PROJECT MANAGEMENT METHODS FOR ACCELERATED PRODUCT DEVELOPMENT

A Project

Presented to

The Faculty of the Department of General Engineering

San José State University

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

by

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April 1999

ABSTRACT

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The applicability of project management methodology to new product development is explored in this literature review, focusing on the growing imperatives of speed, flexibility, and market acceptance. Traditional project management methods are efficient at coordinating predefined tasks among dispersed participants, controlling development cost, and managing technical risk. In contrast, newer variations are more effective at promoting cross-functional collaboration, speeding time-to-market, and reducing market risk. Fast-paced development projects often employ integrated teams, overlapping project phases, and incremental product cycles as part of a project portfolio strategy. These require project managers to be effective leaders, strategists, marketers, politicians, and change agents. Successful projects act as engines for building product development capability and driving product strategy. However, concurrent engineering pitfalls are numerous, and no one leadership style or team structure is best for all projects. Guidelines are presented for selecting and adapting various methods to a given technology, market opportunity, and organization.

Contents

1. INTRODUCTION 1

1.1. PURPOSE 1
1.2. SCOPE 4
1.3. MOTIVATION 8

2. THE PRODUCT DEVELOPMENT CHALLENGE 16

2.1. INTRODUCTION 16
2.2. INNOVATION 18
2.3. PRODUCT DEVELOPMENT PROCESS 22
2.4. PRODUCT DEVELOPMENT STRATEGY 26
2.5. ENVIRONMENTAL FORCES 28
2.6. COMPETITIVE CAPABILITIES 31
2.7. DEVELOPMENT SPEED 32

3. BUILDING PRODUCT DEVELOPMENT CAPABILITY 45

3.1. COMMON PROBLEMS IN DEVELOPMENT PROJECTS 45
3.2. COMMON FACTORS IN PROJECT SUCCESS 48
  3.2.1. Factors for technical success: 49
  3.2.2. Factors for commercial success: 49
  3.2.3. Other commercial success factors 50
3.3. QUALITIES OF SUCCESSFUL COMPANIES 51
3.4. ORGANIZATIONAL PRINCIPLES THAT FAVOR INNOVATION 55
3.5. SKILLS FOR IMPROVING PRODUCT DEVELOPMENT PROCESSES 59
3.6. FUNCTIONAL MAPS 61
3.7. DEVELOPMENT FUNNEL 62
  3.7.1. Large Firms with R&D Groups 63
  3.7.2. Smaller Firms 64
  3.7.3. Recommended Model 65
3.8. SPEEDING PROJECT IDENTIFICATION 70
3.9. SEPARATING INVENTION FROM DEVELOPMENT 72
3.10. PICKING WINNING PROJECTS 73
3.11. INFLUENCE OF TECHNOLOGY ON SUCCESS 77
3.12. DECISION TOOLS 80
3.13. SELECTING THE PROJECT MIX 83
  3.13.1. Aggregate Project Plan 83
  3.13.2. Product Portfolio 85
  3.13.3. Project Portfolio 86
  3.13.4. Product Maps 86
  3.13.5. Product-Market Matrix 88
3.14. RETURN-ON-INVESTMENT 89

3.15. NPD STRATEGY AND ORGANIZATIONAL LEARNING 93
3.16. CREATING A DEVELOPMENT STRATEGY: CASE STUDY 97
3.17. DEMONSTRATION PROJECT: CASE STUDY 99
3.18. BENCHMARKING 100

4. PROJECT MANAGEMENT PHILOSOPHIES 101

4.1. WHY FOCUS ON PROJECT MANAGEMENT? 104
4.2. RELATED CONCEPTS 109
4.3. TRADITIONAL PROJECT MANAGEMENT 110
4.4. ACCELERATED PROJECT MANAGEMENT 114
4.5. INCREMENTAL INNOVATION 116
4.6. OVERLAPPING OR SIMULTANEOUS PROJECT PHASES 123
4.7. PROJECT PLANNING PHILOSOPHY 132
4.8. LIMITATIONS AND PITFALLS OF CONCURRENT ENGINEERING 134

5. ORGANIZING FOR SUCCESS 143

5.1. ORGANIZATIONAL STRUCTURES 145
  5.1.1. Classic Functional Structures 147
  5.1.2. Functional Structure Within Divisions 148
  5.1.3. Matrix Project Management with Long-Range Planning 148
  5.1.4. New Enterprise Division 149
5.2. TEAM STRUCTURES 151
  5.2.1. Functional Team 152
  5.2.2. Lightweight Team 152
  5.2.3. Heavyweight Team 153
  5.2.4. Autonomous Team or “Tiger Team” 154
  5.2.5. Evolution of Organizational and Team Structure 155
5.3. SUCCESS RATES FOR VARIOUS STRUCTURES 156
  5.3.1. Top-down Structure Led by Commercial Line Management 157
  5.3.2. Top-down Structure Led by Technical Line Management 157
  5.3.3. New Product Departments 158
  5.3.4. New Ventures Departments 158
  5.3.5. Project Teams with Commercial Project Manager 159
  5.3.6. Project Teams with Technical Project Manager 160
  5.3.7. New Product Committees 161
  5.3.8. Dyads and Counterparts 162
  5.3.9. Commercial One-Man Shows 163
  5.3.10. Technical One-Man Shows 163
  5.3.11. Situational Application of Team Structures 164

6. LEADING DEVELOPMENT TEAMS 167

6.1. PROJECT MANAGER RESPONSIBILITIES 167
  6.1.1. From Engineer to Manager 168

6.1.2. Traditional Project Manager Responsibilities 170
6.1.3. Additional Responsibilities in Product Development 174
6.2. TEAM FORMATION 187
6.2.1. Project Charter 188
6.2.2. Contract Book 188
6.2.3. Staffing 189
6.2.4. Initial Project Manager Roles 192
6.2.5. Team Member Roles 193
6.2.6. Launching the Team 194
6.3. MEETINGS 198
6.4. GROUP DECISION MAKING METHODS 201
6.4.1. Ordinary Group Procedure 207
6.4.2. Brainstorming 208
6.4.3. Ideawriting 211
6.4.4. Delphi Technique 211
6.4.5. Nominal Group Technique 212
6.4.6. Quality Teams 213
6.4.7. High Velocity Environments 213
6.4.8. Practical Considerations 214
6.4.9. Decision Tools and Decision Support Systems 215
6.5. MEASURES OF TEAM PERFORMANCE 216
6.6. TEAM REWARDS 220
6.7. IMPLEMENTING TEAM REWARDS AND PERFORMANCE APPRAISALS 222
6.8. UPPER MANAGEMENT SUPPORT 225
6.9. EMPOWERMENT 231
6.10. CONFLICTS 238
6.11. POLITICS 240
6.12. EXAMPLES FROM THE AUTHOR'S WORK EXPERIENCE 243

