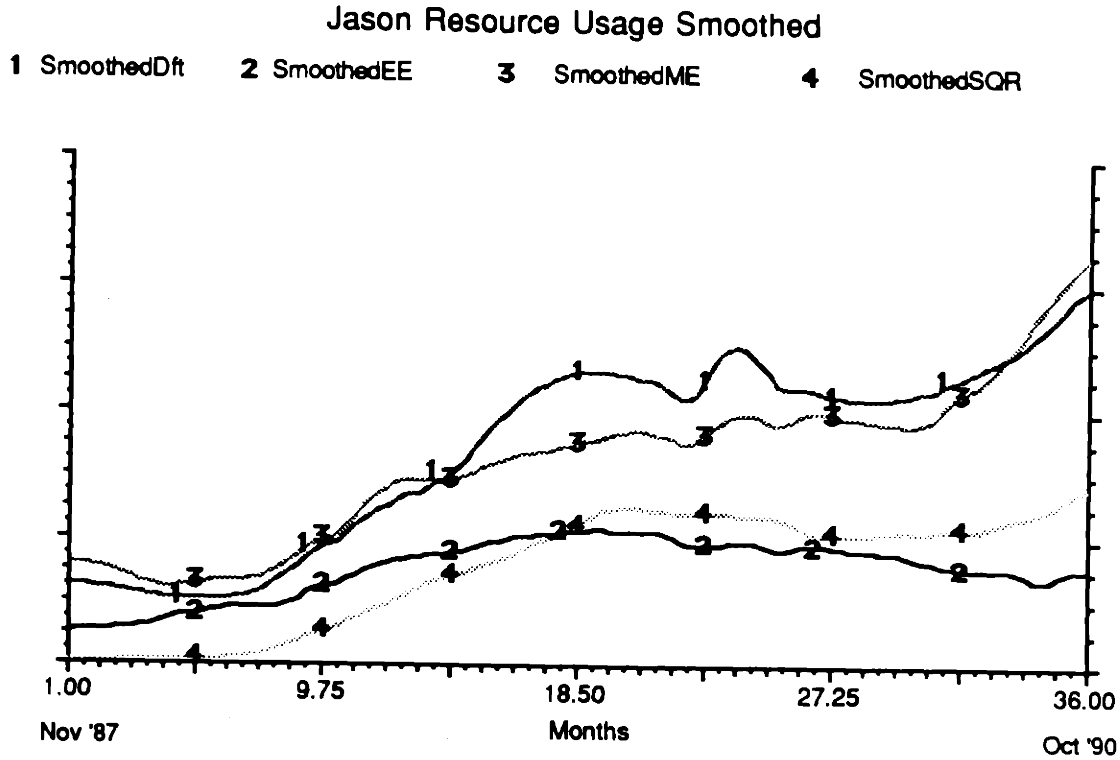

Figure 6.6

It is interesting to note from the Jason data that the shape of the manpower curves for drafters, mechanical engineers, and SQ&R, are almost identical. The use of electrical engineers however, seems to be tapering off. Recall that development work was "stopped" on all but electric

1 See page 370 of the *Stella Users Guide*, High Performance Systems, Lyme, NH (1987) for a complete description of this filter. This filter introduced an average peak-to-peak lag of three months.

subsystems from May 1989 to January 1990 (equivalent to months 19 and 26 respectively). As a result, electrical engineers seem to be "over the hump" for this product, whereas mechanical engineers and others are trying to catch-up in development.

There is also some indication that SQ&R was a secondary activity in the project. Substantial work in SQ&R did not begin until the eighth month of the data.

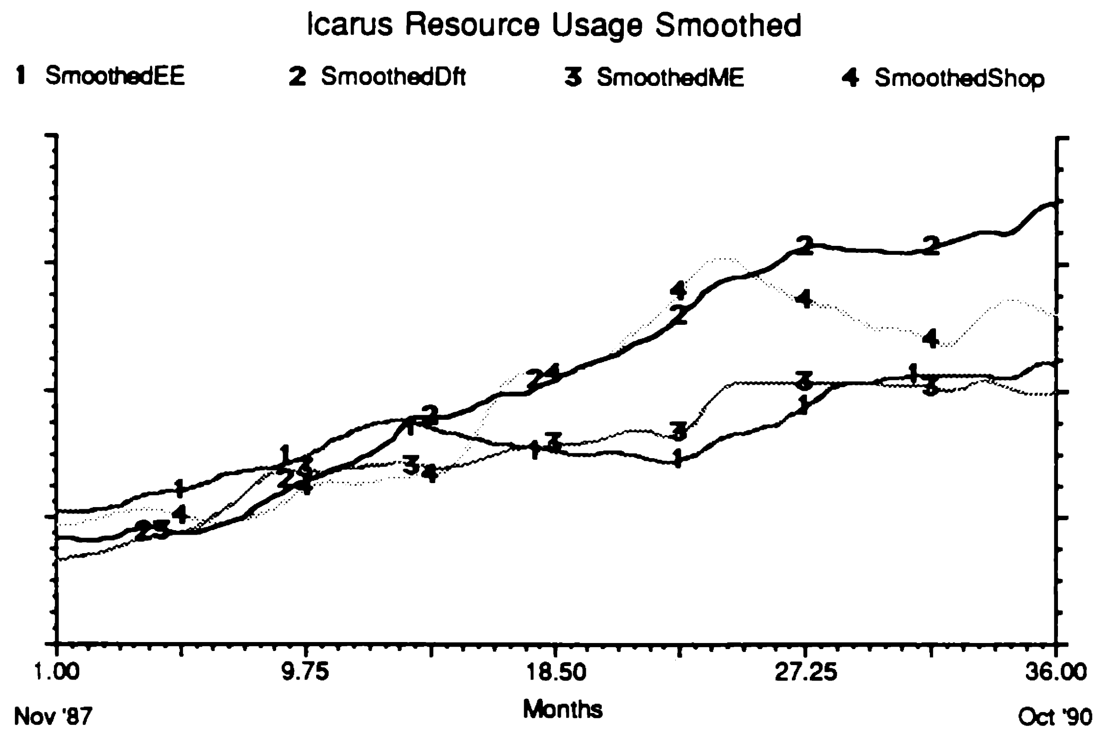

Figure 6.7

The Icarus data in Figure 6.7 paints a different picture. Use of electrical and mechanical engineers is very similar both in the shape of the curve and the absolute headcount. The use of shop resources peaked out in the 25th month (December 1989) and seems to be falling. Meanwhile the use of drafters continues to increase. Work seems to be passing from engineers, to prototype model builders (shop), to the drafters. Note however that in both examples there is a high degree of concurrence in the resource usage.

To get a better idea of how work passes through these resources we conducted an informal regression analysis, the results of which are not included here. Individual manpower usage figures for Jason and Icarus were regressed on the total project manpower usage, time, and time squared. For most resources, the total manpower usage was the best independent variable and accounted for 60-90% of the variability in resource usage. The second best indicator was time squared suggesting that resource usage follows a hyperbolic curve.

For these two projects the distribution of work among the resources seems to stay fairly constant throughout the product development cycle. One possible explanation for this, eluded to previously, is that the level of analysis is not sufficiently detailed. The movement from development to drafting to model building describes the progression of a subsystem or part. A better model formulation may attempt to focus at that level, although the electronic timecard data cannot provide this resolution.

CHAPTER 7: ALTERNATIVE MODEL FORMULATIONS AND FUTURE RESEARCH

This final chapter on the queueing network model of product development has three purposes. First we provide a framework to help structure a modeling approach and describe three possible models with different work rate and queue discipline assumptions. Second we summarize the results of this preliminary analysis of product engineering and its implications for management. Finally, we outline the areas for potential future research.

A Framework for Alternative Model Formulations

In Chapters 4 through 6, we analyzed electronic timecard data from product engineering with a conceptual queueing network model in mind. The specific model formulation resulted from a combination of data availability, and our first approximation of what type of model would best represent reality. In this section, a framework is proposed to facilitate future modeling efforts, and better define the structure of the decision-support tool we intend to build.

A Framework

The structure of the queueing network can be subdivided into resources and customers or jobs. We define resources as "anywhere a project can wait." Resource-related characteristics include

- resource structure
- routing probabilities
- queueing discipline, and
- service or work rates.

Customers or jobs are defined as "anything that consumes resources." Customer or job characteristics include:

- customer types
- queueing discipline
- arrival rates, and
- demand profiles.

Resources and jobs determine the structure of the queueing network model.

The decision variables for a simulation model include:

- the number and characteristics of the programs/products to be developed, and
- the allocation of resources.

Finally, the output of the model is:

- the development cycle time distribution (time to market), and
- the most likely bottleneck resources.

Choice of specific resource and job formulations should be dictated by the potential for a queueing model to be useful. Those levels which demonstrate the highest variability, and highest utilization seem to be the best candidates for analysis.

Level of Analysis and Data Problems

There are many potential levels of analysis for both resources and jobs as shown in Figure 7.1. Human resources can be modelled at the department or functional level (e.g., Product Engineering), the general skill level (e.g., mechanical engineers), the specific skill level (e.g., software coder), or the people level (e.g., John Smith). In addition we could include capital (e.g., climate room) and administrative (e.g., capital appropriations process) resources. Our analysis focused only on one department of human resources at the general skill level, largely because this was the only data available.

Characterization of jobs or customers also has many possibilities. Product related jobs can be modelled at the program level (e.g., Icarus), the product level (e.g., Dillon), the sub-assembly level (mechanical subassembly #1 for Dillon), or the piece part level (part number HD-103). Other types of jobs are also possible and may include "absence" and "core technology." If possible, "absence" could be characterized as a customer type with preemptive priority over other customer types to represent the fact that other jobs become stalled when a person goes on vacation.

<u>Levels of Analysis for Resources and Jobs</u>

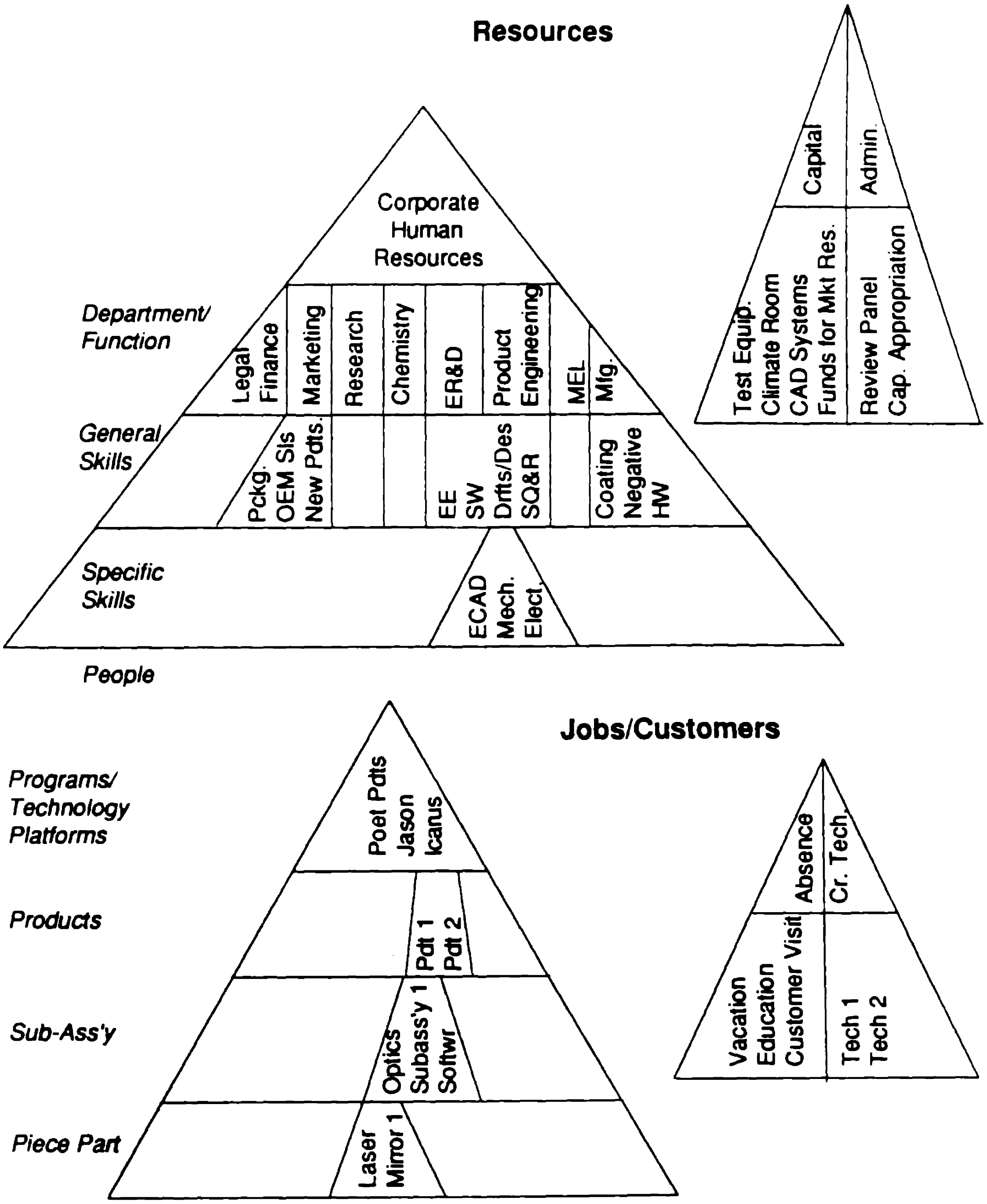

Figure 7.1

Unfortunately, the available database is not consistent in the use of descriptors for program (essentially a technology platform) and products. Table 7.1 shows the relationship between the hierarchy of jobs described in Figure 7.1 and the specific timecard database structure. In the future, these descriptors could possibly be made consistent by modifying either the database, or the analysis methodology. Future work may try to collect some of the subassembly or piece part data to support the analysis.

The Relationship between Queueing Jobs and Database Structure

Queueing Job	Timecard Data Key
Program	Subgroup
Product	Trunk code or Subgroup
Subassembly	Trunk code or Not available
Piece part	Not available

Table 7.1

Promising Model Formulations

There are a number of potential model formulations. The following is a discussion of three different approaches that seem promising.

Model 1 - Traditional fixed work rate

This was the model assumed throughout this analysis. The work rate was assumed to be fixed at some constant service rate distribution. Service capacity varies directly with the headcount. Queues form primarily as a result of the amount of work (arrival rate) that arrives at the resource. The advantage of this formulation is that we can rely on a large body of theoretical research. The disadvantage, however, is that it may not be appropriate. Specifically, one is hard pressed to identify queues of work waiting to be done when walking around the product engineering department. Furthermore, we suspect that the work rate may not be constant over time.

Model 2- Work rate varies with queue length

An alternative model was initially proposed by Graves.[1] This model assumes that the work rate varies as a function of the amount of work in the queue. That is, as the queue gets longer, people work faster. Likewise as they see the queue diminishing they work slower. A priori this seems to be a good model of human behavior. It implies that it would be very difficult to view periods of underutilization of resources. This is consistent with the preceding analysis. To test this formulation one needs an objective measure of the work rate. Potential measures such as the number of part numbers assigned per time period are proposed in the final section of this chapter.

Model 3-Work rate dictated by demand

An alternate model formulation would have the work rate dictated by demand. In this model no queues actually form since the resource works on <u>all</u> arrivals, but at a slower rate. The work in progress (or number of projects) becomes the effective queue. This model could be appropriate in some circumstances if the company takes on more work than it knows it can do.

To judge whether this model is accurate, one could evaluate whether new project arrivals result in a slower work pace for other projects. This could be measured in terms of average man-months of labor per month, or using objective output measures described in the last section of this chapter.

Results of Analysis

The primary objective of this analysis was to explore the application of queueing theory to a portfolio of product development projects. We have some indication that queues are forming. The relative queue length seems to be indicated by three queue indicators identified in Chapter 5: absence,

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[1] Graves, S.C, "A tactical planning model for a job shop," *Operations Research* 34(4):522-533, 1986.

contract workers, and overtime. More data is needed however, to quantify the effect of these queues on time to market.

The analysis has a few implications for management at the sponsor company. These suggestions fall into four areas: bottleneck management, resource utilization goals, redeployment of resources, and managing development starts.

Bottleneck Management

Chapter 5 identified a few bottleneck resources in the Product Engineering department (see Table 5.3). Software engineers, drafter and designers, mechanical engineers, and shop personnel experienced the most queueing (from highest to lowest) of all resources.

Recognizing these bottlenecks, one is faced with three alternatives: add resources, cancel projects, or manage the flow.[2] By adding resources to the bottleneck, one hopes to speed the progress of jobs through the resource. We expect that an investment in resources for the bottleneck will have the largest impact on time to market performance. Typically, after adding resources to the bottleneck, additional bottleneck resources appear. Adding resources works best if the process of product development is already under control. We describe what this means below.

The second alternative is to reduce the demand on the bottleneck resource. Projects could be cancelled until managers are comfortable that sufficient resources exist. The time to market performance of the remaining projects should be significantly improved.

The third alternative takes the second one step farther and uses the bottlenecks to manage the flow through the department. This is a common practice in manufacturing management that has many parallels in product development. The risk in an environment with highly complex and stochastic processes is to try to manage around missing resources. People run out of work because of congestion at a bottleneck and begin taking on additional work to keep busy. This additional work interferes with the

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2 For similar discussions see *Everyday Heroes*, by Perry Gluckman and Diana Reynolds Roome, SPC Press, Knoxville, Tenn., 1989, Chapter 4 or *The Goal* by Eliyahu M Goldratt and Jeff Cox, North River Press, Croton-on-Hudson, NY, 1986.

initial job as bottleneck resources become available. Soon the interaction between schedules causes all projects to be late.

The alternative approach is to use the bottleneck resource to manage the flow. The most important projects are scheduled, in their entirety, through the bottleneck resource. These schedules in turn provide schedules for upstream and downstream resources. No other work is started until its downstream work can be scheduled through the bottleneck, that is, the flow of projects becomes managed. These schedules must be sacred however. Schedule slippage in an upstream activity should signal that all project activities should be stopped until the bottleneck resource can be rescheduled. In effect, "[One] becomes more flexible because [one] becomes more rigid."[3]

In terms of the preceding analysis, software engineering seems to require additional resources. Few products use the resource so the resource would not be an effective "pacing resource." Drafters and designers seem to be the second most visible bottleneck resource. Most product development projects do use this resource so it may be an effective area with which to pace the rest of the department. CAD systems have been identified as bottleneck resources at other Leaders for Manufacturing companies.[4] Future work will try to determine if the capital resource (CAD systems) or the human resource (CAD-capable drafters) is the true bottleneck at the sponsor company.

Resource Utilization Goals

Bottleneck management implies that only the bottleneck is scheduled for 100% utilization. Other resources should be significantly below 100% utilization according to their relationship to the use of bottleneck resources. Queueing theory also suggests that given a premium for fast product development, the goal should be significantly less than 100% utilization. Traditional queueing theory shows that as the utilization approaches 100%, the queue length rises exponentially.

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3 Gluckman, Perry and Diana Reynolds Roome, *Everyday Heroes*, SPC Press, Knoxville, Tenn., 1989, pg.100.

4 Shaffer, John C., A Method for Simulating the Chrysler Car-Body Development Process, Unpublished Masters Thesis, MIT, Cambridge, 1990.

As discussed in Chapter 6, the sponsor company has traditionally scheduled essentially all of its company resources during annual budgets. We propose that the number of projects should be significantly reduced until the process of product development is under control. We suspect that by doing so products will be developed much faster. In the end, the productivity of the department should increase substantially.

Of course, the optimal level of resource utilization is based on a number of factors: the relationship of the resource to the bottleneck resource, the cost of learning (in terms of lead time) when resources are moved between jobs, the value of time to market for each project, and the variability in project activity times. At a minimum, we hope this queueing analysis contributes to decision-making about hiring and retraining resources in the department.

Redeployment of Resources

The analysis in Chapter 6 also raised some issues regarding how fast resources can actually be redeployed from one project to another. The Jason example appears to indicate that momentum in the system kept 70% of the resources from finding additional projects to work on. In light of this "system response," managers should never delay a project. The benefit of the delay (freed resources) is not realizable, and the cost (slowed time to market) is not recoverable.

This raises the question of "how to change the system?" Are there mechanisms that would allow faster redeployment of resources to projects that need them? Are there incentives to horde resources in anticipation of their use, and how might these be dismantled? This analysis did not address these issues. We raise them here for further discussion.

Managing Development Starts

In Chapter 6 we also commented on the decision to start two large corporate programs at the same time. We suggest that if the company was "managing the flow" of projects through product engineering they would not have started both projects concurrently. Company officials have recognized the need to manage the flow more exactly. Processes are currently being designed to address this issue.

Further Research

There are many opportunities for further research in this area, some of which have been mentioned already. While there is some support for the hypothesis that queues are forming at product development resources, we need further quantification of the specific effects on time to market, and thus more data. There are also many alternative model formulations which should be tested. A simulation model could help sort through the most important aspects of the application, and also provide a tool for more effective product development management. Finally, there are numerous opportunities to refine and expand the analysis of Product Engineering.

Additional Data Collection

Since the data needed for all resources is not available we cannot make a good linkage between actual time to market performance and the complete system behavior. Instead, we need an objective measure of the output of the department, for example, average wait times and length of queues, or possibly some indication of the quality of work in the department. Some proposed department measures are:

- number of new part numbers per time period (work rate)
- lines of software code per time period (work rate)
- number of prototype models per time period (work rate)
- number of engineering change orders (ECOs) (quality indicator)
- schedule slippage rates (measure of queueing effect)
- ratio of value-added time to total turn around time (measure of queue waiting time)
- number of jobs in the queue (queue length measure).

Chapter 5 found three second order effects of queues (absence, per diems, and overtime) that seemed to be good indicators of queues. More direct, first order effects would include actual manifestations of the queues. For example, it may be that some central resources (shop or drafters) keep track of the pending number of prototypes and parts to be drafted on an on-going basis. New measures could be tracked such as the ratio of value-added time (e.g., the time it takes to design a part) to the total time including waiting time. We suspect that as queues form, the service rate increases but the quality may decrease, causing rework cycles. An ECO measure may highlight this effect. Future work will search out data at a more local level.

A Simulation Model

The previous section described numerous alternative model formulations which may or may not accurately describe product development behavior. Many of these variations require considerable work in terms of the development of new queueing network theory. A simulation model would provide the flexibility to test some of these approaches to see which are the most promising. In addition, a simulation model could provide a useful decision-making tool to manage product development more effectively in the short run.

Refining and Expanding the Product Engineering Analysis

The preceding chapters have highlighted numerous ways in which the analysis of Product Engineering could be refined. For example, a more accurate tracking of products versus programs could help clarify system behavior. There is also the option of expanding the analysis to ER&D, the other hardware development resource. This would be especially useful since many projects rely on resources from both departments.

A similar analysis of marketing and manufacturing will be more difficult since, to the author's knowledge, similar time tracking systems do not exist. One suggestion is that product development teams start collecting this data in some form. The framework proposed in Chapter 3 and included in Appendix B would facilitate this data collection.

CHAPTER 8: IMPLEMENTING A TIME-BASED STRATEGY- A CASE STUDY AT BELLEX CORPORATION

This chapter analyzes a case study included in Appendix C. The case describes the implementation of the Product Delivery Process at Bellex Corporation (a disguised name). The case is reviewed and key points are drawn out of the case. After a thorough analysis, suggestions are made to aid the implementation process. Issues addressed will include the following:

- the need for clear goals to drive implementation
- alternate implementation strategies (top-down versus bottom-up)
- ways to measure success
- management's role when implementing a time-based strategy.

Specific organizational development tools, such as force field analysis, and Schein's organizational culture framework (values, artifacts, and assumptions) and three-stage model of change are applied. These tools are described in Schein,[1] Schein,[2] and Beckhard and Harris.[3] An article by Beer, Eisenstat, and Spector also contributed to the analysis.[4]

A Description of PDP

The Product Delivery Process ('PDP') is a six phase codification of what should be done and who should be invclved to develop a new product at Bellex. A key feature of the process is seven review meetings designed to approve or disapprove projects from passing to the next development phase (see Exhibit 1 in the case). Four of these meetings are run by a senior

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1 Schein, Edgar H., *Process Consultation: Volume I*, Addison-Wesley, Reading, Mass., 1988 and *Process Consultation: Volume II*, Addison-Wesley, Reading, Mass., 1987.

2 Schein, Edgar H., "Organizational Culture", *American Psychologist*, February, 1990, pp.109-119.

3 Beckhard, Richard and Harris, Reuben T., *Organizational Transactions*, Addison-Wesley, Reading, Mass., 1987.

4 Beer, Michael, Russell A. Eisenstat, and Bert Spector, "Why Change Programs Don't Produce Change," Harvard Business Review, Nov-Dec 1990, pg. 158-166.

management review panel, especially designed to review all corporate programs. The other three are each run by the product development team, the team and key functional managers, and the team and other interested program (project) and functional managers.

Although the stated overall goals of PDP are faster time to market, better quality and lower cost products, the intent of the program was to provide a guideline of activities for Program Managers and management for successful product development. PDP is supposed to ensure that:

- all functions (R&D, manufacturing, marketing, finance) are involved from the beginning and operating as a team
- business as well as technical feasibility is proven, and
- the quality of the product is assured.

Additionally, PDP is supposed to help management stop projects that lack potential earlier than in the past to save cost and redeploy valuable resources.

PDP was also developed to try to give some organizational weight to the role of Program Manager, a new integrative management position created about four years ago to manage product development. Program Managers are the PDP Implementation Group's primary contact.

The Design and Implementation of PDP

The case highlights a number of potential problems resulting from the design and implementation of PDP:

- the lack of consensus among top management as to what PDP should be, and what its goals were before implementation began,
- the decision to push forward with PDP as a "skunkworks" versus a top down corporate program with which all officers were in agreement,
- the total change in PDP team members from the design phase to the implementation phase of PDP,
- the lack of any plan or goals for the implementation of PDP ("it was an experiment"),
- the lack of discipline or process analysis in the Bellex culture, and

- the lack of frequent top management statements or actions that demonstrate PDP is important for Bellex.

The case includes a section which uses quotes from various people in product development areas. The most surprising result of these interviews is the total concurrence of workers in research, engineering, manufacturing, and marketing that PDP is the right thing for Bellex to do, and similarly their belief that it is unlikely that anything will really change or that PDP will survive. Employees believe top management is not committed to the program, and has shown this by not enforcing tough rules like "thou shall not proceed without a PDP review meeting." Additional 'signs' described included the infrequency of mentioning PDP publicly, letting questionable projects pass review, and noting that "two senior people fell asleep during the review meeting after we spent three weekends preparing for it." In general product development people do not believe change is possible largely because "it is in their culture, to be nice to people." "We are not good at telling people they did not deliver." Thus, the decision-making structure of PDP seems to conflict with the perceived Bellex culture.

At the functional manager level, the reactions are much more mixed: feelings of indifference, tentative support, and total disagreement with the methodology are equally probable. Some argue that the firm is trying to do too much (both in terms of changing the company, and developing too many products). Others see it as too bureaucratic; one officer level Vice President has coined the term the "Product Delay Process."

Top management remains divided on the issue. The CEO seems to change his opinion depending on the situation. In his unsupportive moods he says, "John Bell would not have done this." Brian Lane, a Member of the Office of the CEO, is the primary support at the very top of the organization. John Chap is the Vice President of Quality that started and continues to champion the process, although his job has just been broadened to include another corporate project, diminishing his attention on PDP.

The last group of primary players are the newly appointed managers of the business units. Bellex is in the process of reorganizing into a matrix organization from a functional one. None of these three managers were involved in the original design discussions of PDP, and at least one believes he should have all power when it comes to product decisions, and therefore constantly skirts the PDP process.

Analysis of the Situation

The Roots of the Current Situation

Bellex has a culture that rewards design and barely recognizes the need or difficulty of implementation. This seems to be the root of the resistance to PDP at the upper management levels. Like many companies that had some great invention and grew quickly, Bellex has not yet successfully made the transformation from an invention factory to a viable long term business. They still search for the all illusive "silver bullet", and this corporate change program is no exception in terms of many employees' expectations.

John Chap, VP of Quality and the PDP champion, consciously tried to reduce expectations and turn PDP into a continuous improvement project. He has been unwilling to set any goals for PDP. "We viewed this as an experiment." He may however, misunderstand how to go about continuously improving. Continuous improvement does not mean that you do not formulate goals (that you might achieve and thus stop improving). Continuous improvement only occurs when you formulate goals, achieve them, and then reformulate new goals.

To a degree, John and the team do this. The case mentions that they learned from the response of managers that PDP needed to prioritize projects, and cancel some. So they tackle one issue. When that one is tackled they tackle the next issue. They do this because "you have to give them what they think they need." While the process undoubtedly improves, it is a very reactionary approach to change.

One suggestion is that John, and indeed Bellex, need to learn how to plan a strategy using a systems approach.[5] First, the end state is defined. Then, and only then, do you try to work back from the end state and figure out how to get there. For PDP, this means defining what the world would be like if PDP was successful, and then figuring out what the milestones would be along the way to that goal. John would argue that PDP did have goals, but that they were internal not articulated. At this point in the implementation process, it is clear that PDP needs a plan with short term goals upon which everyone can focus (see Exhibit 1 for a prototype plan).

The counter argument may be that a systems approach will not be successful if it clearly violates a firm's typical way of doing business. It is possible that the change required is too countercultural and thus destined to get rejected immediately. John has envisioned a much more subtle, evolutionary change process. Unfortunately the competitive environment may not allow enough time to make the necessary changes.

An equally intractable issue was whether or not it was a good decision to proceed without full concurrence at the officer level. At first glance one may categorize this as a major tactical error by John. However a careful analysis of the culture probably supports John's actions. PDP challenges some serious cultural values such as creativity (glory of the designer) and the assumption at Bellex that technology conquers all.

John realized that the problem with product development was a cultural issue, and for that reason decided to push forward with only limited support in case "they realized the magnitude of the task." The reality is that he could have probably argued until he was blue in the face and still would not have had a consensus at the highest levels.

One mistake he and the design team probably did make was to try to hand off the PDP process to an implementation team. Not only does this

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5 Ackoff, Russell L., *Creating the Corporate Future: Plan of be Planned For*, John Wiley & Sons, New York, 1981. Ackoff refers to the current planning system at Bellex as *reactivism*. See page 55 of the above for a discussion.

contradict the premise of PDP (one team supports a product from concept to manufacturing), but it also misses an opportunity to set up a 'parallel learning structure' and learn and define a new organizational culture within the PDP team itself.[6] Like any new product, something is always lost in the transfer of a project between teams. Moreover, the transfer confirms that "more glory goes to designers" unnecessarily dooming the implementation effort.

Force Field Analysis and Schein's Three Stage Model of Change

It is useful to use a force field analysis common in the Total Quality literature to diagnose the current situation (see Exhibit 2). The width of the arrows is a rough estimate of the strength or power of these forces. The arrow beside "Some Business Sector Heads" indicates that this group is gaining power as the organization goes from a functional to a matrix structure. Conversely, Functional Heads are losing power, although understandably they continue to grasp for it.

It is clear that many of the strongest forces are rooted in culture. Using Schein's organizational culture framework, there are *values* , *artifacts*, and *assumptions* at Bellex that conflict with PDP. For example, a Bellex *value* is "be good to your people." In some people's minds this precludes management from telling someone that they did not deliver. Two *assumptions* are "constant growth," and "creativity as the source of all that is good in the world" both of which continue to be challenged in the marketplace. The Bellsound fiasco is an *artifact*, the first ever 'perceived' failure of John Bell, and the beginning of the *disconfirming information* for the Bellex culture.

Ed Schein's three stage model of change is helpful here.[7] Bellex is somewhere between stages 1 and 2 of Schein's model. Stage 1, or *Unfreezing*, is evidenced by plenty of *disconfirming information*, and a high

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6 Bushe, Gervase R. & Shani, *Parallel Learning Structures*, Addison-Wesley, Reading, Mass., 1990.

7 Schein, Edgar H., *Process Consultation: Vol. II*, Addison-Wesley, Reading , Mass., 1987.

degree of *anxiety*. Yet for all this anxiety, few have been able to find *psychological safety*. Few at Bellex have been able to accept the disconfirming information because they feel humiliated that Bellex is not a world class product development company anymore. The information challenges the belief that there was more to Bellex than John Bell.

Bellex can also be viewed as being in Stage 2 or *Changing through Cognitive Restructuring*. They have begun to *scan the environment* for new ways of doing business, visiting other companies to learn how they manage product development. But they have yet to identify good *role models* to help them see the world from a different perspective. The CEO's comment that "John Bell would not do this" is a case in point. He still relies on John Bell as his primary role model. Similarly, the functional managers probably need new role models to redefine their position in a matrix organization.

Suggestions and Recommendations

The force field analysis suggests a few ways to strengthen the forces working for PDP, and weaken those working against PDP. As mentioned earlier, it was very surprising to learn through interviews that the people that actually do the product development fully agreed with the goals and design of PDP. This represents a huge, largely untapped resource for change that has been ignored. The implementation strategy was to teach and convince the functional, and business heads first so that they would pass it down to their subordinates. The problem is two-fold: not only have the managers slowed the implementation (more on this later), but the public announcement of PDP has raised expectations that changes are imminent. Worse than not changing at all, PDP runs the risk of compounding problems in product development as people become demotivated because implementation did not meet expectations.

Exhibit 3 shows some potential new forces that could help avoid this consequence. Specific management actions, planning, and education could significantly improve adoption of PDP as originally intended.

The first box in Exhibit 3 represents the potential force of product development people that support PDP. Company officials have begun surveying these people to help improve their change process. If the survey verifies the dramatic support and frustration indicated in this analysis, we expect functional and business unit managers will being to fall in line with the precepts of PDP. Another tactic to tap this force may be to use the power of public relations. Views of employees could be communicated through internal publications indicating to managers where the organization is headed.

The case describes many people yearning for *signs* from management that things are changing. The second box in Exhibit 3 is a response to this fundamental human need. Management needs to begin changing its own behaviors: stopping projects definitively, showing support for PDP by constantly mentioning it publicly, and generally raising the visibility of development efforts.

The fifth force is a related management action. PDP Review Meetings are the most visible contact product development people have with upper management and to date mark their only form of feedback as to their success or failure. Product development people expect these reviews to be rigorous and for the outcomes to be decisive and meaningful. To date the reviews have had none of these characteristics. The fact that two reviewers "fell asleep" exacerbated the problem. Top management should take an active interest in this issue to ensure reviewers are prepared and attentive. Changes should be made to ensure decision-makers have authority consistent with their responsibility. A program to train these reviewers how to act may be in order. They are a critical force in the change program.

The third suggestion addresses Schein's model of change: people need new role models to define their change target and give them confidence that the target is possible and desirable. As discussed in the case, the roles of functional heads are changing at Bellex. People with similar roles at other companies should be identified to help these managers understand their new roles. Similarly Cam, the CEO, often refers to John Bell as his role model. While this role model was appropriate to the competitive pressures and size of the company in the 60s and 70s, it is much less applicable today. Cam, and all the senior officers, need to identify new role models at a corporation that has successfully transformed its product development processes.

The fourth suggestion ("widely broadcast specific success stories") is a counter-cultural but much needed action from management. Case study interviews indicated frustration with management, and waning confidence that Bellex was capable of change. Management has to rebuild that confidence by clearly identifying and widely disseminating success stories, many of which the author learned about during the interview process. This is especially critical given the long time lag between the changes being implemented and the expected results. Time to market improvements will take two to five years to judge. Instead of waiting for what may or may not occur, management has to recognize those teams that appear to be changing for the better: operating effectively as a cross-functional team, establishing technical and business feasibility early in the cycle, freezing design specifications early, meeting schedules, and developing a quality product that meets customer needs. Recognizing those teams that seem to be using successful processes (as defined by external role models) will have strong motivational effects on the recognized. More importantly though, top level recognition indicates what success looks like and where the company is headed. Broadcasting success helps others in the company internalize the change targets and better align the organization.

The final two potential forces concern planning and goals for change. Despite what John believes, it is the author's opinion that PDP needs goals, milestones, and ways to measure success. Without these, things may still change, but will they change as fast as they could? Many people at Bellex seem to think that only quantifiable metrics are worth anything (the technocratic approach). As shown in Exhibit 1, there are a whole host of measures: quantitative measures of time to market performance such as breakeven time (BET), time to market, and the percentage of revenues from new products; qualitative measures that capture necessary organizational, incentive, training, decision-making, and process changes such as the number of Program Managers promoted to vice president, changes in employee incentive programs to team-based compensation, and advances in decisiveness Formulating a clear and widely accepted plan has many benefits:

- short term milestones give employees achievable goals they can relate to,
- the scope of the necessary changes becomes evident to all parties forcing consensus as to future directions, and
- competitive realities define goals and objectives that are neither too low nor too high.

Finally there is the strong resistance of the functional and business sector heads. One hypothesis is that these managers have effectively become the bottleneck in the corporation. Upper management has introduced so many change projects that they have not been able to implement any effectively. In the last two years Bellex has witnessed a New Pay Plan, Total Quality Ownership, PDP, and Work Redesign. It may be time for Bellex to start tying all these programs together, and starting them at a more reasonable rate. This, coupled with a focus on implementation rather than design will help continue and accelerate the improvement process already in place.

Summary

The case study of Bellex Corporation is representative of the experience of many companies that have begun to improve their product development processes. Changes in strategy, organization, process, technology, and skill base, are necessary for this transformation. These changes are risky, painful, and often very slow. Furthermore, there is no one formula for change that works everywhere. Companies must tailor both the tools adopted and the implementation methods used to their specific needs based on existing systems and culture. There simply is no one right way.

In the case of Bellex, one of its cultural strengths is creativity and innovation. The company has been recognized by customers and competitors as an innovation leader. Unfortunately, many at Bellex perceive a conflict between this strength and a disciplined approach to product development. Employees fear that a disciplined approach will somehow stifle creativity. It is the author's opinion that this is not true. Nonetheless, PDP, or any other disciplined process, should not be adopted if it compromises a core strength. Instead the two should be carefully defined so that they can co-exist, and reinforce each other.

Many American companies are wrestling with this issue as they recognize the success of much more disciplined and process-driven Japanese companies. However, the strength of American companies has long been innovation and creativity. Although the Japanese have made gains in this area, they have yet to match this American strength. American companies have to carefully determine those aspects of Japanese techniques that will work in their specific company circumstance. Failure to do so risks losing an important competitive advantage.