7. PROJECT PLANNING AND EXECUTION 252

7.1. PROJECT CONTROL 256
7.1.1. Recommendations for Rapid Product Development 257
7.1.2. Design Controls 262
7.1.3. Design Reviews 266
7.2. STRUCTURING THE PROJECT 273
7.2.1. Traditional Project Planning Methods 273
7.2.2. Accelerated Product Development Projects 274
7.2.3. Project Activities in Each Phase 279
7.2.4. Technology Transfer 291
7.3. REQUIREMENTS DEFINITION 300
7.3.1. Common Problems 300
7.3.2. Cross-Functional Participation 302
7.3.3. Level of Detail 302

7.3.4. Voice of the Customer 303
7.3.5. Quality Function Deployment 306
7.3.6. Practical Suggestions 307
7.4. CHALLENGES IN CROSS-FUNCTIONAL INTEGRATION 310
7.4.1. Issues at the Marketing-Engineering Interface 311
7.4.2. Issues at the Engineering-Manufacturing Interface 316
7.4.3. Vendors and Contractors 320
7.5. RISK MANAGEMENT 324
7.6. ARCHITECTURE 328
7.6.1. Modularity 330
7.6.2. Functional Allocation 331
7.6.3. Performance Targets 332
7.6.4. Interfaces 332
7.6.5. Technical Risk 333
7.6.6. Contingency plans 333
7.6.7. General issues 334
7.7. DFM TOOLS 334
7.8. PROTOTYPING 337
7.9. COMPUTER AUGMENTED DESIGN TOOLS 343
7.10. PROJECT MANAGEMENT SOFTWARE 356
7.10.1. Stand-Alone Application Package Example 360
7.10.2. Managing the Project Portfolio 362
7.11. POST-PROJECT AUDIT 366

8. SUMMARY AND CONCLUSIONS 370

9. REFERENCES 379

1. INTRODUCTION

1.1. Purpose

This paper explores the evolving role of project manager in the development of innovative products for fast-paced, competitive markets. Project management methods are often taught in abstract isolation from any industry or market, as if unrelated to the business context; one generic approach is presented as if it is relevant to many industries and products. Every engineering manager is familiar with phase-based structuring of projects and the ubiquitous Gantt and PERT charts which have become synonymous with project management. However, these tools and the assumptions that underlie them came from projects that had little in common with the challenges of product development for a competitive marketplace. Project management methods were developed for large aerospace, defense, and civil engineering projects that usually had a single sponsor, huge budgets, long development schedules, and massive resources. Emphasis was on breaking down large projects into predefined work packages that could be subcontracted, coordinating these tasks across geographically-dispersed participants, predicting and controlling expense burn rate, managing technical risks, and monitoring of progress by top management or the sponsor. How relevant are these to fast-paced development of products for which market life may be less than a year?

Projects to develop products for competitive markets are driven by a different set of imperatives. Small differences in development time, strategy, and customer knowledge mean survival of one competitor over another. In particular, speeding time-to-market has become a focus of the 1990's, just as quality was an emerging priority in the 1980's in the United States. Products have ever-shorter market lifetimes, and more product varieties are needed to satisfy increasingly sophisticated customers. Competition has intensified as trade barriers have fallen, forcing manufacturers to rethink every aspect of their operations. Technological change has increased, and new products that combine technologies in new ways compound the complexities and market uncertainties. Manufacturers must select concepts and commit to development based on relatively little information, relying on collaborative teams to deal with the increasing complexity.

Nowhere is this more evident than among the entrepreneurial high-technology firms in the Silicon Valley, where the lifetimes of some firms are as short as the market lives of many products. Here, the harsh conditions of brutal competition, technological change, shifting customer preferences, and brief product lifetimes give rise to rapid innovation fertilized by an ecosystem of clusters of related firms, consultants, universities, venture capitalists, early adopters, and lead users. New, agile start-ups can easily enter certain market segments (such as software and medical devices) with revolutionary technologies or product concepts that rapidly become new standards. The resulting constantly changing population of start-ups, spin-offs, acquisitions, IPOs, and failures puts into question whether the only goal of an enterprise is to become a stable, ongoing operation. Effectiveness among such knowledge-based clusters of enterprises is also found in the resulting innovation and re-cycling of information and talent that helps drive growth in markets and of the ecosystem itself. The high failure rate serves to increase experimentation and flexibility. The people, ideas, and intellectual property of failed firms are recycled in new ventures and acquisitions, and the close proximity of firms and the fluid mobility among them leads to cross-fertilization of ideas and knowledge (Bahrami and Evans 1995). In an environment where firms come and go, and proprietary information and technology rapidly becomes obsolete, the key to success seems to be a flexible product development capability — creating winning concepts, managing their rapid development, and continually adjusting to change.

If project management education is not to become so generic as to lose meaning in such a context, it must be reworked to reflect the changing business environment. Engineering and product development literature reveals an evolution in management methods among product development projects, increasingly diverging from traditional methods. A student of project management cannot simply study one generic set of practices; the market context is increasingly important.

This paper is an introduction to those changes. It describes project management methods, perspectives, and skills for the development of products for a competitive marketplace in small and mid-sized firms. Issues that have the greatest impact on a product’s commercial success and an organization’s growth will be described, along with the skills needed to manage them. Information for this paper is drawn from literature in the overlapping fields of new product development and project management, synthesized with the author’s work experience in diverse projects such as NASA flight systems, innovative medical device platforms, and incremental product improvements. Quantitative research, case studies, and essays were culled to identify changing methods and perspectives, and to examine variations in their implementation. The goal is to provide a thought-provoking overview that will guide the reader in applying project management methods to product development efforts. Extensive references help the reader investigate further.

1.2. Scope

Even with the focus specified above, a Masters degree project could not hope to provide a comprehensive review of project management tools and techniques. The topic of project management, even if limited to a specific kind of project, is both broad and deep, inviting much more detail than would be appropriate for a paper of this length. Therefore, just enough breadth is provided to introduce the reader to the basic concepts of product development, and enough depth to describe a selection of project management perspectives, methods, and tools most suited to speeding time-to-market and winning in a competitive marketplace. Specifically, this paper focuses on the following:

- The impacts of accelerating technological change, intense global competition, and demanding, fractured markets on product development are examined in Chapter 2. The early stages of product development are explored, namely, the idea generation and project selection phases. These activities immediately precede project formation and implementation, and offer important opportunities to speed development, deepen understanding of the intended customers, and launch the subsequent project toward commercial success. The effects of cultural climate on cross-functional collaboration and innovation are examined.

- Chapter 3 explores some critical factors in the product development process that influence project and product success. Concepts and methods are offered to improve these important pre-development stages. Ways to sharpen product selection and overall product strategy are examined. The role of development projects in building an organization's overall product strategy, development capability, and technical knowledge base is emphasized.
- Chapter 4 narrows the focus to project management — the implementation stage of the product development process — and highlights the growing importance and relevance of project management methods in product development and elsewhere in industry. A distinction is made between traditional project management methodology and emerging approaches aimed at accelerating time-to-market and improving product distinctiveness in a competitive marketplace. The concepts of concurrent engineering and

functional integration are emphasized, noting their impact on project planning and monitoring, along with common pitfalls.