Exhibit 1

Proposed PDP Plan

Quantifiable Goals

Quality	Define Baseline/Goals	2X	5X	10X
Time to Market (or BET)	Define Baseline	10% Reduction	25% Avg.	50% Avg.
% Successful Pdts.	Define Baseline	50% Successful Meet Program Goals	65%	75%
% Sales from New Pdts	Define Baseline	15% Introduced last 3 years	20%	25%

Qualitative Goals

Organizational	Bi-Weekly PM Muster	Mentor Program for PMs	1+ PM promoted to VP	20% VPs from PM
Incentives	Design Separate Incentive Program for PD Team Members	Introduce NPD Incentives -monetary -nonmonetary	25% of pay PDT Goal Dependant Std.Dev. in pay = 80% of mean	
Training	Pilot PM Training	20 Fully Trained PMs	In-House Training Seminar	
Monitoring	All Programs categorized by phase with schedule projections	All PD teams using standard scheduling package	Aggregate actual & forecast data avail. inc. phase, proj type,resource commitment	Full functioning PD portfolio mgmt network model
Decision-Making	Published Screening Criteria by Segment and project type (new to world/line extension)	Screening decisions balanced to resource allocation		

Process

- Ain't It Awful (Aug.88)
- Audit of Bellex Strengths & Weakness
- Survey of Best Practices
- Develop PDP
- Pilot 3 Programs
- All major programs incorporated in PDP (11/89)
- Propose PD Support Center
- Receive funding/ resources for PD Support Center
- Top Management issues Quality/TTM stretch goal

1989 1990 1991 1992 1993 1994

Exhibit 2

Implementation of the Product Delivery Process

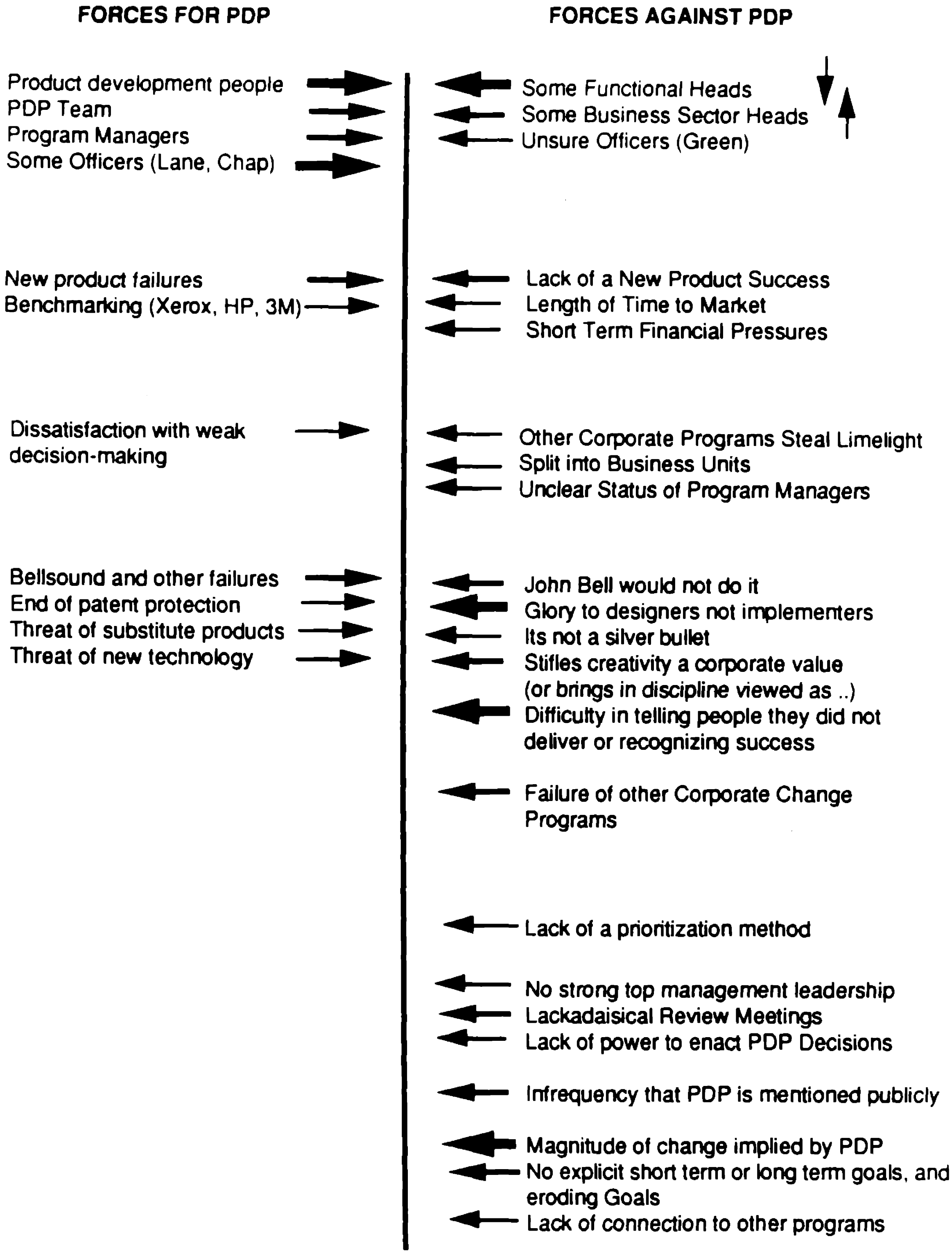


Exhibit 3

Suggestions for Implementation of PDP

[box] = Potential New Forces

FORCES FOR PDP

- Product development people [box]
- PDP Team
- Program Managers
- Some Officers (Lane,Chap)
- New product failures
- Benchmarking (Xerox, HP, 3M)
- Dissatisfaction with weak decision-making
- Bellsound and other failures
- End of patent protection
- Threat of substitute products
- Threat of new technology
- Signs that management values process [box]
- Education about what it is by potential role models [box]
- Widely broadcast specific success stories [box]
- Review Meetings (attentive, rigorous, prepared, decisive, powerful) [box]
- New Product process definition and metrics [box]
- Formal Presentation of a Five Year Plan with Short Term Milestones [box]

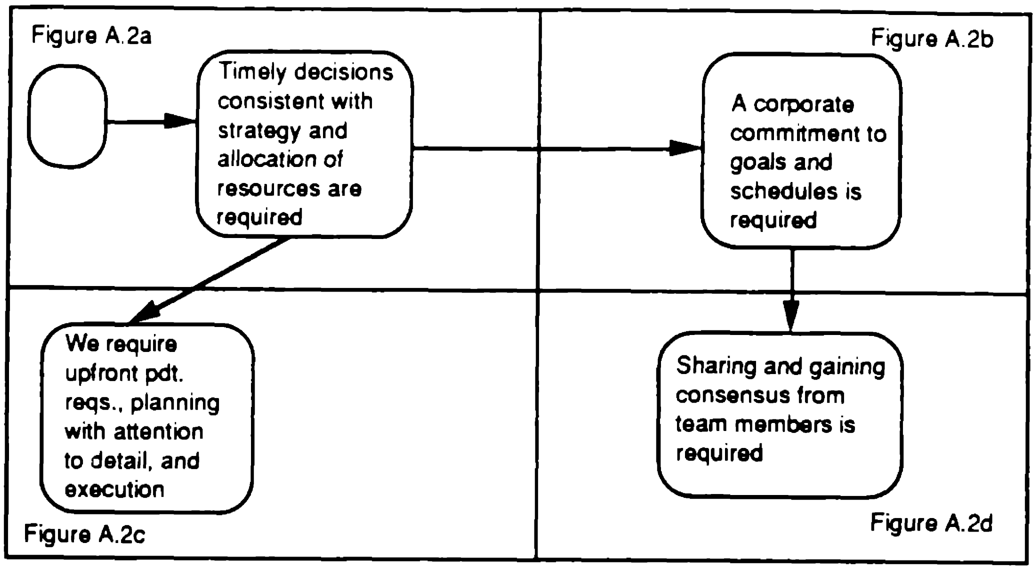
FORCES AGAINST PDP

- Some Functional Heads
- Some Business Sector Heads
- Unsure Officers (Green)
- Lack of a New Product Success
- Length of Time to Market
- Short Term Financial Pressures
- Other Corporate Programs Steal Limelight
- Split into Business Units
- Unclear Status of Program Managers
- John Bell would not do it
- Glory to designers not implementers
- Its not a silver bullet
- Stifles creativity a corporate value (or brings in discipline viewed as ..)
- Difficulty in telling people they did not deliver or recognizing success
- Failure of other Corporate Change Programs
- Lack of a prioritization method
- No strong top management leadership
- Lackadaisical Review Meetings
- Lack of power to enact PDP Decisions
- Infrequency that PDP is mentioned publicly
- Magnitude of change implied by PDP
- No explicit short term or long term goals, and eroding Goals
- Lack of connection to other programs

APPENDIX A: RESULTS OF THE JULY 3RD KJ

A Key to the Following KJ Results

Group A Results



Group B Results

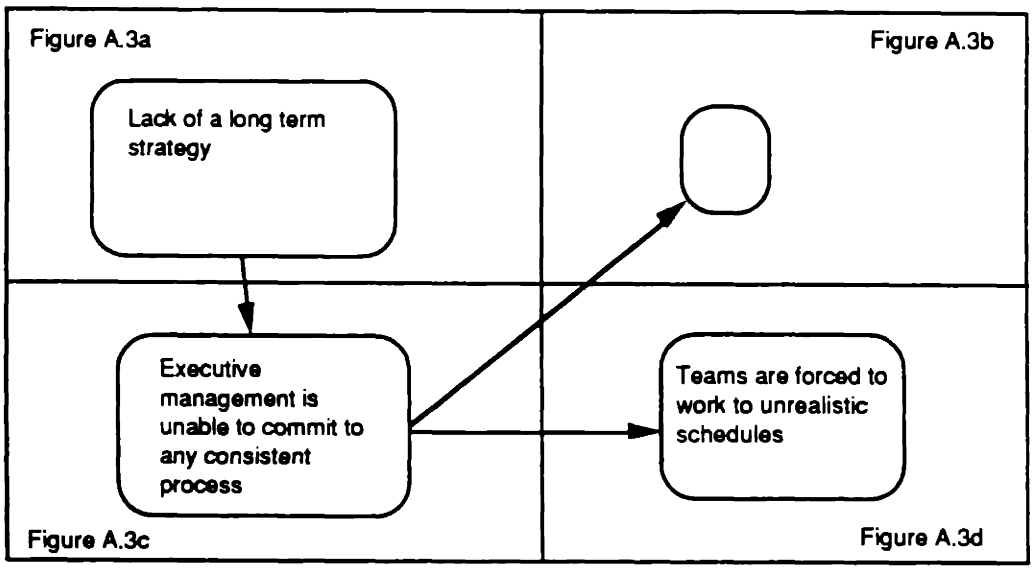


Figure A.1

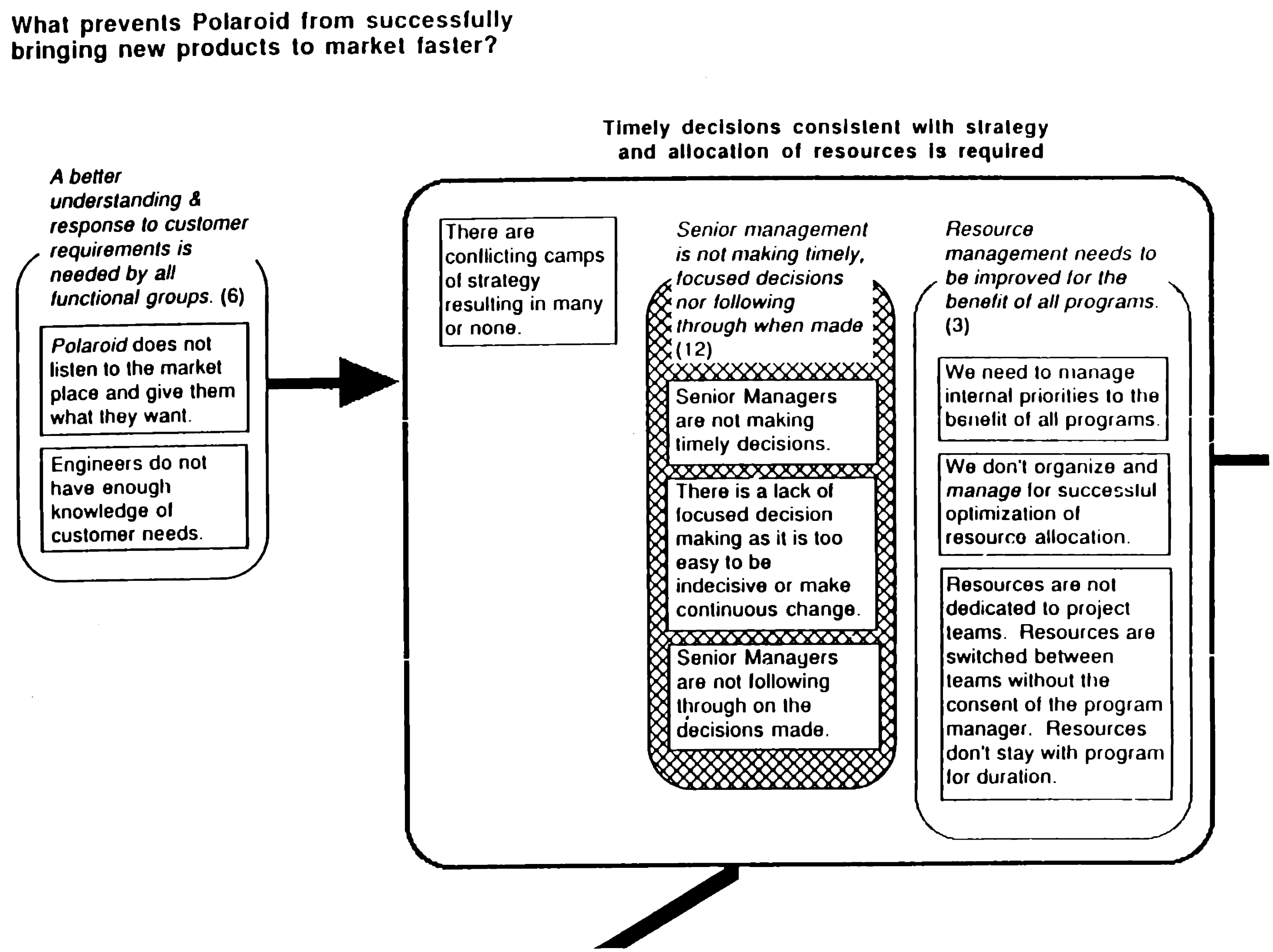

What prevents Polaroid from successfully bringing new products to market faster?
A better understanding & response to customer requirements is needed by all functional groups. (6)
Polaroid does not listen to the market place and give them what they want.
Engineers do not have enough knowledge of customer needs.
Timely decisions consistent with strategy and allocation of resources is required
There are conflicting camps of strategy resulting in many or none.
Senior management is not making timely, focused decisions nor following through when made (12)
Senior Managers are not making timely decisions.
There is a lack of focused decision making as it is too easy to be indecisive or make continuous change.
Senior Managers are not following through on the decisions made.
Resource management needs to be improved for the benefit of all programs. (3)
We need to manage internal priorities to the benefit of all programs.
We don't organize and manage for successful optimization of resource allocation.
Resources are not dedicated to project teams. Resources are switched between teams without the consent of the program manager. Resources don't stay with program for duration.

Figure A.2a

Group A Conclusion: Polaroid needs to make timely, focused decisions and to follow them through when made.

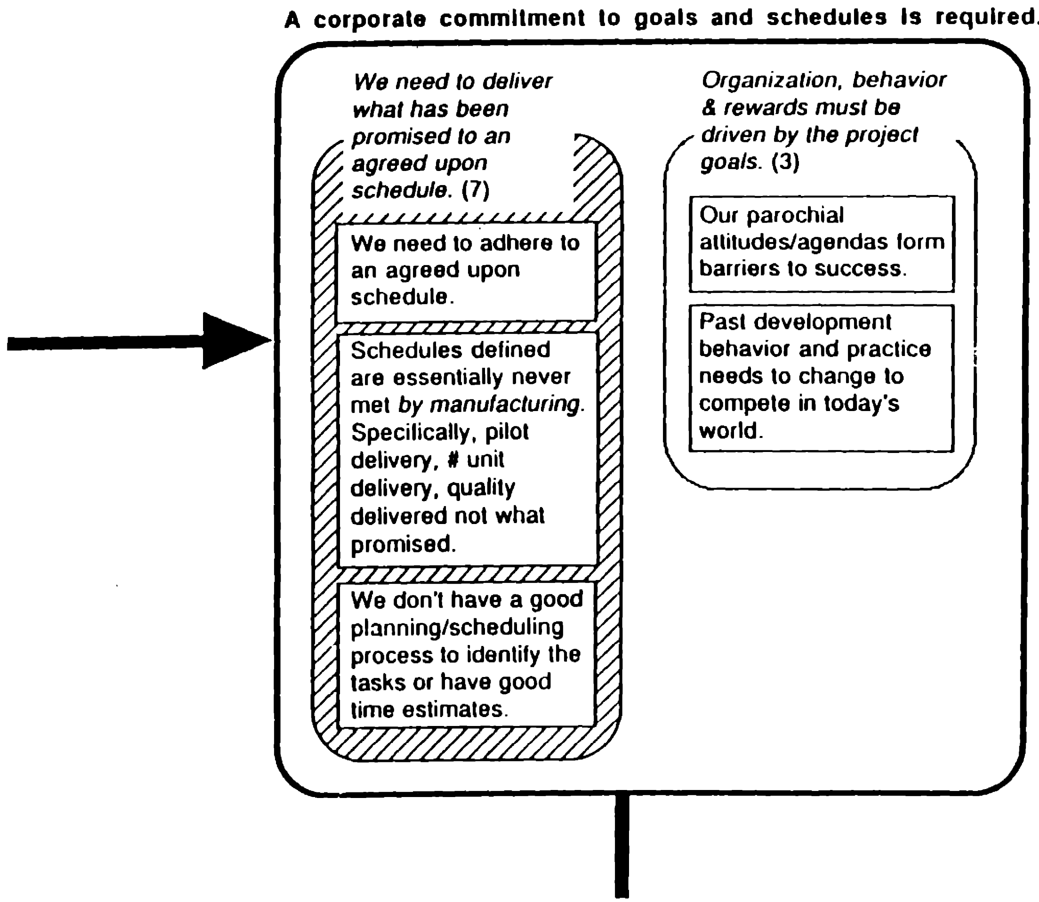


Figure A.2b

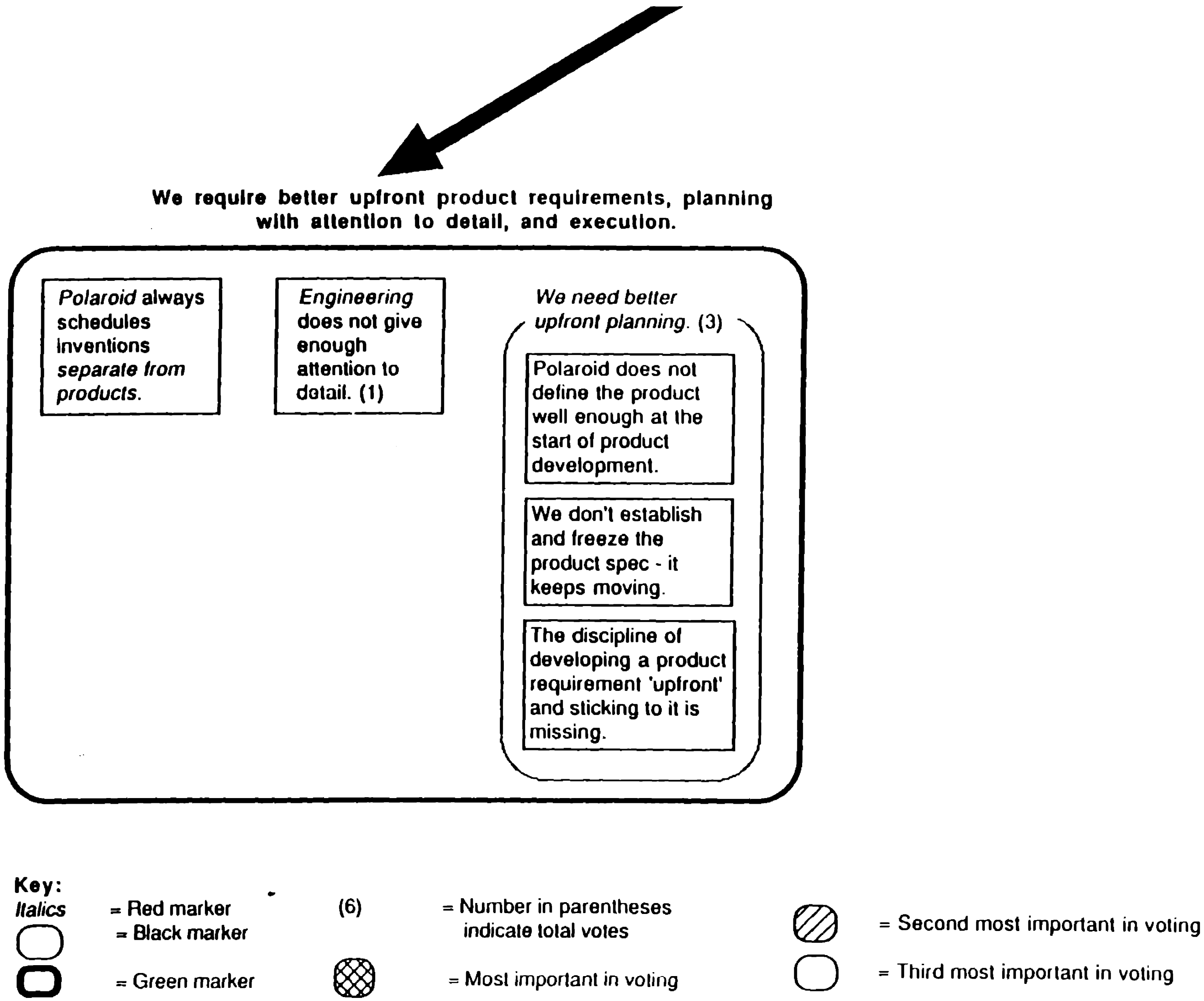
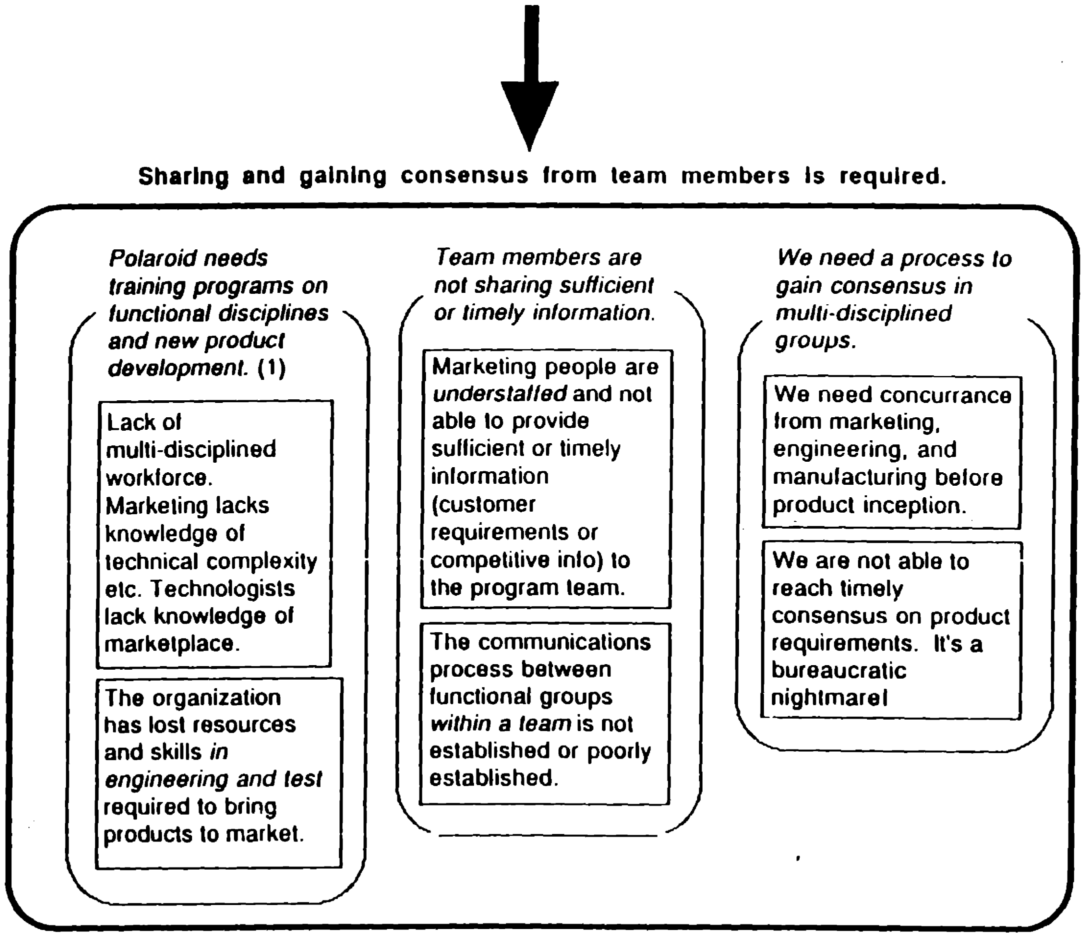

We require better upfront product requirements, planning with attention to detail, and execution.
Polaroid always schedules inventions separate from products.
Engineering does not give enough attention to detail. (1)
We need better upfront planning. (3)
Polaroid does not define the product well enough at the start of product development.
We don't establish and freeze the product spec - it keeps moving.
The discipline of developing a product requirement 'upfront' and sticking to it is missing.
Key:
Italics = Red marker
= Black marker
= Green marker
(6) = Number in parentheses indicate total votes
= Most important in voting
= Second most important in voting
= Third most important in voting

Figure A.2c



July 3, 1990
575 Tech Square, 4B

LC, FC, KS, FS,TT, PT

Figure A.2d

What prevents Polaroid from successfully bringing new products to market faster?

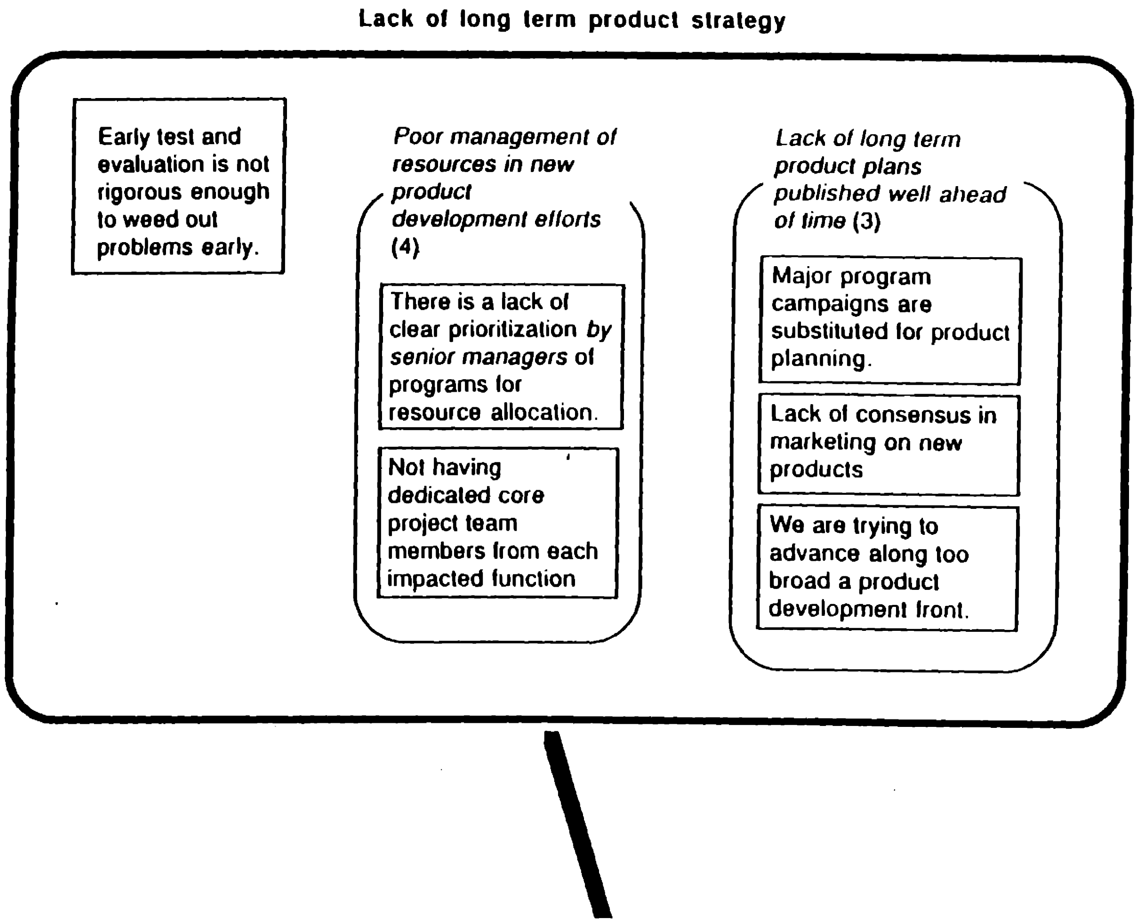


Figure A.3a

Group B Conclusion: The decision-making process is inadequately defined and controlled.

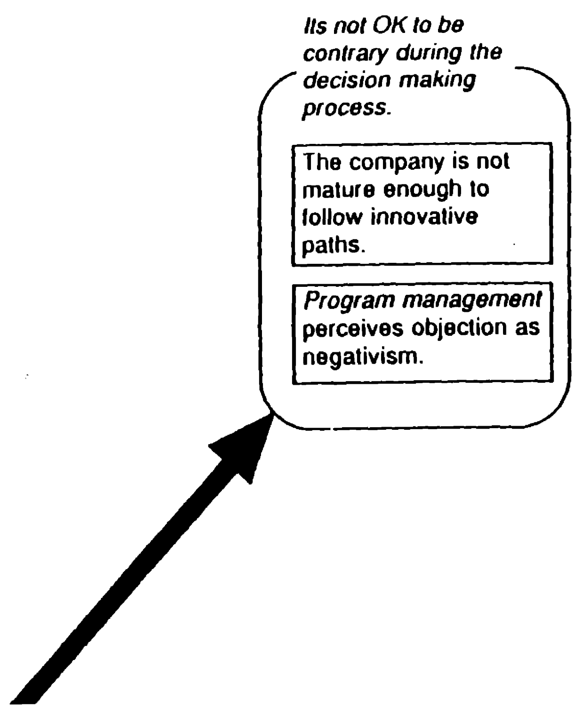


Figure A.3b

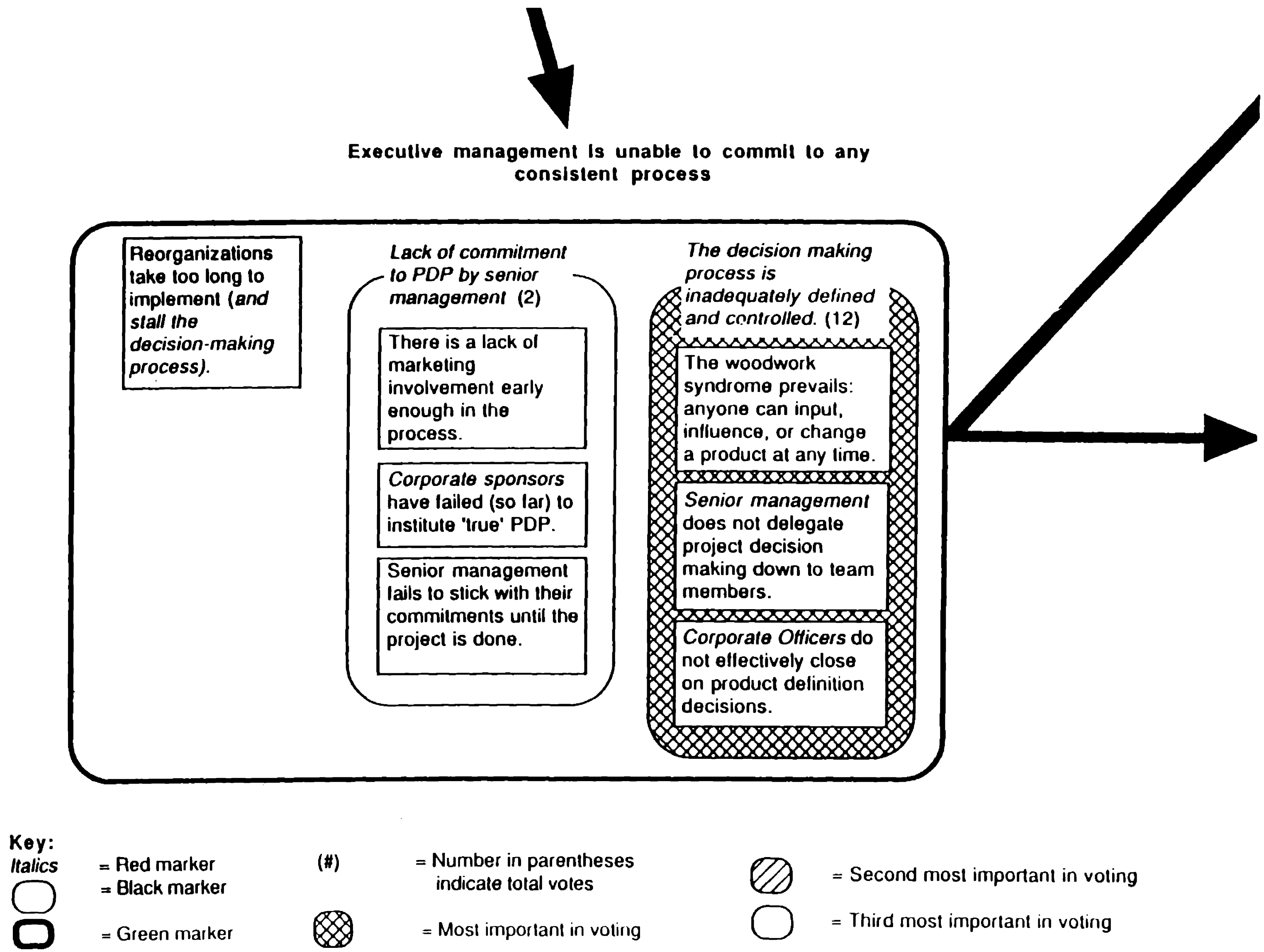
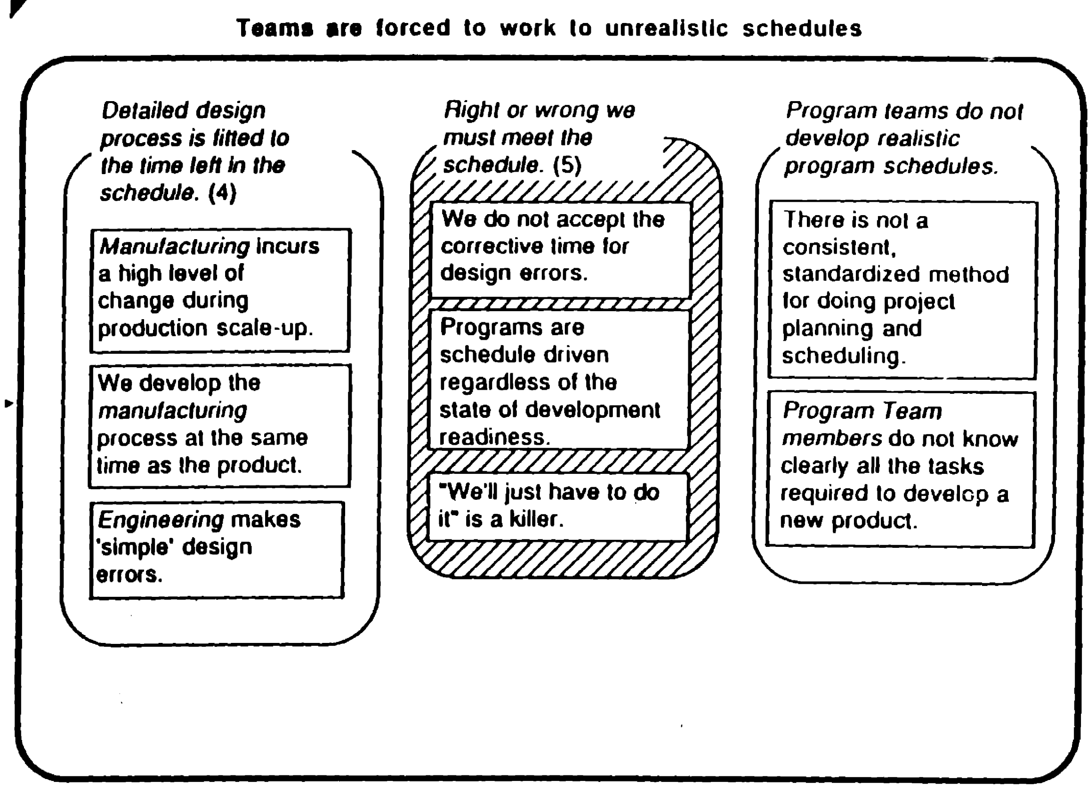

Executive management is unable to commit to any consistent process
Reorganizations take too long to implement (*and stall the decision-making process*).
Lack of commitment to PDP by senior management (2)
There is a lack of marketing involvement early enough in the process.
Corporate sponsors have failed (so far) to institute 'true' PDP.
Senior management fails to stick with their commitments until the project is done.
The decision making process is inadequately defined and controlled. (12)
The woodwork syndrome prevails: anyone can input, influence, or change a product at any time.
Senior management does not delegate project decision making down to team members.
Corporate Officers do not effectively close on product definition decisions.
Key:
Italics = Red marker
= Black marker
= Green marker
(#) = Number in parentheses indicate total votes
= Most important in voting
= Second most important in voting
= Third most important in voting

Figure A.3c



July 3, 1990
575 Tech Square, 3B

DC, EC, GF, SJ, LM, PS

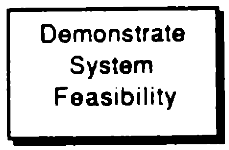
Figure A.3d

APPENDIX B: A GENERIC PRODUCT DEVELOPMENT SCHEDULE

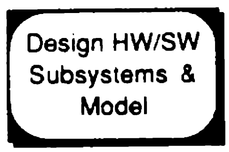
A Key to Project Pluto

The generic model has been created using MacProject II. The following is a key to symbols:

Milestone

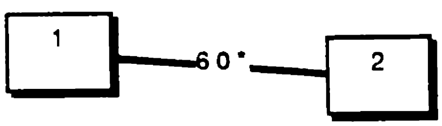


Step or Task

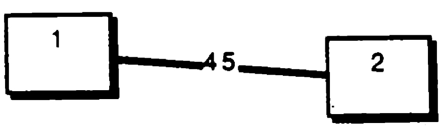


Subproject: indicates that the step is contigent on a sub-network of steps/tasks

Indicates precedence, i.e. task 1 must be completed before task 2 can be started.

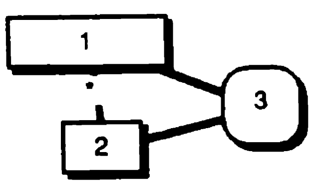


The start of task 1 must precede the start of task 2 by 60 days

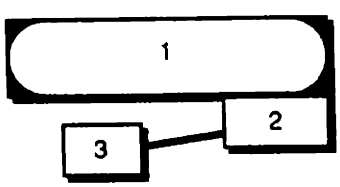


The end of task 1 must precede the start of task 2 by 45 days

Other inventions:



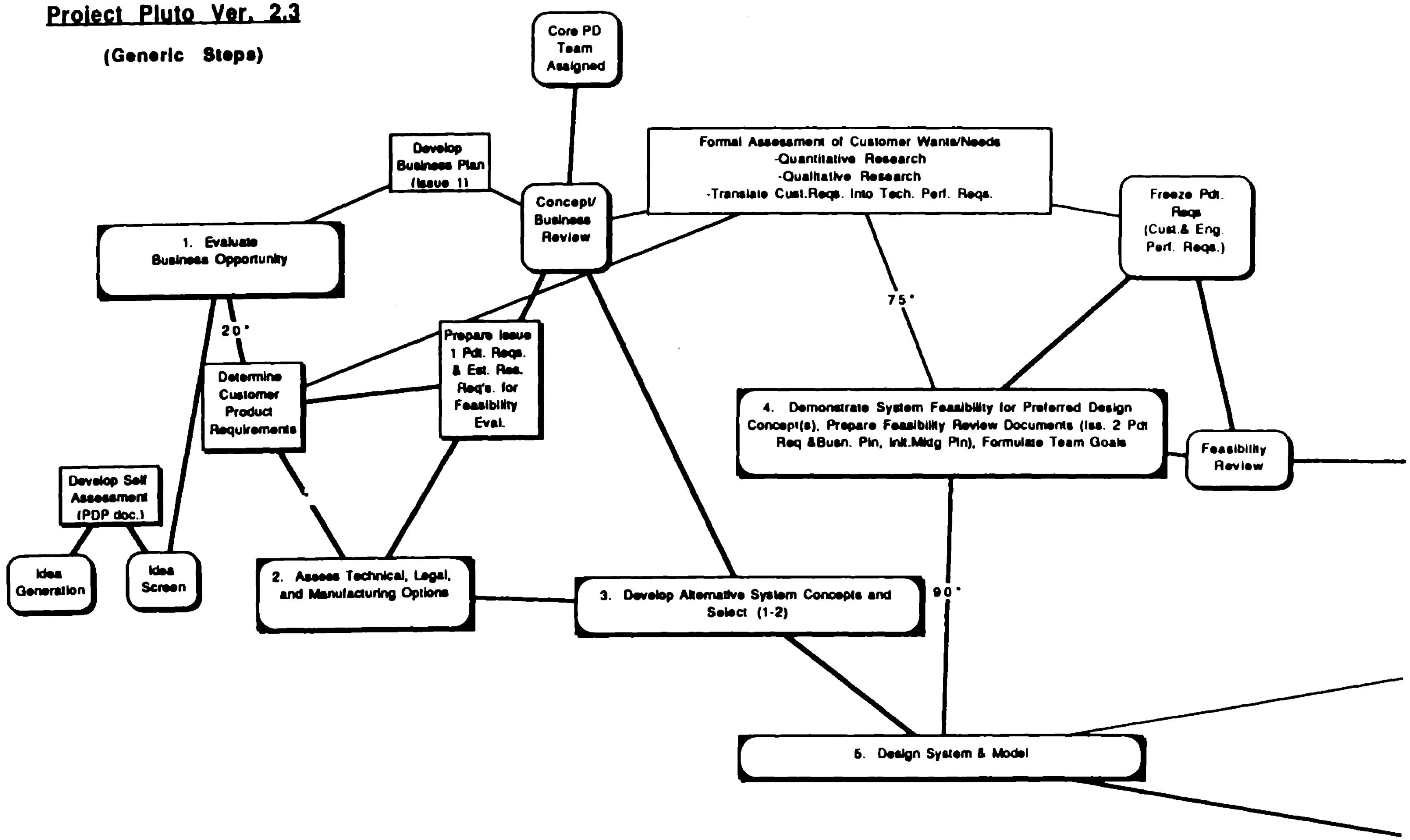
Task 1 and 2 must be done concurrently and are dependant on each other