- Chapter 5 describes various types of organizational structures used in firms and projects teams. The critical choices of a project manager and the team structure are shown to greatly influence project success rates. Some general recommendations for team structure and leadership styles are made, but the importance of adapting to each project and its context is emphasized, such as the degree of technological maturity, customer knowledge, and market risk.
- Chapter 6 focuses on building and managing an effective project team, starting with the important early steps a manager must take. Project manager responsibilities and the skills required for success in accelerated product development are identified. The roles of team members are explored and contrasted with traditional functional roles. A distinction is made between collaboration, which is a collective creative process, and simple communication or coordination, noting the relative importance of each according to a project's technical and market uncertainties. Group decision-making methods are outlined, emphasizing the importance of group process and conflict resolution in getting the most out of collaborative teams.
- Chapter 7 addresses some of the issues that must be managed during project execution to achieve project success. Special challenges in cross-functional

cooperation and risk management are discussed, and tools are described that enable teams to work quickly and efficiently.

A main purpose of the paper is to resolve a perceived separation between project management teachings and product development practice, a gap that stems from the origins and underlying assumptions in the traditional project management methodology. After critical examination, it is hoped that the benefits of project management tools and procedures may be more available to product developers who had previously rejected them as inappropriate. Those managers already employing the project management body of knowledge may benefit from guidelines for accelerating their projects and dealing with risk more effectively.

The ambition of this paper is to give the reader a broad understanding of project management methods as applied to development projects, rather than to provide detailed instruction in those methods. Consequently, the reader may find the paper relatively strategic and business-oriented, as contrasted with more analytical, structured approaches typical of engineering texts. This is by design. One of the most common recommendations found in the literature was that project managers and team members need to have a better understanding of the business objectives and constraints that gave birth to their projects. They need to be general managers in their perspectives, not just engineers. The author's perspective, after 20 years of leading and participating in interdisciplinary projects in a variety of settings, is that problems usually arise in the gaps between functional groups where cooperation breaks down.

Each group is well trained in its specialization, but neither knows very well how to bridge the gaps. Here at San José State University, the Business and Engineering Schools have cooperated in offering an engineering management concentration to help fill this type of gap in traditional education. This paper is a product of that cooperation. Readers desiring a more in-depth coverage of the project management tools and methods referred to in this paper will find many excellent resources, some of which are listed in the attached references.

1.3. Motivation

The subject of this paper was chosen for several reasons. First, it was designed to reflect, apply, and extend the author's coursework from both Business and Engineering schools at San José State University, completed toward fulfillment of a Master of Science degree in General Engineering with a concentration of Engineering Management. Most engineering Masters degree projects consist of an individual design effort within a functional specialization; however, management, by definition, involves activities conducted by a group and carried out over a period of time. Furthermore, coursework for this Masters degree program spanned many engineering disciplines. As a graduate from the University of California at Los Angeles in physics with twenty years of work experience, I pursued this Master degree to sharpen my management skills and broaden my engineering knowledge, rather than to focus on a specific technical expertise.

The project management focus was chosen to address both its growing importance in industry and its relevance to my career. The role of project manager is demanding and multi-faceted, and lies at the heart of product development. It is task- and product-oriented, rather than functionally-oriented, and so better matches my multi-functional experience. And, it is relevant to a variety of industries, making this paper accessible to more readers.

I began my career at Jet Propulsion Laboratory, conducting research in physics under NASA contracts, and developing and designing materials-processing experiment systems that flew aboard five space shuttle flights. My work spanned many roles, providing useful insights into the sources of problems in development efforts. I was both an engineer developing flight experiment systems, and a physicist conducting research aboard these systems and sponsoring their development. I created a role for myself as project coordinator, a bridge between the science and engineering organizations based in two different divisions with markedly different backgrounds, cultures, and motivations. Specialists from mechanical, electrical, thermal, materials, and software engineering groups, each under different management and occupied by other, larger NASA or DOD projects, had to be brought into our small effort and managed by coordinators such as myself without any position power or authority. I learned first-hand the problems that result when issues “fall through the cracks” between dissimilar and contentious functional groups. I found various ways to bridge that gap, first by performing the missing tasks myself, and later by coordinating the efforts of others to eliminate the gap. Despite the fast pace and long hours required by such project work, I found it more enlivening and growthful than the pure research that first brought me to JPL, piquing my interest in product development within the private sector.

My second decade of work experience was gained at medical device firms in Silicon Valley. I observed a substantial difference in project management practices between the NASA and private industry, which led to the theme for this paper and my literature search. These projects were organized as either heavyweight or autonomous teams, as opposed to the lightweight teams of the JPL matrix structure. Project management methods that were developed for large, costly projects with single customers such as NASA and DOD did not seem appropriate to the realities of competitive product development. Time-to-market, customer orientation, and product distinctiveness have grown in importance as technological change and global competition accelerate. My choice a decade ago to leave Jet Propulsion Laboratory for private industry reflected my interest in these changes. Some practitioners feel that project management methods of these two environments have little in common. But, my experiences suggest a deeply overlapping set of practices, but which had evolved in different directions according to the objectives, environmental forces, and priorities of each environment.

Literature reviewed for this paper reflects the increasing importance and relevance of project management skills and methodology to industry. However, various references disagree, not about the basic concepts and methods of project management, but about their adaptation. One text advocates a systematic planning stage, while another recommends planning only the minimum necessary up-front. One describes a linear, sequential approach, while another advocates massively simultaneous attack. During early research for this paper, I formed the hypothesis that project management is being adapted to specific industries, but that authors are not making clear to which environmental conditions their recommendations apply. One author describes "project management" but never mentions that his context is architectural construction; another neglects to mention the job-shop production environment. Still others address methods for product development without ever acknowledging the project management roots of some of their methods.

Eventually, I found references with titles such as *The New Project Management* (Laufer 1997), making explicit this implicit contradiction. A new kind of project management is evolving that emphasizes strategy, leadership, and constant cross-functional communication. Particularly in smaller firms, a project manager is an entrepreneur with a broad understanding of the business and its markets. In start-ups, the project manager may be one of the principals or first few employees, serving many functions and enjoying nearly unlimited upward potential. In some larger firms, project mangers play key roles in leading organizational change using their development projects to break new ground, helping to shape the product development process, company culture, and strategic direction.

Selection of a project manager is critical, and competition is keen, but there is little to prepare an R&D engineer for project management other than work experience. Engineers are often promoted to management based on technical expertise, with little management training. Project managers drawn from marketing organizations seem to succeed more often than those from engineering (Souder 1987). A business background helps project managers achieve higher success rates when market uncertainty and customer knowledge are priorities. This reflects the monochromatic training that most engineers receive, and underscores the value of educational programs such as the Engineering Management concentration of the San José State University General Engineering Department. As project management becomes more about leadership skills and judgement compared to the traditional functions of planning and control, engineering managers must stretch even further. Fortunately, these behaviors can be codified and learned.