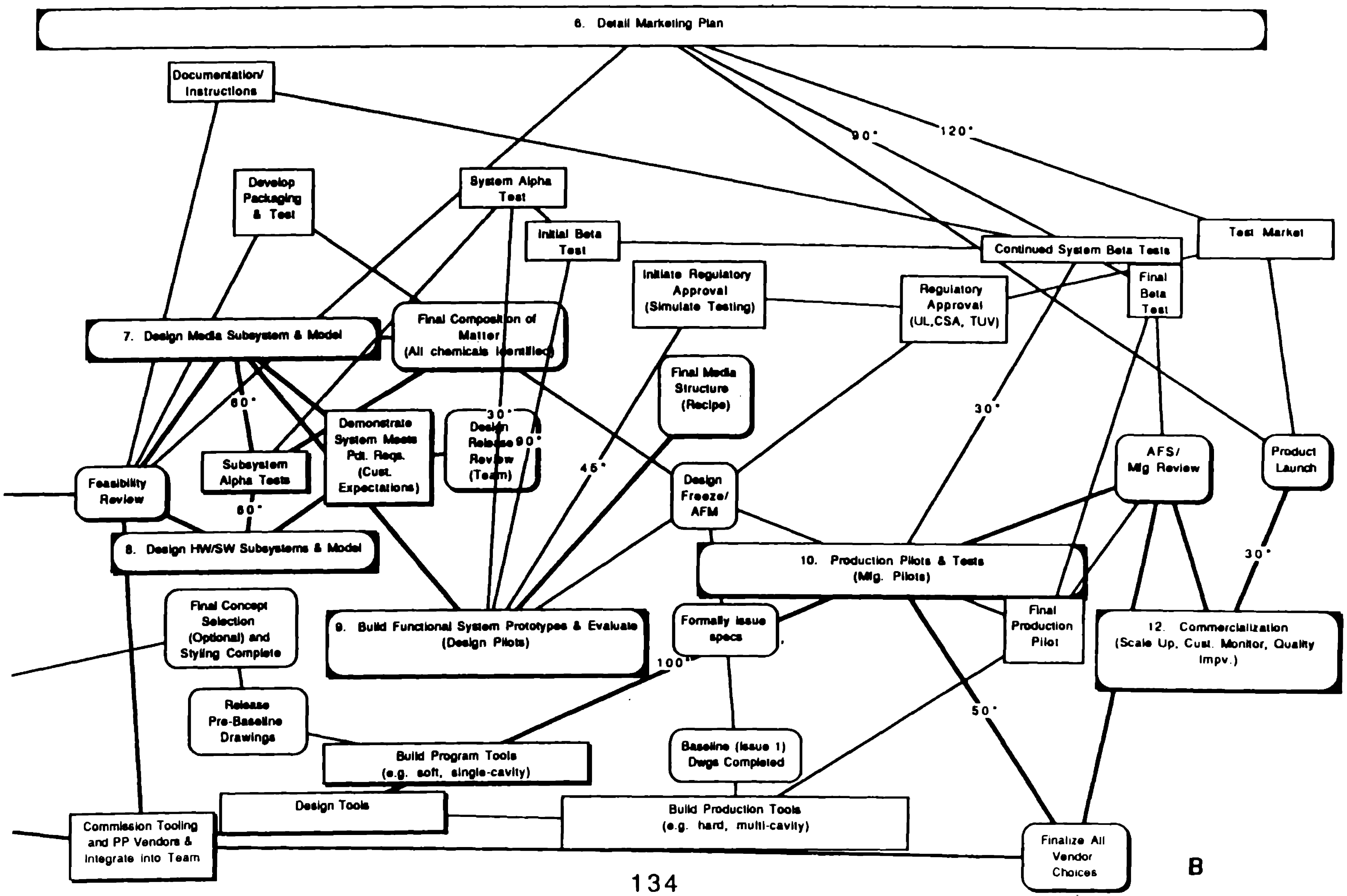
The end of task 3 precedes the end of task 1 by the duration of task 2

Project Pluto Ver. 2.3

(Generic Steps)



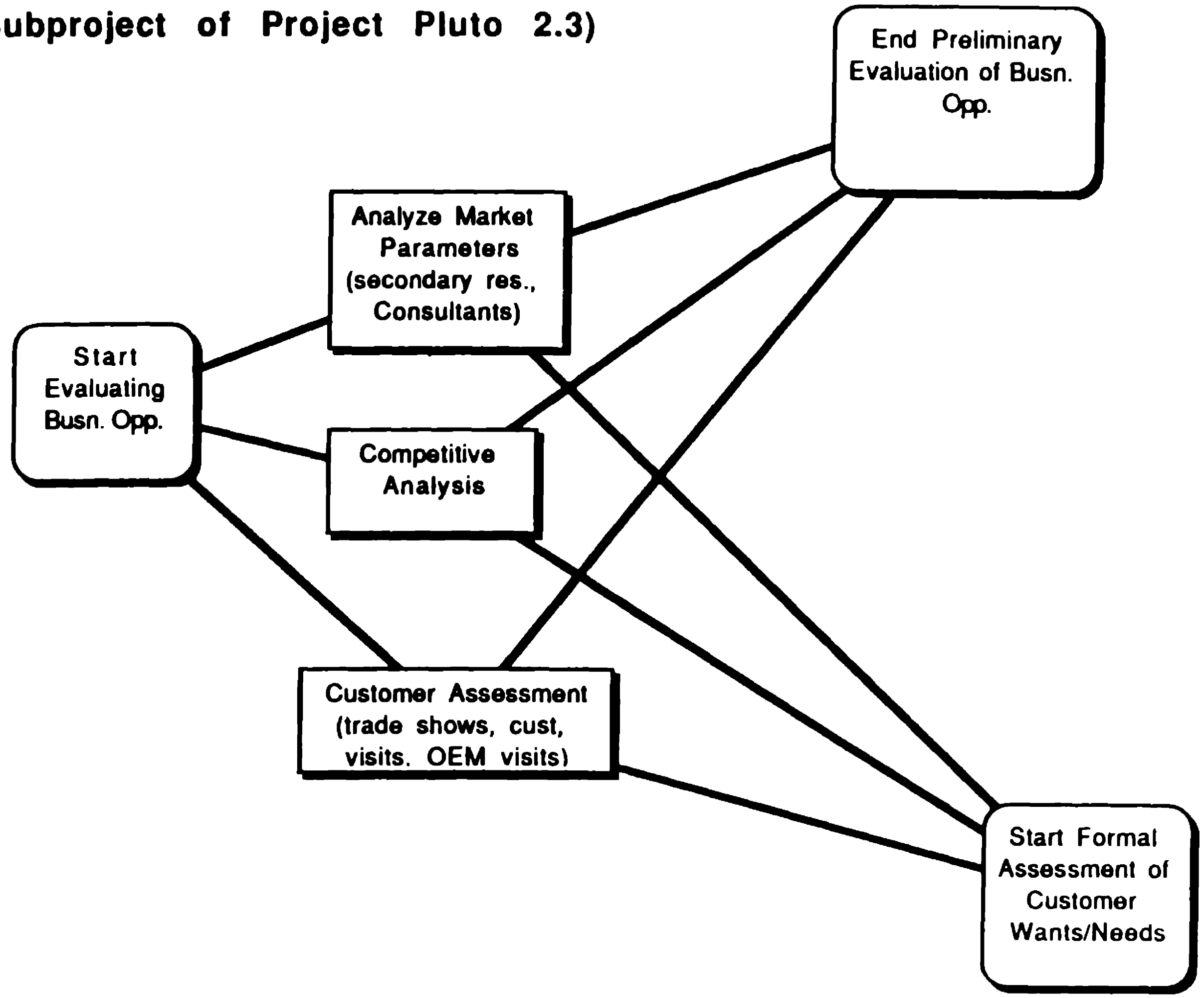
A


6. Detail Marketing Plan
Documentation/ Instructions
Develop Packaging & Test
System Alpha Test
Initial Beta Test
Initiate Regulatory Approval (Simulate Testing)
Regulatory Approval (UL,CSA, TUV)
Continued System Beta Tests
Test Market
Final Beta Test
7. Design Media Subsystem & Model
Final Composition of Matter (All chemicals identified)
Final Media Structure (Recipe)
Feasibility Review
Subsystem Alpha Tests
Demonstrate System Meets Pdt. Reqs. (Cust. Expectations)
Design Release Review (Team)
Design Freeze/ AFM
AFS/ Mfg Review
Product Launch
8. Design HW/SW Subsystems & Model
10. Production Pilots & Tests (Mfg. Pilots)
Final Concept Selection (Optional) and Styling Complete
9. Build Functional System Prototypes & Evaluate (Design Pilots)
Formally issue specs
Final Production Pilot
12. Commercialization (Scale Up, Cust. Monitor, Quality Impv.)
Release Pre-Baseline Drawings
Build Program Tools (e.g. soft, single-cavity)
Baseline (Issue 1) Dwgs Completed
Design Tools
Build Production Tools (e.g. hard, multi-cavity)
Commission Tooling and PP Vendors & Integrate into Team
Finalize All Vendor Choices
120°
90°
30°
60°
60°
30°
90°
45°
30°
100°
50°
30°

B

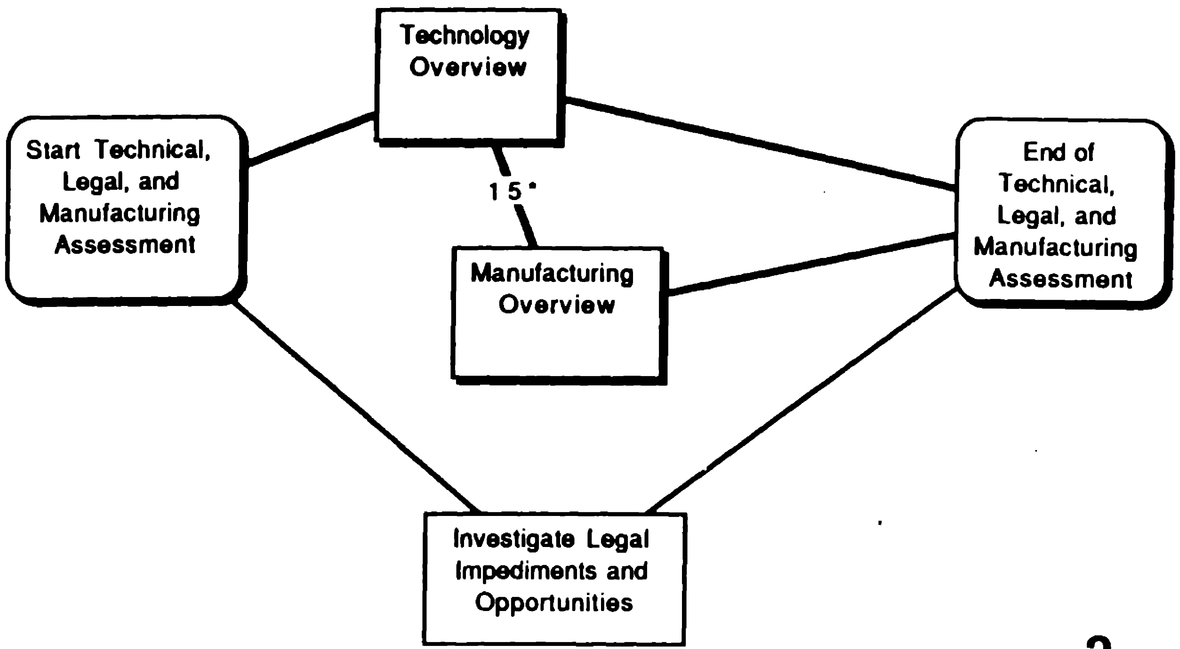
Evaluate Business Opportunity

(Subproject of Project Pluto 2.3)



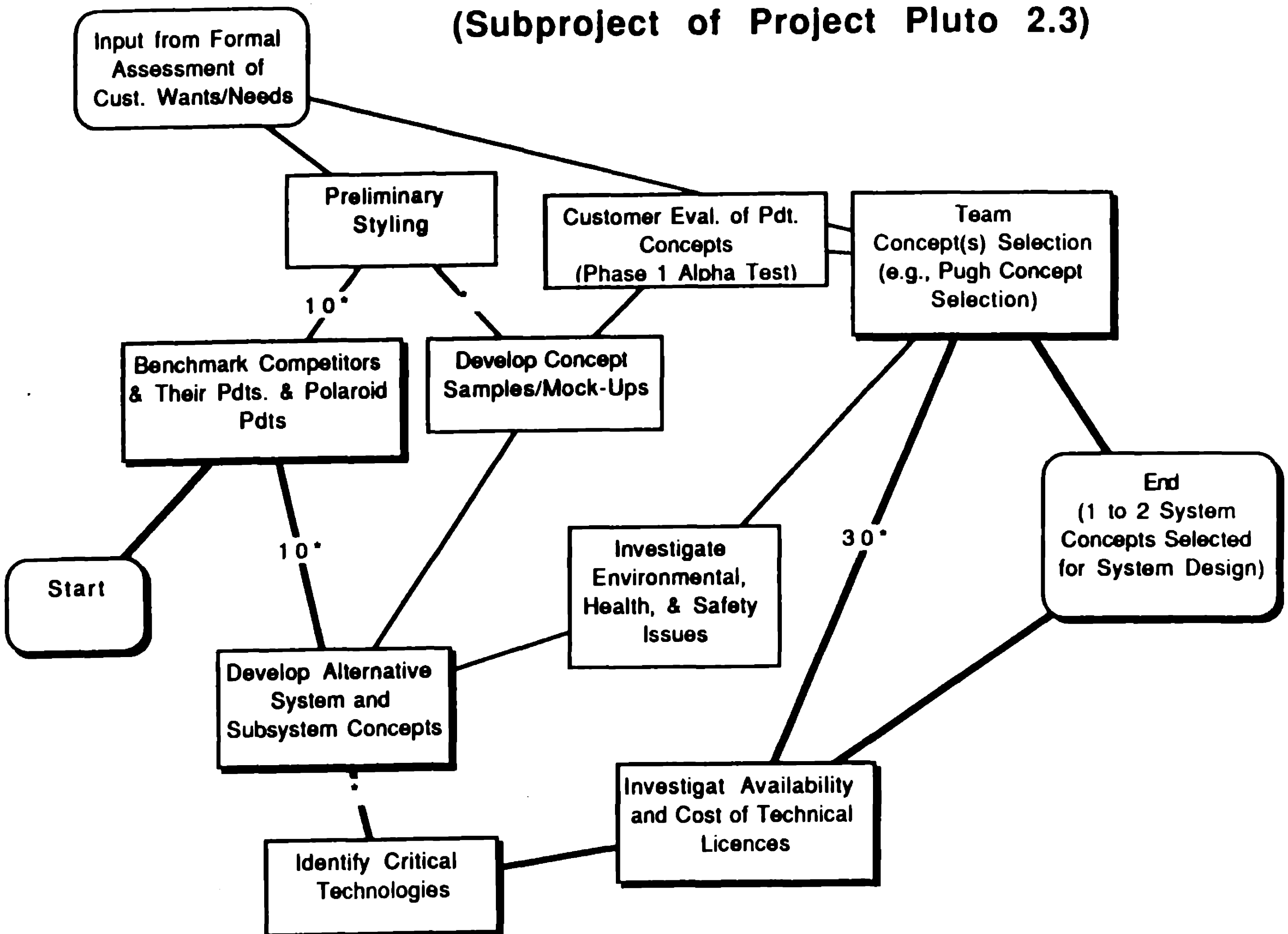
1

Assess Technical, Legal, and Manufacturing Options (Subproject of Project Pluto 2.3)



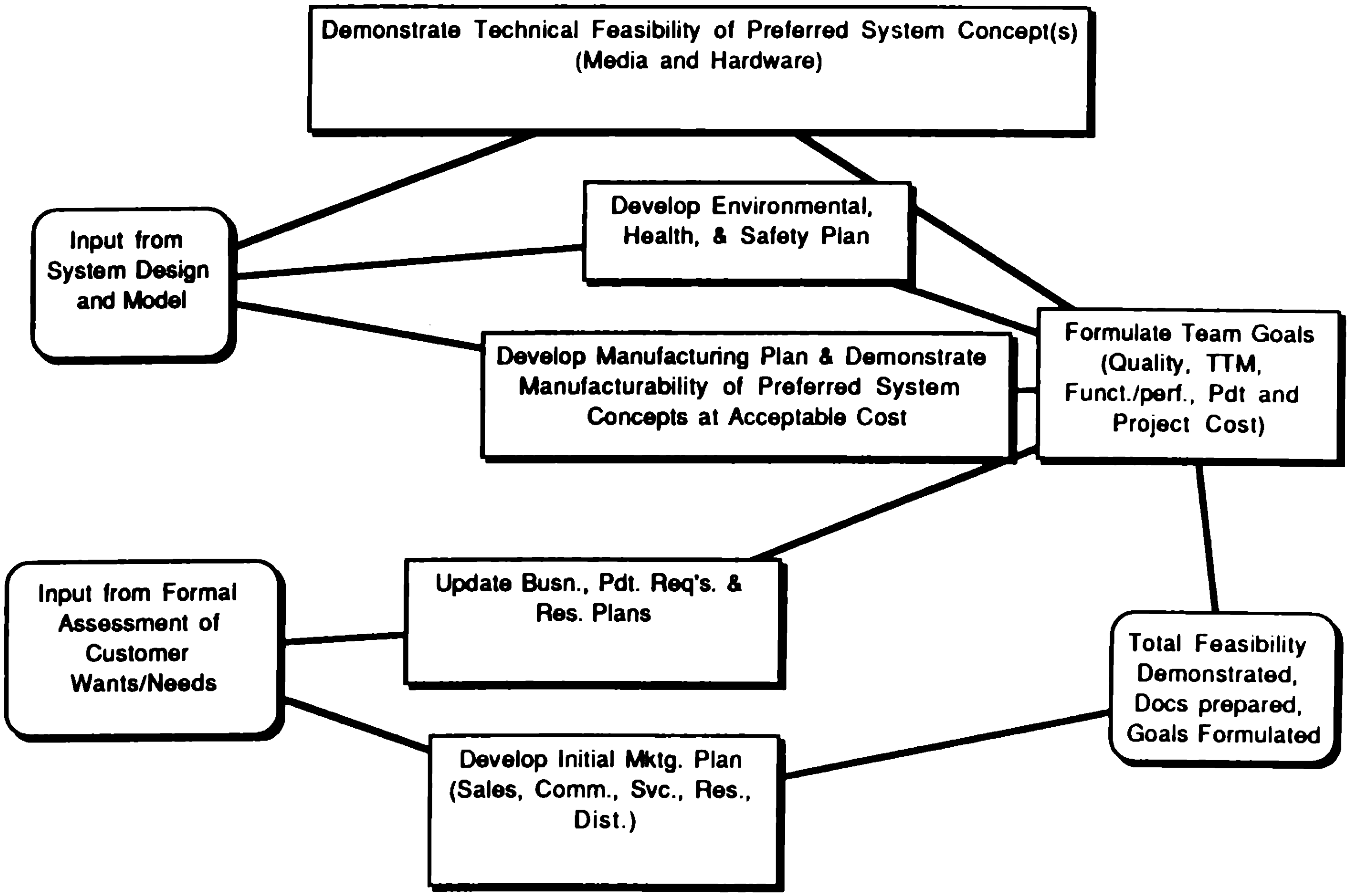
2

Develop Alternative System Concepts and Select (Subproject of Project Pluto 2.3)