Companies are increasingly focusing on project portfolios and product strategy to strengthen their identity and competitiveness. Development projects may be mapped out to capture a greater share of traditional markets and niches through a series of fast, successive enhancements of existing products, while conducting longer-range development to reach into new markets and eventually to cannibalize existing products before competitors do. Projects within a firm can share technical information and business processes to mutual benefit. Resources and facilities may be time-shared to reduce costs. Project managers work closely with senior management to achieve these goals.

Examples from the medical device industry figure prominently in this paper, given the author's recent work history. California has the greatest number of medical device companies of any state, with Silicon Valley as a focal point. One in five medical device manufacturers are located here, of over 9200 U.S. registered firms (Allen 1997). Workers in the medical device field enjoy a tight labor market and good compensation thanks to industry-specific experience and knowledge. Clinical research and regulatory requirements are central to most medical device projects, and the technologies employed in design, fabrication, and testing are often specific to the industry.

Project management in medical device development is an interesting and intense challenge. One must deal with a complex and changing environment, including growing regulatory requirements, evolving medical modes of treatment, changing health-care market economics, complex multi-disciplinary designs, materials sources drying up due to product liability concerns, venture capital funding cycles, acquisitions, and wrenching organizational upheavals. A project manager must possess enough resiliency and political poise to survive and even thrive under these conditions. Regulatory requirements and clinical trials dominate many project timelines, and strict control and documentation systems are mandated by regulators. Yet, developers cannot afford to lose time to inefficient procedures and bureaucracies. Competition is intensifying, technology is rapidly changing, and product lifetimes are becoming shorter. The development pipeline must be kept full of innovative new products. Few medical devices are considered commodities, and those that are suffer intense pricing pressure and distribution challenges. In addition to demonstrating efficacy and basic safety, products must be tested to meet detailed and stringent regulatory requirements for dozens of performance characteristics such as sterilizability, biocompatibility, electromagnetic compatibility, and thermal performance. Even after the company is convinced that requirements have been met, there is still a chance that the FDA or other regulatory body will demand more information or testing, or challenge the efficacy or cost effectiveness of the product. Managers must plan product releases and project schedules carefully to minimize the need for regulatory submissions, anticipate design changes, allow for unforeseen regulatory snags, and work around approval delays.

Such challenges act to differentiate between the excellent and the merely competent, providing competitive advantage to those firms most skilled at anticipating and minimizing their impact (Bethune 1997). Regulatory and technological complexities provide even more incentive to use incremental development cycles, overlapping phases, cross-functional teams, and early prototyping.

Unfortunately, developers often perceive regulators as barriers rather than partners. Ideally, regulatory requirements work in harmony with a firm’s product development process, each reinforcing the objectives of the other. A product that is developed in compliance with regulatory and quality standards is also more likely to succeed in achieving its performance and safety goals. Compliance with standards such as ISO 9000 and FDA Good Manufacturing Practices can serve to reinforce a firm's product development process, strengthening assurance of quality, safety, and performance. But, particularly in large or mature firms, such standards may translate into cumbersome processes and bureaucracies. Product development processes must undergo continuous improvement and redesign to achieve both compliance and development speed. Thus, even apparently mundane tasks such as setting up design control systems will benefit from an awareness of product development strategy and a commitment to building development capability in a firm.

2. THE PRODUCT DEVELOPMENT CHALLENGE

2.1. Introduction

This paper addresses management of projects of a specific type — the development of innovative products for markets in which speed yields competitive advantage. Such products have short market lifetimes and are continuously replaced by successive generations employing newer technologies, built for lower costs, and better designed for market trends and evolving customer expectations.

Development projects can be seen as the second half of the product development process, during which project management methods are utilized to turn concepts into marketable products. The first part of this process consists of defining and selecting new product concept to keep the pipeline full. The process of envisioning and selecting new ideas for products is not obvious or easy. Successful product concepts must be right both for the market and for the firm carrying out their development. Good front-end planning lays the foundation for the success of each development project and of the overall product portfolio. Effective product planning allow a project to begin earlier, focus it on satisfying customer needs, make best use of organizational capabilities, and build management alignment and commitment. In order to critique project management methods for fast-paced product development, and to learn to apply them effectively, we must first explore the larger product development process.

This chapter examines the environmental forces, strategic considerations, management approaches, and organizational climates that most influence project selection and ultimate commercial success. It also looks at the legacy left by successful projects, which includes improvement of the process itself, new market and customer knowledge, and new technologies and organizational capabilities. This chapter does not attempt to detail a wide range of strategies and tools for soliciting and screening ideas and selecting projects. Instead, the goal is to give an overview of the main stages of product development and identify some valuable approaches that result in successful products.

Product development is defined as “the translation of research findings or other knowledge into a new product, process, or service” (Cleland and Kerzner 1985). Some firms develop products in departments called “research and development,” particularly if they wish to denote innovation or application of new knowledge. This is often true in medical device firms where new medical information and technologies are being applied. Other firms use the term “engineering,” particularly if product design consists largely of applying established technologies and methods. For present purposes, “research and development” will be used in its broader sense, as “the activity aimed at discovering new knowledge in hopes that such activity will be useful in creating a new product, process, or service or improving a present product, process, or service; *and* the translation of research findings or other knowledge into a new or improved product, process, or service” (Cleland and Kerzner 1985). We may consider product development to be the second half of this definition of R&D, the translation of knowledge into products.

2.2. Innovation

The traditional notion of research and development is as a continuous evolution of knowledge from fundamental principles to applications of increasing practicality. Products are seen as the outcome of a step-by-step reduction to practice of new scientific knowledge. Examples include the Manhattan project, Dupont's development of nylon, or the development of transistors which became widely available in 1948. This matches the traditional, Victorian concept of "progress" (Clark and Wheelwright 1995).

However, this model does not match actual practice, in most cases (Nonaka and Kenney 1991), and is not particularly useful for increasing innovation within a firm. It focuses on the scientists' ideas and knowledge, while the customer taken for granted. This model focuses on the subset of innovations that yield a temporary windfall to the inventors until others catch up. Fundamental discoveries do not usually conform to schedules (Clark and Wheelwright 1995).

More often, innovation results from a haphazard combination of influences and processes (Souder 1987). Factors such as emerging market demands, newly recognized customer needs, changing attitudes, and experimentation may eventually come together in a complex interaction of many participants within a firm. To stay competitive, any firm must constantly be creating new strategies, new products, and methods of manufacturing, distributing, and selling them. These innovative ideas are disseminated and discussed on many levels of abstraction, setting off further innovation. The emphasis is not on deduction but on emergence and synthesis. Use of metaphors and analogies are common for helping conceptualize difficult parts of the project. Through this ripple effect, new ideas occur, are discussed and evaluated, and make their way into new products and new business processes (Nonaka and Kenney 1991).

While fundamental breakthroughs sometimes occur, most product cycles are much less dramatic. Incremental improvements play the most important role in the commercialization of technology. Examples include the gradual replacement of steel with plastic, improvements in shatter resistance of glass, and reductions in size of the microprocessor. In fact, most development work is done just one step ahead of manufacturing (Clark and Wheelwright 1995). Innovations spread as customers accept new technology and firms imitate their competitors or borrow creatively from other industries. A typical S-shaped pattern of acceptance results as a technology is developed, costs are reduced, more firms gain from experiences of the pioneers, resistance to change fades, performance increases, and diffusion through the industry gains momentum (Grübler 1997). Most innovations must endure several growth-decline patterns until a combination of environmental factors lead to acceptance (Souder 1987).

The market drives product development much more than does fundamental research. Products that originate with a new technological capability (technology push) are less likely to be commercially successful than those created in response to a market problem or opportunity (market pull). The generation of new technologies and proposals for turning them into products is not enough (Rosenau 1990). Product advances often stem from using new combinations of technologies. For example, technologies that grow out of the computer industry are being employed across many industries. Within firms, spending on development is diversifying, and joint R&D ventures are becoming more common as firms find themselves unable to master all the relevant technologies (Clark and Wheelwright 1995). The old maxim, “one technology – one industry” no longer applies.

Ideas for improving products are proposed continuously from all functions and phases of a product life-cycle, whether from within the company or from competitors, customers, user professional groups, universities, consultants, contractors, and suppliers. There is a growing body of evidence that indicates creation of innovative ideas throughout a firm rather than merely at upper management levels, and emphasizes the frequency and quality of social interaction to achieve this. One barrier to innovation is that high or low status may be assigned to the source of the idea; proposals from field service, for example, may be assigned low status by the research and development department. It is up to senior management to set the tone within an organization for cross-functional respect and interaction. In rare cases, innovative products were developed despite opposition from upper management (the Macintosh computer, for example) (Nonaka and Kenney 1991). Recommendations for improving idea generation and decision-making abound. The subsequent project activity is a pressure-cooker of cross-functional interaction that helps to build product strategy while it attempts to fulfill it.

Large or mature firms that understand the innovative process have impressive records of developing new technologies and products, despite the perception that only small firms can innovate. The key is to create an environment in which new ideas can arise from chaos and decisions can result from interaction (Nonaka and Kenney 1991). This requires leadership and careful management of the cultural climate and vision, business processes, organizational structure, and system of incentives and rewards. Big and small innovators accept the essentially chaotic nature of advanced development. They pay close attention to their users needs and desires, avoid excessive detail in early technical and marketing plans, and allow entrepreneurial teams to pursue competing alternatives within a clearly conceived framework of goals and limits. They use complex portfolio planning to balance the needs of existing product lines against those of potential lines, and use incremental approaches for speed and abundant feedback (Quinn 1985). Later sections will address these approaches in more detail as they apply to the concept selection and implementation phases of development, focusing on the need for frequent, ongoing communication among members of a project team, marketing, manufacturing, and customers.

The cross-functional and chaotic nature of product innovation argues against the prevalent view among universities and high-tech firms that separated career paths should exist for technologists and managers, and that each function need not know much about the other. The perception has been that product development issues can be decomposed into these parts (Clark and Wheelwright 1993). In practice, innovation is enhanced if all employees are aware of the business and market priorities.

2.3. Product Development Process

A product development process is an overall framework of activities conducted by a firm for setting product goals and carrying out development (see figure 1). Use of the term “process” suggests a persistent set of procedures, policies, and practices, which evolve as knowledge and experience are gained. In most companies, particularly larger ones, the product development process is formalized and documented.

The process begins with technology and market assessments and forecasts, formulation of strategy, and evaluation of opportunities and risks, leading to decisions on development of goals and objectives. Various specific development project ideas are solicited and evaluated, leading to an “aggregate project plan.” Execution of the plan consists of a stream of projects, each intended to bring to market a new product platform, product variation, accessory, enhancement, quality improvement, and/or cost reduction. Customer response, financial results, and post project learning provide feedback to the assessment strategy and for improvement of the process itself. Traditionally, product planning was done on a yearly or periodic cycle. Now, due to intense competition, shorter product life-cycles, and shorter development times, product planning is done more frequently or on a continuous basis.

Every organization must make choices about how this basic framework is carried out. These details can have a powerful impact on performance. Development steps may be chosen explicitly or implicitly; they may be well or poorly understood; they may be sketchy and confusing, or overly bureaucratic and rooted in forgotten history. Authors Clark and Wheelwright (Clark and Wheelwright 1993) break these elements into six dimensions of activity, which will be explored further throughout this paper:

1. Project Definition: How the firm sets project scope, bounds, and objectives. This includes initial concept development, defining the project effort, gathering initial internal and external inputs, and selling the project to management and the organization.

2. Project Organization and Staffing: Who will work on a project, how they will organize and locate, definition of reporting relationships, individual responsibilities, and relationship to support groups must all be resolved.

3. Project Management and Leadership: This dimension includes the nature and role of project leaders, project phases and how they are sequenced, the means and degree of coordination, methods of task management and monitoring, and milestones or other checkpoints.

4. Problem Solving, Testing, and Prototyping: This dimension is closely related to the previous one, but the focus is on individual work steps and acquisition of knowledge to solve problems. Both technical and management problem-

solving must be addressed. Testing and prototyping approaches are important to validate progress, confirm choices, and focus remaining tasks.

5. Senior Management Reward and Control: The way in which managers review, evaluate, and modify a project and its goals over time sends powerful signals to the team about how much authority, discretion, and responsibility has been delegated to them, and affects team motivation and incentives. Seemingly minor differences in the timing and format of communication and reviews can have a big impact.

6. Real Time, Midcourse Corrections: Feedback and revisions are often necessary due to ambiguity and uncertainty in the technology, market, and organizational factors affecting the project. Critical choice processes include evaluating status, rescheduling and resequencing of tasks, resolving differences in lab and customer feedback, and determining readiness for production scale-up. Subtle issues include the influence of early conflicts and their resolution, trade-offs between making changes and avoiding delays, and the impact of changes on motivation.