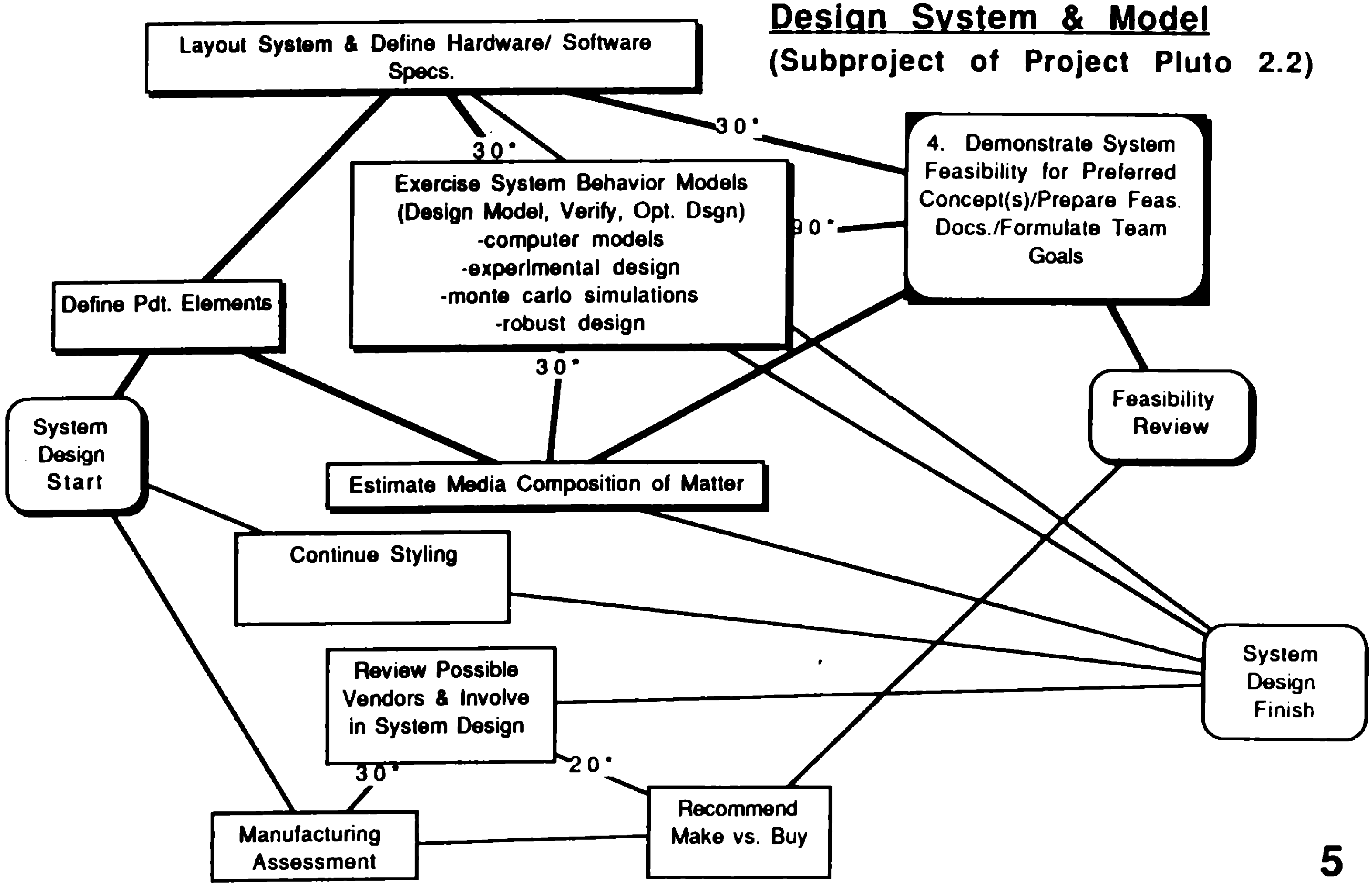
3

Demo Feasibility, Prepare Review Documents and Formulate Team Goals (Subproject of Project Pluto 2.3)



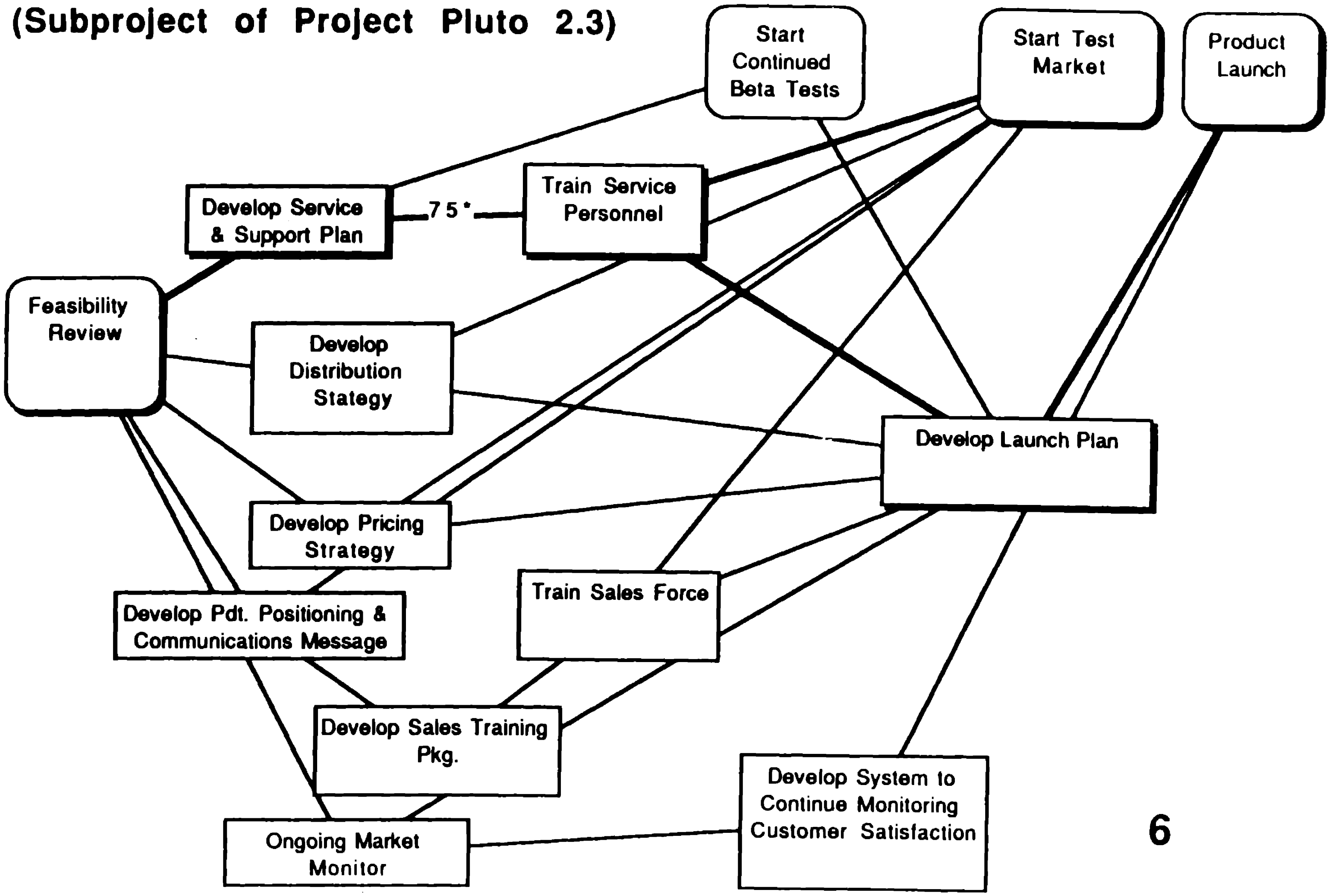
4

Design System & Model
(Subproject of Project Pluto 2.2)



5

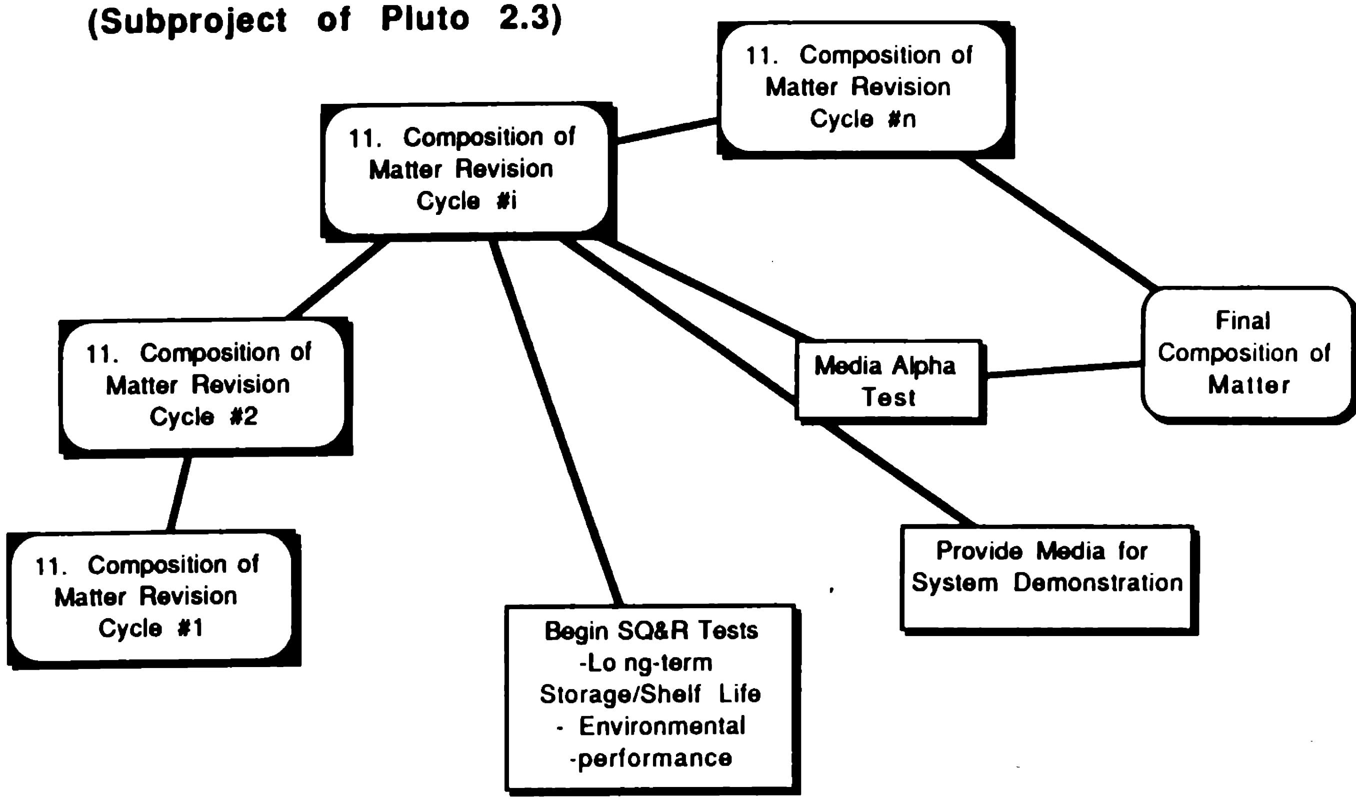
Detail Marketing Plan
(Subproject of Project Pluto 2.3)



6

Design Media Subsystems & Model

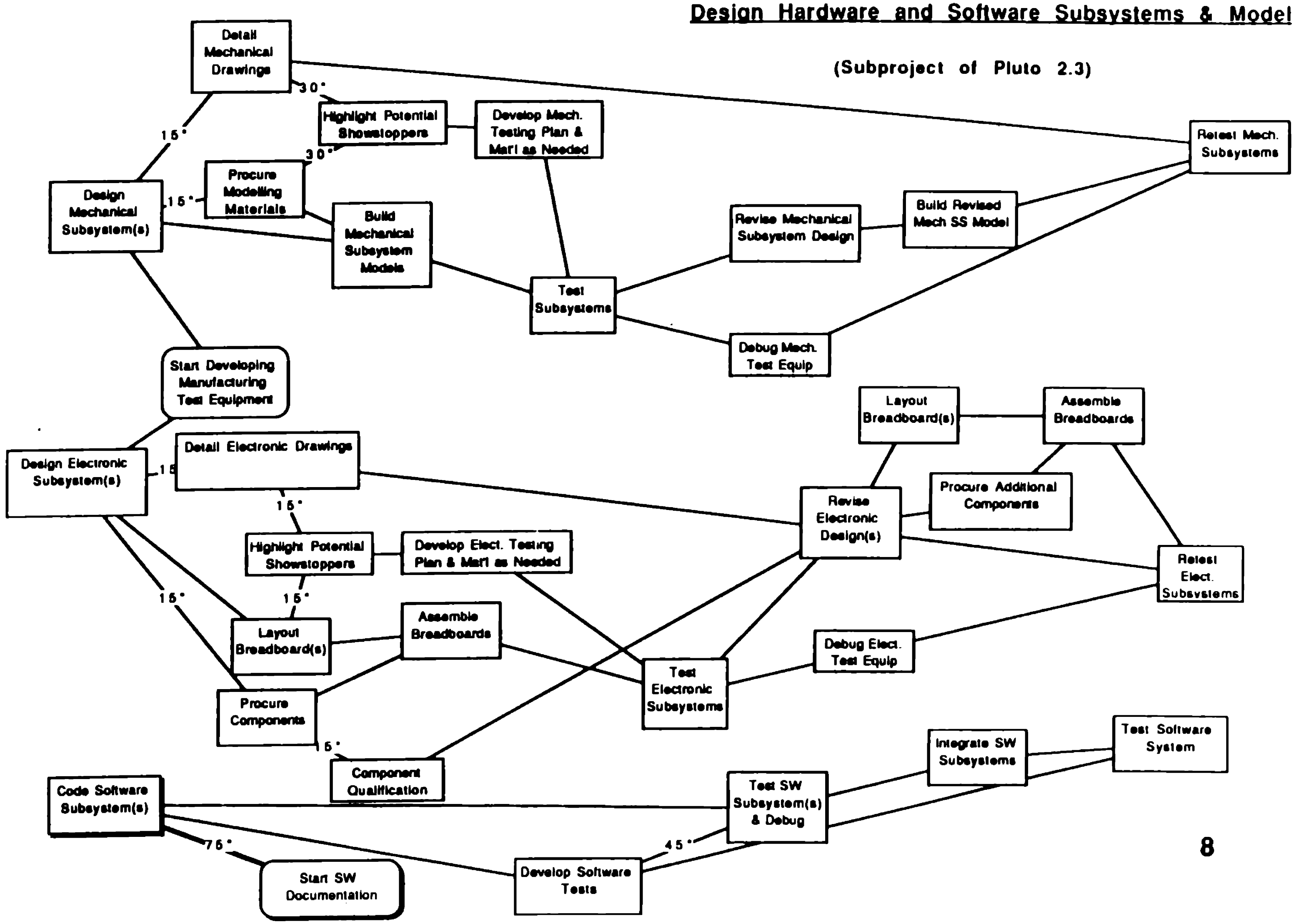
(Subproject of Pluto 2.3)



7

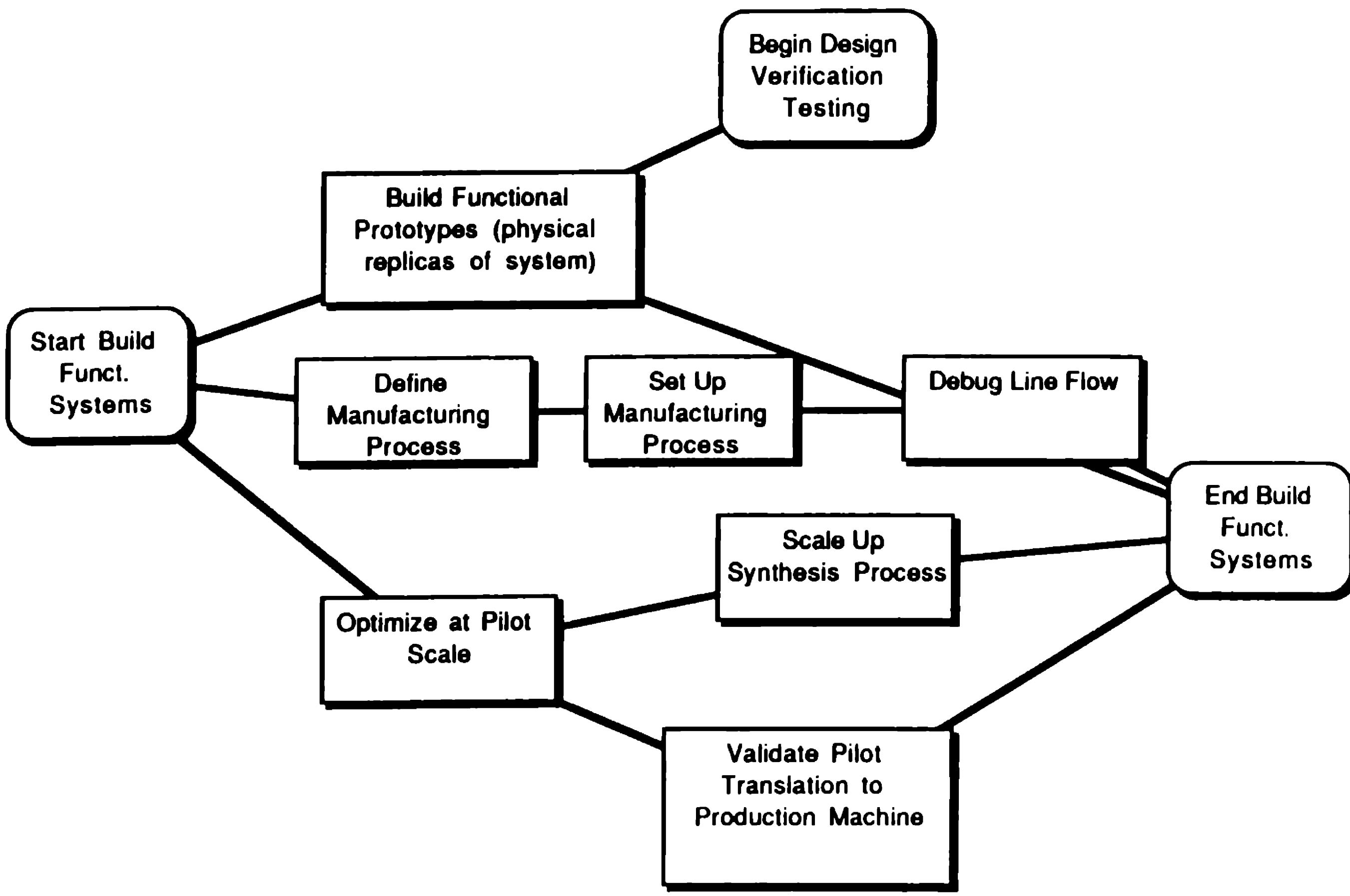
Design Hardware and Software Subsystems & Model

(Subproject of Pluto 2.3)



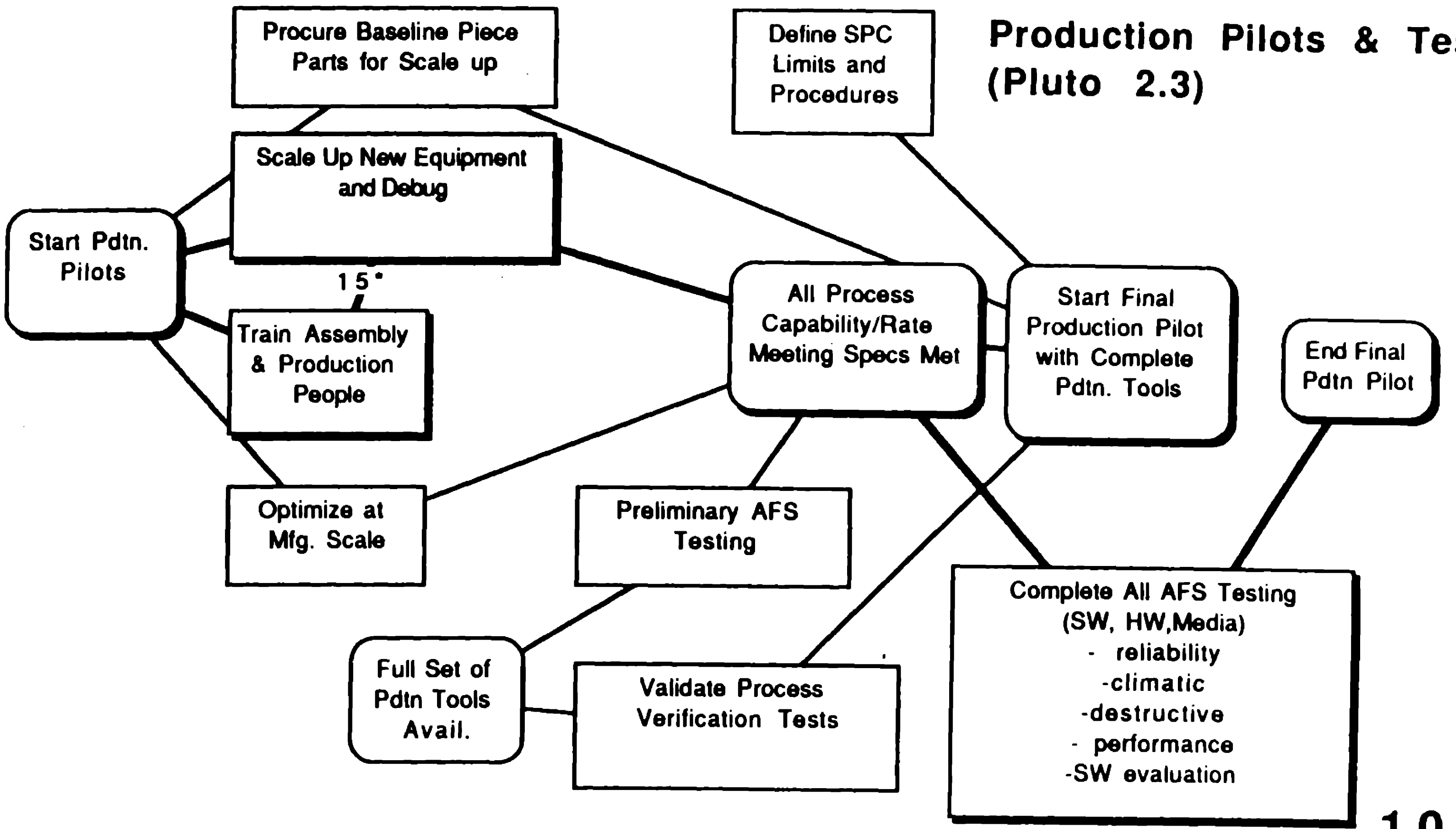
8

Build Functional Systems & Evaluate (Project Pluto 2.3)



9

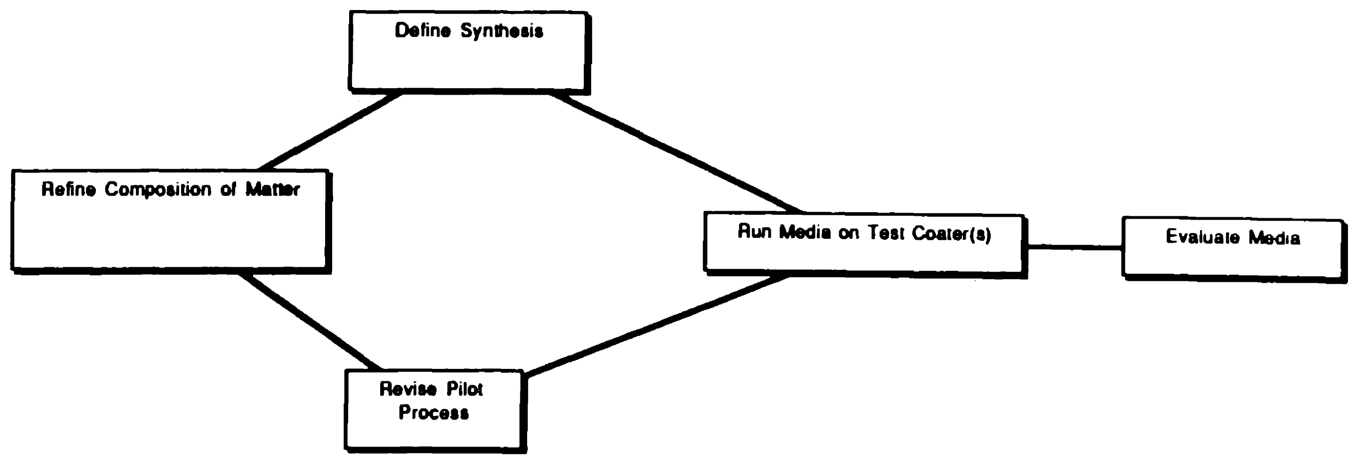
Production Pilots & Test (Pluto 2.3)



10

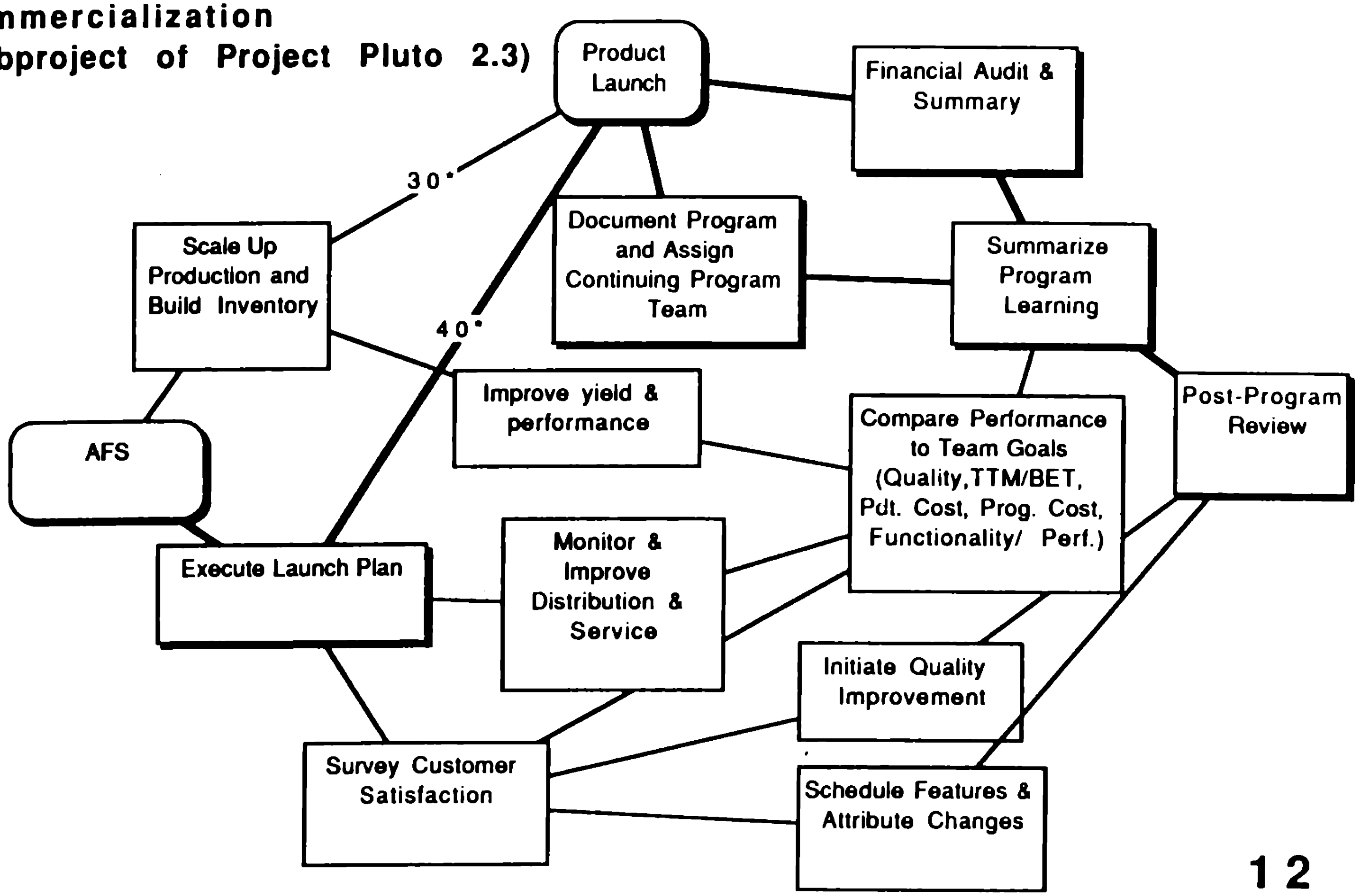
Composition of Matter Revision Cycle

(Sub- subproject of Pluto 2.3)



11

Commercialization
(Subproject of Project Pluto 2.3)



12

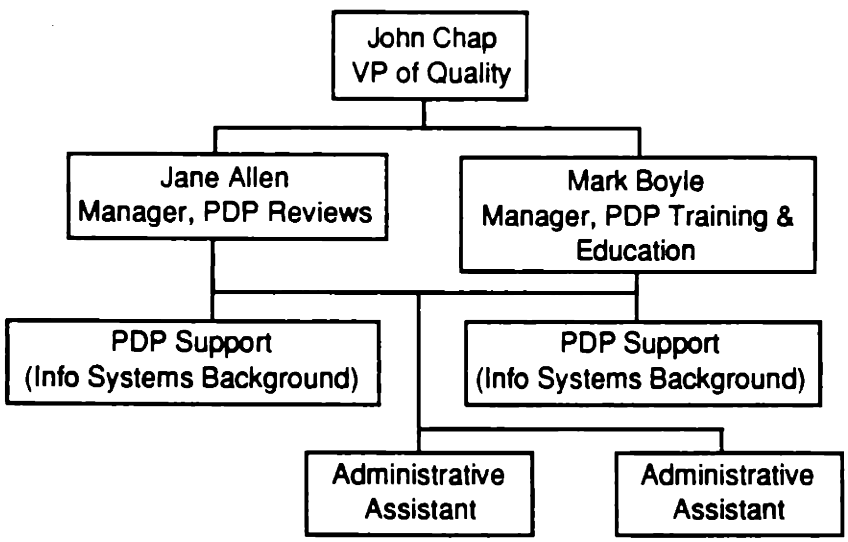
APPENDIX C: A CASE STUDY AT BELLEX CORPORATION[1]

[1] Bellex Corporation is a fictitious name, although events described and comments are authentic.

Prelude

Jane Allen and Mark Boyle scanned the poster covered walls of their windowless office. At eight o'clock on a blustery November evening, they had returned from another bi-weekly Program Manager's Muster with mixed feelings of accomplishment and failure. After a year on the implementation team for Bellex's Product Delivery Process (PDP) (see Figure 1 below), Jane and Mark were questioning whether the cultural and structural changes their team had begun could be accelerated.

Figure 1
The PDP Implementation Team



PDP is an effort to systemize the process of product development at Bellex. It attempts to incorporate 'industry best practices' such as cross-functional teamwork, extensive upfront business and technical analysis, concurrent engineering, and design for manufacturability and reliability. The process consists of six phases with seven review meetings designed to periodically check the progress of development efforts (see Exhibit 1).

The implementation of PDP had not been without its difficulties. Jane reflected:

> PDP is an attempt to change our culture. Up to this, point we have been very unstructured and undisciplined; creativity has been a corporate value since our founding. When you think about it, it is not surprising that many top managers cannot buy-in to PDP. It's counter to everything they have known and been rewarded for at Bellex.

Mark was quick to recognize some progress:

> Of course there have been some naysayers - that's Bellex culture. But look how far we have come. Did you hear the Program Managers tonight? They were full of confidence, strategizing how they would convince Cam [the CEO] to prioritize projects. Six months ago they would have just bitched and flung their hands in the air.
>
> And what about the quality of review meetings? The last review meeting for *Voyager* had everything. The team defined their market, they have evaluated the risks, and they are going to deliver a super product. If only we had a few successes now to prove that PDP works.

Certainly, the long cycle time to develop products had made it difficult to measure PDP's success. Just over a year into PDP implementation, no programs (product development projects) had gone completely through the PDP process. Indeed, this was the source of some of Jane's frustration.

More specifically though, there had been a few indications that continued support for PDP was not viewed as important. The team's proposal to increase its staff and set up a PDP support center had been refused. Even worse, they were told that the team may be downsized by two people. Jane lamented:

> If you look at the actions of top management, it seems we have not done a good job. At the same time, they continue to tell us we are doing everything right. It's just like this company not to recognize success or failure.
>
> Maybe I just have to be more patient.

Although Jane and Mark agreed that some gains had been made, they worried that without constant pressure, their efforts might go to waste. Moreover, they questioned whether the changes were occurring fast enough.

Company Background

History and Culture

Bellex was founded in the 1930s when John Bell incorporated his laboratory in order to commercialize a synthetic material he had invented. The company grew quickly to over $1 billion in sales, primarily of audio recording products. By 1982, John Bell had amassed countless personal patents, and retired a legend both in and outside Bellex. Although Bell is gone in 1990, his legacy still lingers. Cam Green, CEO of Bellex, confirmed the effect of Bell when he recently stated to a class of Sloan students, "we are finally closing the door on Bell, eight years after he left."

Despite Green's claim, Bellex is still dominated to a large extent by the people, values, and skill-base brought to the company by Bell. Technology, entrepreneurship, invention and design are revered at the company. Technical people, and specifically those with a background in synthetic materials, Bellex's most lucrative business, continue to dominate the power structure of the company. Approximately 90% of Bellex's officers come from the synthetic materials business as opposed to those that support recording equipment. Similarly, the most powerful people, including Cam Green and Brian Lane of the newly formed Office of the CEO, are old friends of Bell.

Marketing had not been a primary focus of Bellex. Bell reportedly commented that market research was useless for the type of innovative, new-to-the-world products he developed. The company began to question this belief after the failure of Bellsound in 1977. Bellsound was an attempt to develop chemical-based digital audio technology. The product was several years late coming to market and the technology was immediately supplanted by magnetic digital audio products. Bell bet the company and lost hundreds of millions of dollars when the product was withdrawn from the market two years later. This "silver bullet" mentality, as it is jokingly referred to within Bellex, is increasingly being challenged as Bellex matures.

Entrepreneurship is valued at the corporation as reflected in numerous on-going "skunkworks". Bellex endeavors to never unnecessarily kill an idea. Some employees refer to company culture as "legalized anarchy". It is not uncommon to find projects that have been formally cut off, still continuing.

The Changing Environment

The eighties and nineties have brought with them a myriad of changes and challenges for Bellex in terms of competition, ownership, and technology.

Competitive pressures are mounting rapidly as Bellex's original patents begin to expire, and new substitute products and technologies challenge its market niche. Recently a competitor took advantage of a patent expiration and introduced a competitive product in Japan that is doing very well. Another ominous indication of what the future might look like for Bellex resulted from the illegal entry of a domestic competitor into Bellex's proprietary equipment market in 1976: the competitor captured 25% of the market in 8 years before being ordered by the government to stop production in 1986. Unfortunately, Bellex's audio equipment business is stagnant or declining as customers move to higher quality magnetic devices. Equally challenging is the prospect of a totally new substitute technology in audio recording called DAT.

Financial markets have exerted additional pressure on Bellex. In 1988 and 1989, Lucky Holdings Inc. attempted to take over Bellex. The battle included tender offers, a new ESOP plan, court rulings on ESOP plans, and a white knight rescue. As a direct result of the takeover attempt, Bellex offered voluntary severance which was accepted by 1,800 employees including eight officers of about thirty. The ESOP put 19% of company equity in the hands of its employees in exchange for a 5% pay cut, and about a 4% reduction in the next pay scale adjustment. Recent poor stock price performance tended to increase the pressure on employees for new product successes.

A Description of PDP

The Product Delivery Process (PDP) is a six phase systemization of what should be done and who should be involved to develop a new product at Bellex. A key feature of the process is seven review meetings designed to approve or disapprove projects passing on to the next development phase. Four of these meetings are run by a senior management review panel, specially designed to review all corporate programs. The other three are run by the product development team, the team and key functional managers, and the team and other interested program (project) and functional managers (see Exhibit 1).

Although the stated overall goals of PDP are faster time to market, better quality and lower cost products, the intent of the program was to provide a guideline of activities for Program Managers and management. PDP is supposed to ensure that:

- all functions (R&D, manufacturing, marketing, finance) are involved from the beginning and operate as a team
- business, as well as technical, feasibility is proven
- the quality of the product is assured.

Additionally, PDP is supposed to help management stop projects that lack potential earlier than in the past to save money and redeploy valuable and limited resources.

PDP was also developed to try to give some organizational weight to the role of Program Manager, a new integrative management position created about four years ago to manage product development. Program Managers are the PDP Implementation Group's primary contact.

Evolution of PDP: A Response to a Problem

John Chap, Vice President of Quality, championed the idea of PDP in response to a series of product development failures:

> We didn't have a plan at the beginning of PDP. We viewed it as an experiment, to address the issues we were facing in late 1988 - products that didn't work, were late, and cost a fortune.

John convened a one day off-site meeting on August 22, 1988 (See Exhibit 2 for an overview of key steps). Fifty-two of the fifty-seven invitees showed up for what became labeled the "*Ain't it awful*" meeting. The group agreed on four problem areas in their current product development (PD) system that needed to be addressed:

- the lack of focus and direction
- the lack of clear accountability
- confusion as to a Program Manager's role in PD
- a need to better balance market and technical input.

Design Phase

A Design subcommittee was formed primarily from the original meeting group. They spent almost half a year benchmarking product development processes at other companies, formulating a proposal, and continually revising the process based on comments from a variety of inputs.

Gerry White, a member of the Design Team from marketing, identified the key features of a proposal drafted in November of that year:

- a six phase process with specific activities in each stage that different functions did in parallel
- a requirement for senior management approval/decisions at three gates (later increased to four)
- Program Managers held responsible for delivering a program at an agreed upon quality, cost, and schedule, and supported by functional organizations
- commitment to clearly prioritize programs and allocate resources at the onset according to corporate strategy
- a common accounting system for costs, schedules, sales, etc.

Over the next month and a half, the Design Team presented their "Strawman Proposal" to Program Managers, and staffs from the Quality, Engineering, Manufacturing, and Marketing departments, and three members of the nine member Management Executive Committee (MEC). Comments and suggestions were collected and categorized. In January of 1989, the eight member PDP Design Team presented their revised proposal to the MEC, and successfully appealed for funding and a public commitment to the features of PDP. Details were added to the proposal and by April, PDP was being piloted by three programs sympathetic to the proposal. In response to John's urging, Brian Lane, an Executive Vice President at the time, began selecting program managers with the skills to operate cross-functionally. Program Managers were typically selected from the ranks of middle technical management, although some came from marketing or manufacturing. The new cadre of Program Managers attended an in-house product development and skill building training program.

In May of 1989, John presented the most recent PDP proposal to the MEC. Although most members agreed with the principles of PDP, discussion turned to how certain details would be worked out and how this corporate program impacted other corporate change programs. Some reported mixed responses from certain functional areas. Staffs from Manufacturing registered lukewarm enthusiasm, with "excitement for proceeding". Research and Engineering offered "resigned acceptance", and Marketing and Sales wanted to be "active participants". The group wrestled with how to characterize PDP: "Is this control management/bureaucracy in sheep's clothing, or a process discipline?" Cam, the CEO reflected, "John Bell, our founder, would not have done this."

In spite of the confusion and questioning, John made a decision to proceed without 100% agreement among committee members. In June of 1989 a draft copy outlining the activities and decision criteria for each of the six phases was circulated to the the various functional staffs.

Implementation Phase

In May of 1989, John began assembling a full time PDP implementation team to oversee the program's roll-out to all current development efforts. John recruited two managers to spearhead the implementation: Jane, previously a process manager from a synthetic materials plant; and Mark, previously a site manager for education and development. Jane and Mark attended Design Team meetings for a few months before the implementation team was dissolved. Jane took responsibility for promoting PDP and ensuring PDP Reviews take place. Mark would orchestrate development of training programs in PDP, teamwork, leadership, and technical skills primarily for Program Managers and other team members. Twelve program managers had been selected, and each of about forty projects was assigned to a program manager. Some program managers were responsible for one large project, while others had a family of up to ten smaller projects.

By November of 1989, the team had added two administrative support people and two people with information system backgrounds to investigate available software for project scheduling and management support. In

November, PDP was officially rolled out; the status of all programs was recorded and an official PDP manual was circulated highlighting review criteria and the activities for each function in each stage. (See Exhibit 3 for the introduction to the PDP manual.)

In the Spring of 1990, Jane and Mark began holding Program Manager Musters on a bi-weekly basis to share insights and frustrations in program management. Al, a Program Manager described this as "invaluable":

> This type of organizational and culture change is not easy. The Musters serve as both a support group and a way to transfer learning between teams.

By August of 1990, the implementation team had produced its second expanded version of a PDP manual. The group sponsored a host of educational activities primarily directed towards Program Managers. Largely, these included bringing in Professors and industry experts to give seminars on specific topics.

As Bellex began its annual budgeting process, managers complained that the company was attempting to develop too many products. Jane commented on their next major milestone:

> Our next hurdle is to get top management to agree on a prioritizing method for programs and then to rank the programs and stop those that we cannot afford.

The PDP implementation team was organizing a seminar to review and choose a method of prioritizing. John reflected:

> You have to give them what they think they need.

Impact of other Corporate Programs and Reorganizations

The reality of any large corporation is that numerous corporate programs compete for the attention of its employees. Bellex was no exception. One senior manufacturing manager noted: "It may be that we are pushing the corporation to do too much."

In November of 1990, there were three major programs sponsored by corporate in various stages of development or implementation:

- Work Redesign
- New Pay Plan
- Total Quality Ownership

Work redesign had existed for about four years and was almost two years into the implementation stage. The program was attempting to flatten the organization, push down responsibility and accountability, and redefine work in a sociotechnical team concept.

The New Pay Plan officially began a phased implementation in April 1990. The Plan instituted two types of pay: Applied Knowledge Pay (AKP) and the Annual Compensation Award (ACA). AKP is a skills-based system in which the required skills for each job are described, and the individual applies his/her skills knowledge to the requirements. As people learn skills that can be applied in their jobs, they can be financially rewarded. ACA is a performance-based pay awarded annually and averaging 7% of total compensation. The company was in the process of fully defining all the AKP skills for every job. Many managers complained about the time involved to get the pay plan started.

Total Quality Ownership (TQO) was another corporate program with seven full-time managers. TQO was a unique mixture of Total Quality Management and Bellex's value of employee ownership. In November of

1990, Bellex was in the midst of preparing to fully educate top management in Total Quality techniques and roll out the program in the Spring of 1991.