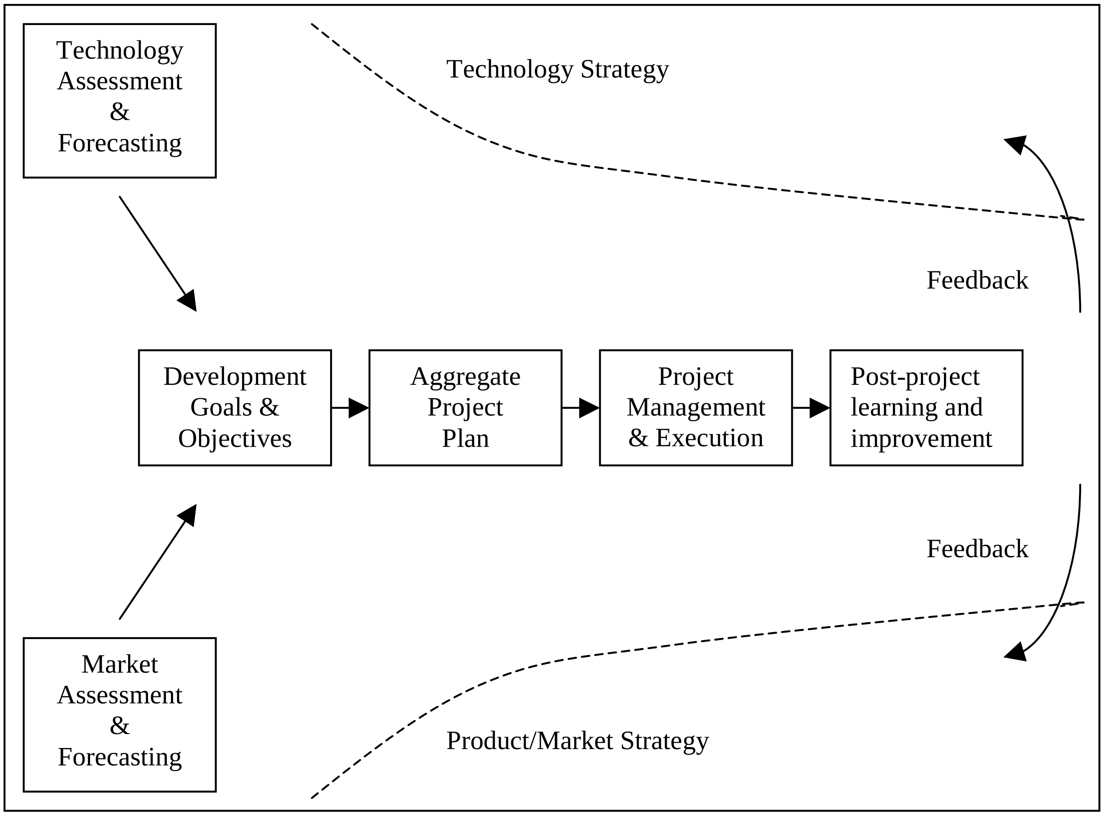


Figure 1. An illustration of the product development process, in which technology and market strategy focus development efforts into a stream of projects and post-project learning and improvement (after Clark and Wheelwright 1993).

This chapter does not attempt to provide much detail about innovation and strategic planning, or the methods and models used. This is not the forum for an investigation of methods for project selection or economic evaluation, for example, which are covered extensively in literature (as the attached list of references begins to indicate). Instead, the focus here is to explore emerging trends in building a product development process, and to gain some capacity to shape project management methods to build competitiveness. The focus is on the project manager's perspective and role, which is evolving from one of planning, monitoring, and control, to a more entrepreneurial and strategic initiator and contributor to the product development process. Prospective project managers should find this paper thought provoking, prompting further investigation, beginning with the referenced literature. In this chapter and the next, perspectives and methods intended to improve product development process and strategy are presented, and implications for project management are the focus of the remaining chapters.

2.4. Product Development Strategy

Project managers and middle managers increasingly participate in product strategic planning, and many considerations that affect project formation and execution are best addressed at the level of strategy. Authors differ in their usage of the phrases "product development process" and "product development strategy," and some authors make little distinction between the terms. Definitions are offered below for the purposes of this paper.

The phrase “product development strategy” is used in several senses in the literature. Product development strategy may refer to a general program of objectives for dealing with the environment, including the marketplace, competition, and evolving technology. It may also refer to the process of arriving at that program; in this sense, it means the first half of the product development process, arriving at a “project plan,” followed by execution of projects as the second half of the process. In general, strategy refers to dealing with the external environment by deciding to take certain actions in certain ways. The literature refers to specific “product development strategies” such as short, overlapping cycles, referring to a specific way of responding to the environment.

“Strategic planning” is the related but higher-level management process of guiding the company as a whole, not just product-market planning. It includes scanning of the technical and market environment, evaluating of risks, setting of targets, performing a gap analysis of the firm’s present status compared to its desired future, and selecting of alternatives to form a plan for the future. Such a plan typically spans one to five years. The resulting “strategic plan” is a focused, comprehensive set of company objectives that may include a prioritization of key environmental conditions and delineation of initiatives to address those conditions, including redeployment of existing resources and plans to develop or acquire new technologies, capabilities, and resources. Strategic planning occurs on many levels, often beginning at top management and flowing down to lower levels within a firm. What is termed “strategy” at one level of management may be considered objectives at the next lower level, where a more detailed strategy is developed to achieve them. Strategy may include, or at least be based upon, a visioning process in which statements of company mission, values, and beliefs may be generated. A visioning process has the most impact when all levels of an organization are perceived as having shared in creating it. Management process and cultural leadership issues may be addressed, as well as market and product objectives.

A company’s “brand” or “brand promise” is the unique image customers hold of the company’s identity and product offerings, involving questions of capability, trust, and loyalty. It is what the company is “good for” in the customer’s eyes, how its products and services offer distinctive value. “Brand strategy” addressed the company’s plan to create or communicate an intended brand promise. A strong brand identity can be a powerful asset to increase customer retention and market share, influence the stock valuation, and position the firm to make technology or marketing partnerships with other firms.

2.5. Environmental Forces

New products are increasingly the focal point of competition. Firms that get products to market more quickly and better match customer needs and expectations create significant advantage. Across a wide range of industries, firms are under growing pressure to introduce new products at an increasing rate. This is driven by several forces:

International competition is becoming more intense. New competitors are growing in number and aggression. The opening of international trade has added competitors with lower costs and more economical production capabilities. The spread of quality methods has helped raise firms from many emerging economies to world class status. The use of information technology enables manufacturers to relocate portions of their operations around the globe to where they can be most economical. Distribution channels and purchasing have similarly been transformed.

Technological change, both breakthroughs and incremental improvements, creates new options for better meeting the needs of customers and reinvigorating their interest. New combinations of technologies are creating new classes of products and solutions or revolutionizing existing products. Engineers and marketers search for ways to make competitive advantage from new materials, electronics technologies, and biological sciences. The dynamics within many industries can be quickly altered by introduction of a novel solution, so even entrenched firms must continually explore ways to stay in the lead. Increasing emphasis on flexible manufacturing, modularity, Just-In-Time methods, and Design-For-Manufacturability (and assembly and producibility) are enabling firms to offer more product varieties while incurring less incremental cost. Generations of products leap-frog each other thanks to reliability and performance increases and cost reductions.