In addition to other corporate change programs 'stealing the limelight', Jane believed that organizational changes had adversely affected the implementation of PDP. In May of 1990, the Management Executive Committee announced a reorganization of Bellex from a functionally-based organization to a business unit organization. (See Exhibit 4 for an organizational chart). Three business units were established around market segments (Consumer Audio, Industrial Audio, Commercial Audio), and one technology unit (Optical Recording) to support all three business units. Unfortunately, two of the three business unit managers were not party to the original PDP discussions. Increasingly, it was becoming clear that business unit heads would play a major role in deciding which programs to continue.

Jane regretted that the future Business Unit Managers had not been involved up front.

> We are beginning to realize that these guys are critical to the success of PDP...They seem to agree with the goals of PDP, but they have different interpretations of how to go about doing it. Nothing is ever easy.

One Business Unit Manager in particular believed he should make all product decisions for his unit.

Employee Evaluation of PDP

The report card for PDP differed greatly depending on managerial level and role in product development. Jane and Mark spoke of very mixed responses both at the highest tier of management, and at the second tier with Business Sector managers and Functional managers. While there were certainly cases of strong resistance to PDP at the highest levels, an informal survey of employees in the Fall of 1990 revealed overwhelming support for PDP among the line managers and their staffs that actually developed products. This support seemed to permeate all the functional and technical areas of the company including engineering, development, research, manufacturing and marketing.

Support for the Goals of PDP and a Control Mechanism

Contrary to many perceptions in the management ranks, product development people fully supported the goals of PDP which they variously described as:

> Forcing decisions to be made early in the development cycle to avoid doing three to four years of work for nothing...
>
> Effectively allocating resources based on business opportunities, and stopping those projects that are less desirable to free up scarce resources..
>
> Systemizing the process, assuring a product has a market, and designing for manufacturability..

People highlighted a variety of benefits of PDP.

PDP..

> Forces collaboration of design, research, manufacturing, marketing and finance people at an early stage.
>
> Forces accountability and discipline all the way through product development.
>
> Rids the company of decisions based on 'gut facts'.

The survey registered strong agreement among a wide cross section of those developing products that PDP was a step in the right direction for Bellex. Employees focused on PDP as a much needed control mechanism.

Interestingly, this characteristic of PDP was the most controversial among top management at the program's inception.

Disbelief that PDP would achieve its goals

At the same time however, there was strong disbelief that PDP would achieve its goals, go as far as was necessary, or be implemented fast enough. Many people believed that PDP lacked the commitment of enough top managers to ensure that it was enforced. To substantiate their claim, many observers quoted a senior manager who had coined the phrase "the Product *Delay* Process".

> PDP needs teeth. You have to make a mechanism to ensure that it is enforced.
>
> Top management has to say no new products without a PDP review, and stop one for not having a review. I don't think they have stopped a program yet.
>
> Its like speeding. I only slow down where I know there is going to be a speed trap.

Many expressed frustration with top management that PDP was not being taken seriously.

> We came in three Saturdays in a row to prepare for a PDP review meeting. We had had some problems so we knew we had to be prepared. The team expected at least a three hour meeting. The day arrived and we were in and out of there in less than an hour. PDP has to ask the hard questions, to show that they are interested. Two senior managers fell asleep during our meeting. In review meetings, any feedback is good. They should at least say they appreciate the work on Saturdays.

Program Managers, marketing, engineering, and manufacturing professionals worried that PDP's lack of power would be its downfall. Al, a Program Manager explained:

> We had an excellent review meeting and got a commitment for four new people. The next day we went to the engineering

manager responsible for the people and he said he didn't have them.

Many complained that it was not the design of PDP that was at fault but management's use of the system:

> Management does not know what questions to ask to ensure the system works. They are overlooking very key issues during phase reviews. As a result, people don't take PDP seriously. Why should they if management doesn't?

History of Change at Bellex

A common theme among product development people was a feeling that nothing would ever change at Bellex.

> Bellex is no good at implementing change.
>
> Our culture doesn't allow fast changes; it is unstructured, free-wheeling, and not terribly goal-oriented. We work for our discipline not our company.
>
> We are complacent because we are too inbred. We need people from outside.
>
> People are not rewarded for trying to make changes.

Jim, an engineering manager, blamed the employee frustration on a lack of management visibility.

> I can't remember the last time Cam spoke to the company publicly. I think it was during the takeover attempt two years ago. How do we know what they are serious about?

When asked to cite corporate change programs that had been implemented well at Bellex, most people were hard pressed for an answer.

> The Safety Program was a success. It had regular meetings, high awareness, audits, and a reward system of perks. I won a coffee cup... Its hard to be cynical about safety.

Sue, a hardware engineer offered some suggestions:

> I don't believe anything will change unless I see a schedule or plan of it... Nobody ever says 'here is how PDP has improved our development process'. We need to brag about some things.

Jim associated the lack of change with cultural issues that were embodied in top management.

> Bellex is no good at telling people they did not deliver. Management gets off easy. No heads rolled for the *Illcon* program even though we spent millions developing a technology before realizing that it didn't fit with our strategy.

John, the PDP champion, recognized this legacy when they began. "Change has been dramatically unsuccessful at Bellex." The PDP Design Team's decision not to make a long term implementation plan was based partly on this realization. "We were learning as we went. We didn't know how difficult it would be. Many of our goals involved behavior changes. Most are not measurable."

Epilogue

John and the PDP Implementation Team reassembled to debrief the latest Program Manager Muster. The discussion digressed to questions about the recent refusal to increase PDP staff and implementation options, both in the past and the future. Mark argued that PDP should have been more of a top down program.

> If we spent more time up front educating and selling top management, like TQO is doing, they would have realized how much we are trying to change. We would have built up support and we would not have run into this resistance.
>
> One thing is for sure, you can't force-feed the old guys that run the company - they already assume they know it. It takes extensive training and visits to other companies to convince them to change.

John recognized a tradeoff between leading the program as an ad hoc exercise, or soliciting and educating top management first to gain full top level support.

On the other hand, skunkworks have the advantage that people get committed before they know the magnitude of the task. If we had shown everyone the scope of the change we were proposing they would have never agreed to it. People weren't ready.

I do regret not getting Sales and Marketing to buy-in from the beginning, but I don't know if they would have even if I had tried.

As the team discussed its frustration, Jane cited one of her professors:

"organizational learning, by its very nature, is always slower than individual learning."

She continued:

We have learned about best practices in product development through our research, visits to other companies, and industry seminars. But the organization as a whole does not have the benefit of our experiences.

Was the organization learning as fast as it could? Or was there some way to hasten the learning? How could PDP measure its success? To what degree would the proposed cuts in PDP staff compromise its results?

Mark worried about the perceptions of those doing product development.

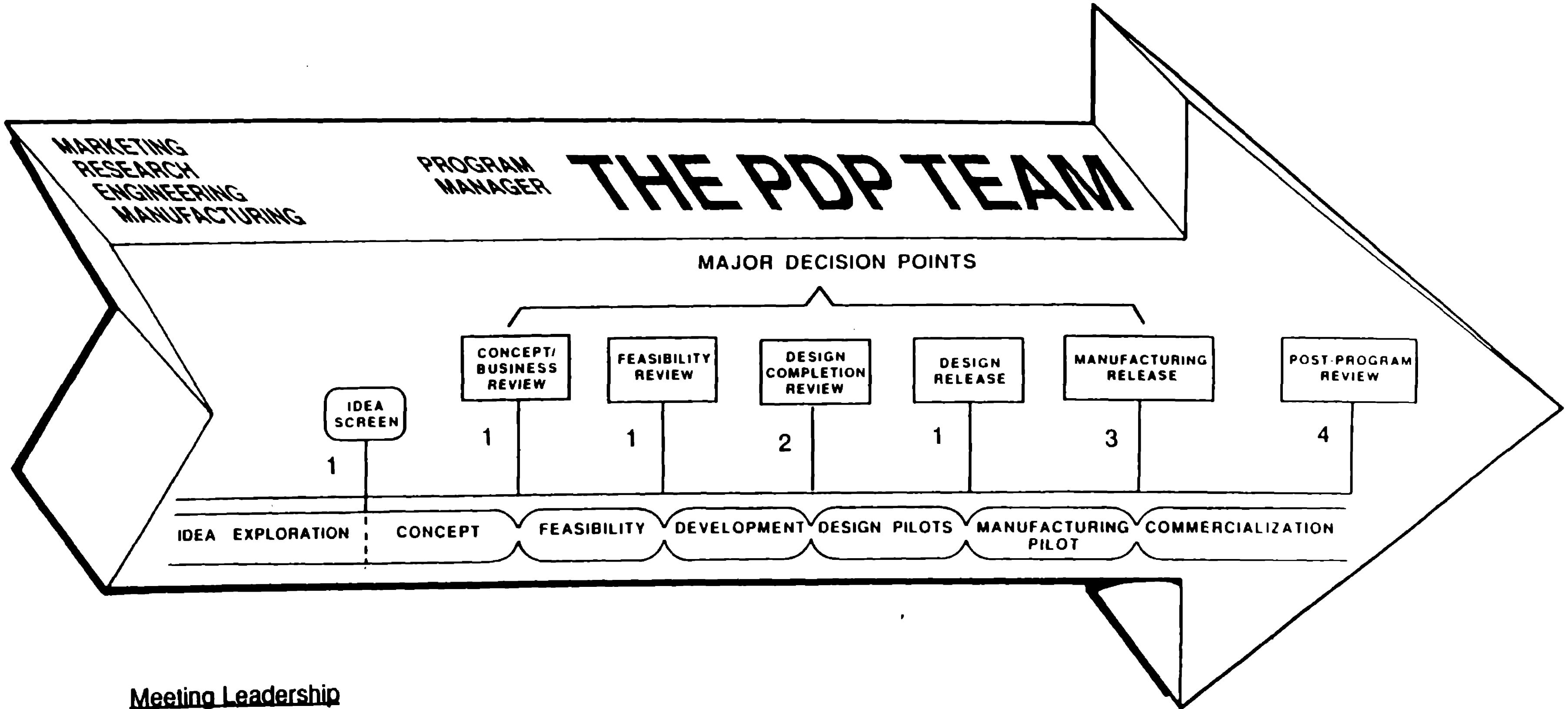
We have been focusing on changing and educating functional and program managers but the message is not getting through. Maybe we should convince Cam to publicly recognize some PDP successes. We know some teams are performing very well, and nobody seems to know that PDP stopped the *Olar* program.

Finally, there was the issue of other corporate programs. TQO seemed to be gaining a ground swell of support throughout the corporation, especially at the highest levels. Should PDP be a part of TQO? Certainly there were a number of underlying principles that seemed to be similar: customer orientation, teamwork, and discipline. The Work Redesign program, although a slow process, was causing more and more departments to reorganize into teams. In many respects, PDP had integrated very well with this effort. Should PDP make efforts to connect with other change programs? Or would this lessen its impact?

Jane offered a final judgement:

> As a company, we are very hard on ourselves. I tend to see the glass as half full. Everyone else always sees it as half empty. We have to learn to recognize our successes sometimes.

Exhibit 1

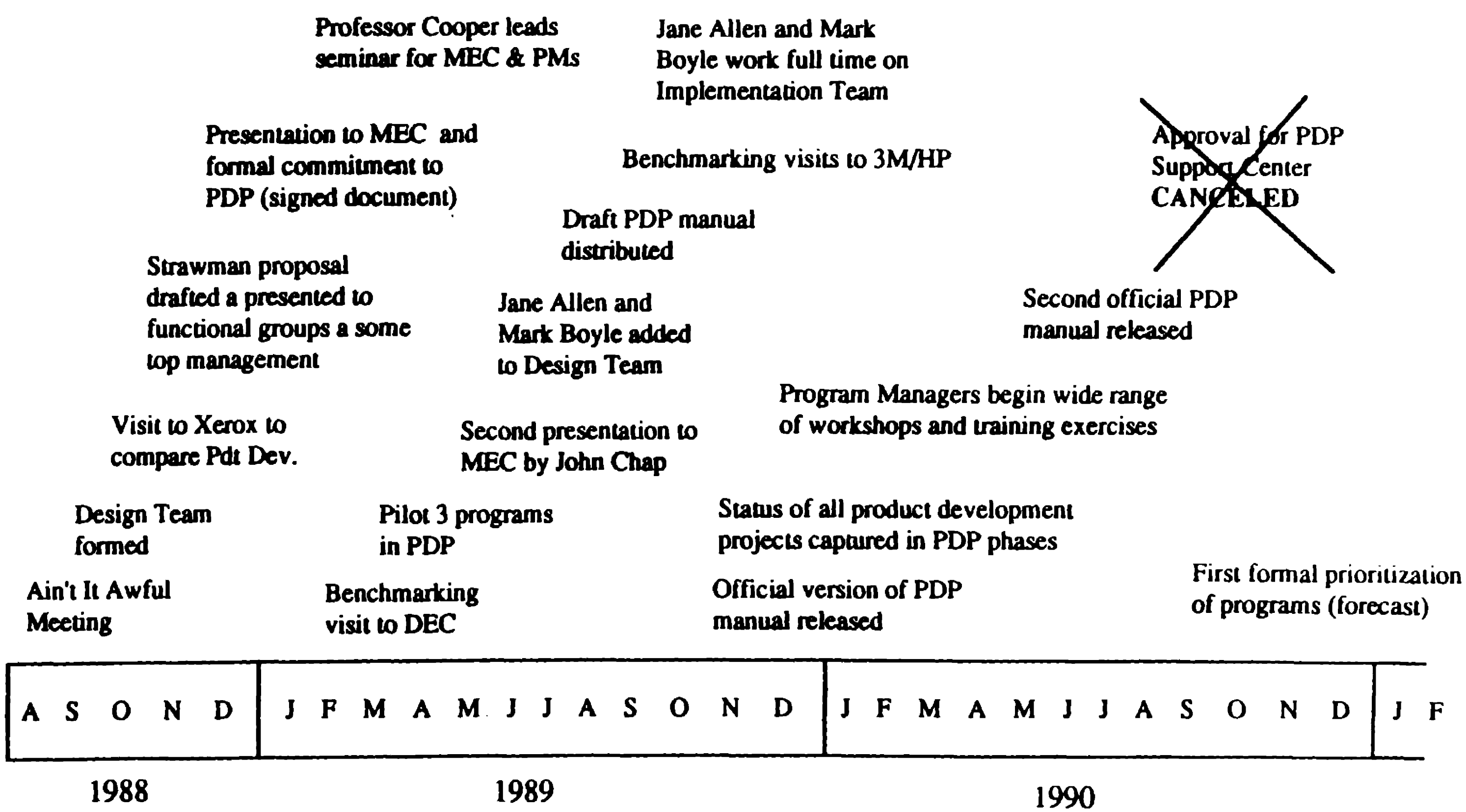


Meeting Leadership
1. Senior management review panel
2. Product development
3. Team and key functional managers
4. Team and other interested program/functional managers

Source: PDP Manual

Exhibit 2

Implementation of the Product Delivery Process



PM = Program Managers
MEC = Management Executive Committee

Source: PDP files, Company interviews

Exhibit 3a

INTRODUCTION

NOTES

A key factor in **Bellex's** success is our ability to deliver a stream of timely new products that are highly desired and valued by our customers and that consistently provide high quality and reliability. The Product Delivery Process (PDP) is a framework for conducting product development and delivery that will help us meet this challenge. PDP divides product delivery into logical phases. It defines the role and actions of those engaged in product development at each phase.

Systems for managing product delivery are by no means unique, although PDP is uniquely tailored to our needs at Bellex The advantages are many:

- Product development is conducted by ***teams*** with Marketing, Product Design, Manufacturing, Sales, Service and Distribution coordinating their efforts in ***parallel,*** rather than in sequence. This shortens product delivery time and allows us to bring more products to the marketplace with our present staff.
- By clarifying decision criteria and responsibilities, PDP promotes sound, clearly focused product and business decisions.
- PDP clarifies the roles of the Program Manager and the functional team members. It empowers the Program Manager as the principal decision maker and increases the accountability of everyone engaged in product development.
- In general PDP fosters better communications, improves corporate planning and provides corporate interaction for products under development.

NOTES

Fundamental to the success of PDP is teamwork. Not mere cooperation or representation of a functional area but a submersion in the "enterprise," which is product excellence and customer satisfaction. Equally important is the spirit of innovation and resourcefulness, for PDP is a framework for "who" and "what." It is not a recipe for "how" things are accomplished.

Bellex management has made a commitment to train, implement and monitor progress in the Product Delivery Process. Individual performance while a member of a PDP Team will be measured by ***contributions*** to the success of that team. All Product Delivery Teams will have finite lives and upon successful completion of the team goal, the members will rejoin their functional organizations or go on to other assignments. Alternating from program to functional assignments will enrich the working lives of many of our people. The corporation's continued success will depend on the expertise of the functional disciplines, and functional management has the extremely important responsibility of developing these vital disciplines.

The Product Delivery Process will continue to evolve and improve with experience as we capture the successes of current programs and build these elements into those of the future.

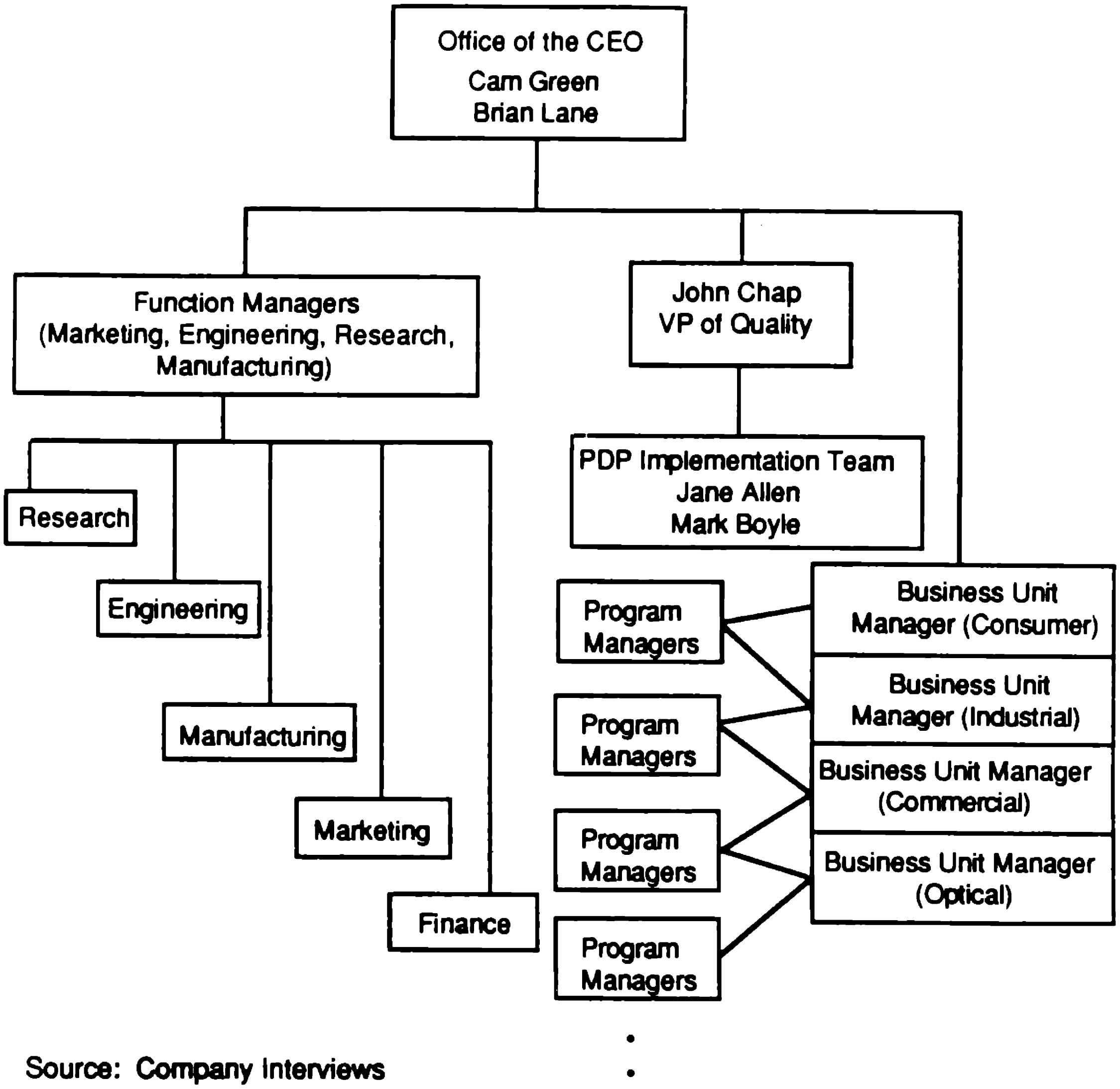
Our work is cut out for us. The goal is to heighten our competitiveness in a world where to stand still is to fall far behind.

Cam Green   Brian Lane

Exhibit 3b

Exhibit 4

Partial Organization Chart



Source: Company Interviews