Markets are becoming more demanding and fragmented into niches and segments. As more types of products are offered, customers have growing expectations and sensitivity to nuances and variations in products. Customers are attracted to newer solutions that better address their needs, that have newer technology, and are easier to use.

These forces are most obvious in emerging high-tech products, for which product variety continues to increase while development cycles shorten. They also affect traditional, mature industries, such as textiles and clothing in which global competition combined with use of information technology has led to close links between suppliers, factories, and distribution channels (Clark and Wheelwright 1993).

Customers expect high-technology product introductions to be followed by even newer models with improvements in reliability, cost, and variety. Managers must think in terms of aggregate project plans, or project portfolios (programs containing many projects), and cannot expect a single product to earn customer loyalty and market share. A familiar example of this is computer software. An experienced customer knows to evaluate the software developer’s record of bug fix updates, upgrade frequency and pricing, and technical support before purchasing. In the medical device marketplace, the early products for atherectomy (removal of blockages from coronary arteries) were followed by many successive improvements, variations, and accessories to allow treatment of more types of patients with better control, efficacy, and safety. These were combined with process improvements to enhance quality, reduce cost, and reduce variance in performance.

2.6. Competitive Capabilities

To remain competitive, firms must respond to these environmental forces by building key capabilities, which Clark and Wheelwright call "Development Imperatives" (Clark and Wheelwright 1993):

Fast and Responsive Development: To respond to intense competition, changing customer expectations, and accelerating technological change, firms must be fast at identifying opportunities and developing products. This implies shorter development cycles and better targeting of products to customers.

High Development Productivity: Efficiency is critical to deal with the growing product variety, lower volume per product, and shrinking product lifetime. Resources must drop dramatically, and critical resources must be utilized to leverage productivity of design and development activities. Products costs must drop with each successive cycle, and running changes may be made between new products to implement further cost reductions.

Products with Distinction and Integrity: Firms must attract and keep customers in an increasing variety of market segments. Customer expectations are growing, so each product generation must add value just to keep up with competition. This demands of any firm a combination of creativity and quality, and suggests use of a cross-functional development process with close customer involvement to provide an ever-deepening understanding of its customers.

To achieve speed, efficiency, and quality, a firm must tightly focus on the technical knowledge and development processes critical to their mission. They must be able to quickly identify and address customer needs, quickly build prototypes, test the designs skillfully, keep development progressing and on target, and produce products of high quality and performance. The resulting knowledge and enthusiasm must be fed back into the development process to do even better with the next generation, building the firm's reputation and market influence. The cyclical reinforcement of project-after-project underscores the importance of project management in building the company's future. Specific implications of these imperatives to project management will be explored in later sections.

2.7. Development Speed

Of these imperatives, shortening the product development cycle time has received the most attention in recent literature. Since the mid 1980s, speed has been a primary focus of competitive advantage (Laufer 1997), building on the attention quality had received in the prior decade. The primary advantages to fast development are listed below:

- Extend sales life is realized by shortening development cycles. Products are introduced earlier and enjoy more time before obsolescence. Development costs are easier to recoup.

- Higher market share is gained by beating competitors to market (see figure 2). This is especially important for those types of products for which the customer would experience a high cost upon switching, such as software or OEM components designed into a system by the customer. Loyalty creates a tail in the sales curve (figure 3). The curve is both higher and longer thanks to earlier introduction.

- Higher profit margins are typically realized from early sales. This is particularly important for products for which technology or competition are pushing prices down.

- Adaptability is a key benefit of short cycles. Fast development allows firms to synchronize development and product releases with the availability of newer technology. Products designs can be more easily adapted to changes in markets or trends (Smith and Reinertsen 1991). Risk is significantly reduced.

Several authors have studied cumulative profits over the life of a product as a function of delays in market introduction. Being a just few months late to market may be even worse than having a 30% development cost overrun (Shtub et al. 1994). In one study, a product that was introduced six months earlier than the competition achieved cumulative profits three times that of the industry average. However, if introduction was six months late, cumulative profits dropped to near zero (Clark and Wheelwright 1993). Another study of high-tech products found that those which were six months late reaching market earned 33% less profit over five years. In contrast, those that came out on time but 50% over budget lost only 4% profits (Gupta and Wilemon 1990). Superior time-to-market allows premium pricing, or depending on market strategy, allows value pricing to gain market share without excessively sacrificing profits. Thus, “time is more money than money.” (Gupta and Wilemon 1990).

Firms that can produce several successive generations of product faster than the competition can achieve both significant economic benefits and rapid performance gains over slower competitors, due to faster learning and customer feedback (Clark and Wheelwright 1993). Such firms respond faster to new technologies, emerging market niches, and changing customer tastes (Gupta and Wilemon 1990). Secondary advantages of superior development speed include:

- Faster implementation of manufacturing cost reductions.
- Lower development costs due to shorter schedules and less rework.
- Improved work environment for employees due to faster results and gaining of experience, breaking of bad habits and vicious cycles, and improved sense of control over outcomes.
- Identity as innovator and leader, responsive to customers' needs (Stalk and Hout 1990).

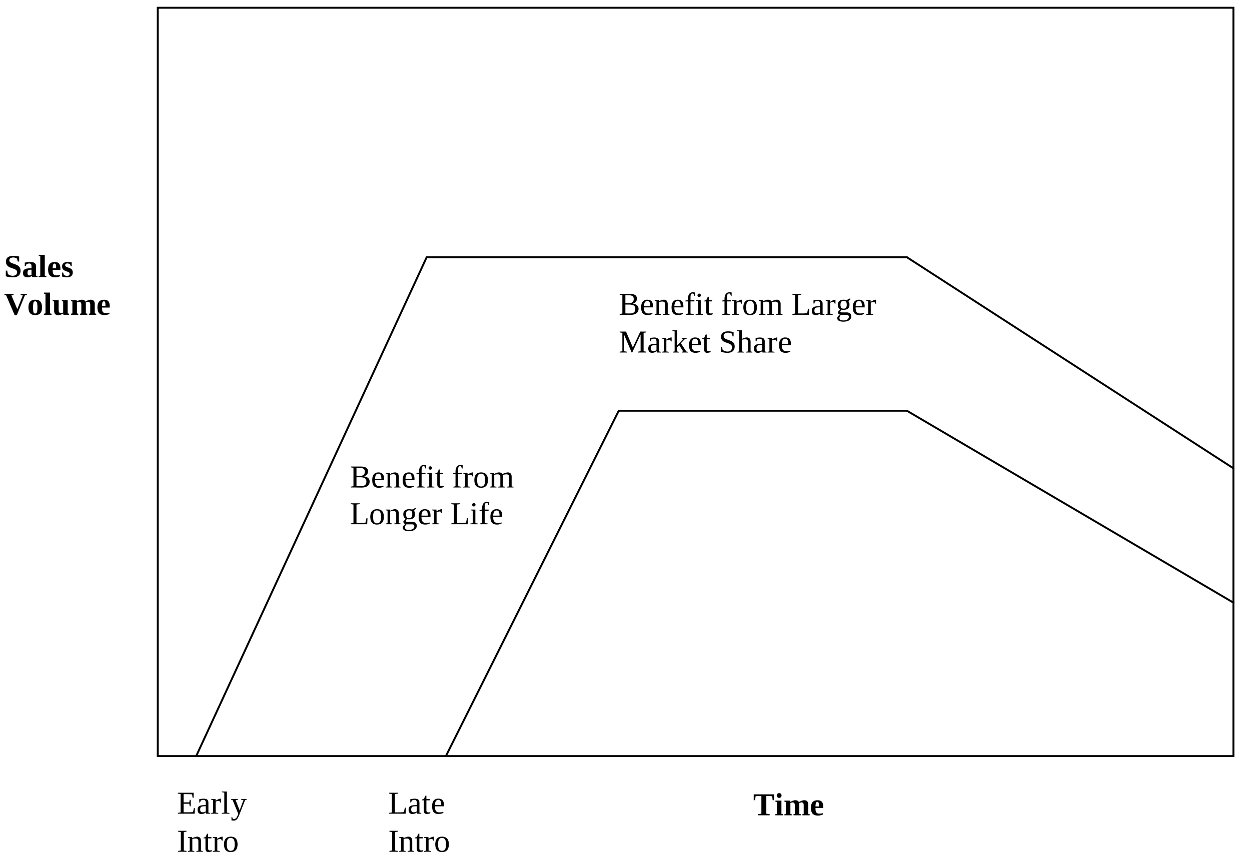


Figure 2. Early introduction of a product can increase market share and sales life.

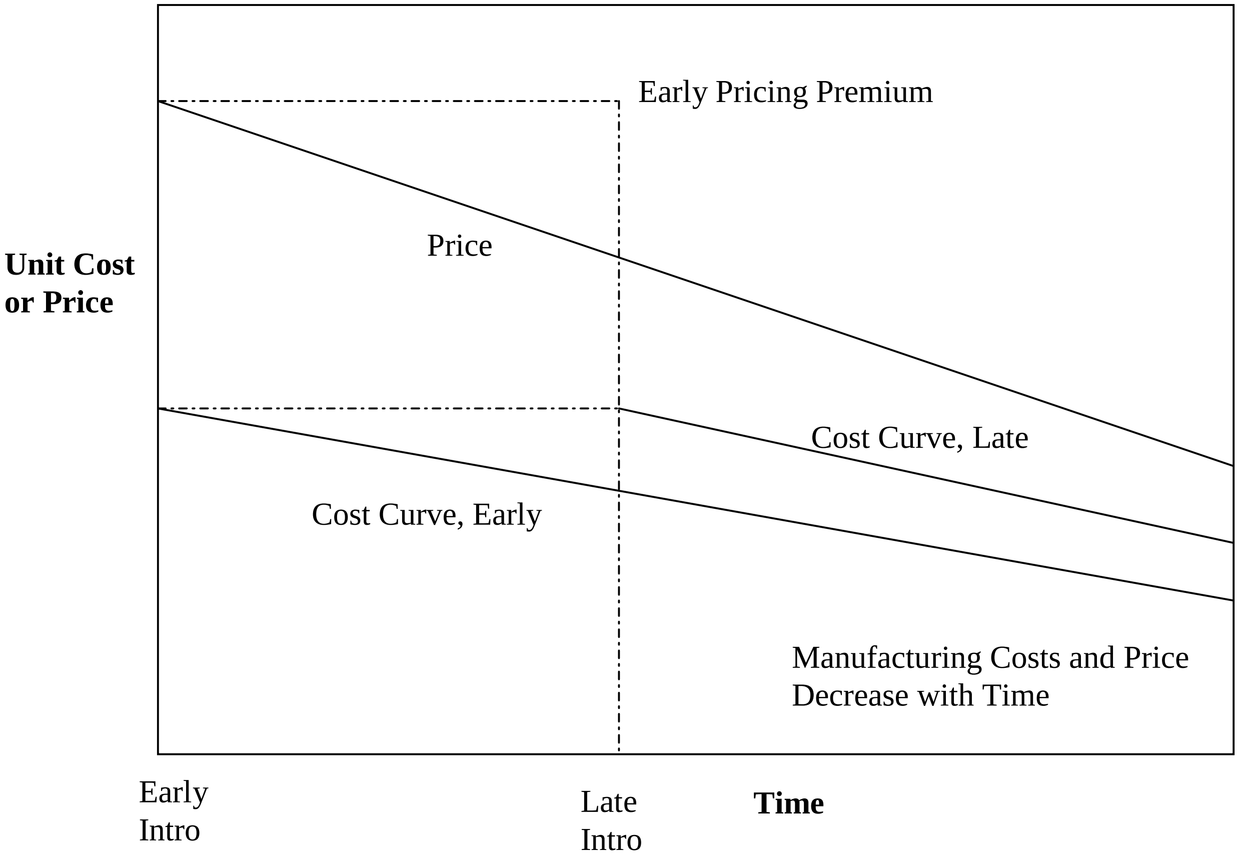


Figure 3. Early launch enjoys pricing premium and cost advantage from manufacturing learning curve.

Speed may pay for itself, but it is not free. Shortening development cycles can cost money (or other tradeoffs, as discussed below), and overlapping tasks creates expense due to inefficiency, repetition due to changes, and contingency plans. By knowing the financial benefits of speed, sound decisions can be made about shortening development cycles. The sales benefits of early introduction (see figures 1 and 2, after Smith and Reinertsen) suggests ways to calculate trade-offs among development time and other factors such as development cost, features, performance, and product cost.

Typically, these trade-offs show that development time is of much higher value than managers have realized (Gupta and Wilemon 1990).

Smith and Reinertsen advocate a simple way to evaluate the economic impact of delays, based on their consulting experience (Smith and Reinertsen 1991). They identify the four product development objectives that are usually the subject of trade-offs during planning and execution:

1. Development speed: Market opportunities have a finite lifetime, and economic returns are highly dependent on time-to-market.
2. Product cost: This is the cost of product as delivered to the customer, including sales and marketing costs, manufacturing start-up costs, and recurring costs including incremental manufactured cost.
3. Product performance: This refers to how well it meets its market-based performance specifications, in the eyes of the customer. This is also referred to as product quality in this context.
4. Development program expense: This one often less important than the other three but receives undue attention from managers. It includes all one-time development costs prior to manufacturing ramp up.

Among these four objectives lie six trade-off relationships, and the cost-benefit trade-off for each can be calculated. For example, time may be consumed trying to develop a better-performing design, or a more cost-effective one. Reduced product cost may also result if performance targets are lowered. Any specific trade-off can be evaluated by modeling the costs and benefits; unfortunately, the costs of delays are rarely considered. The stated reason is often that they are hard to calculate. However, data already generated by a firm in evaluating the worth of the project may be adequate for this purpose. Marketing and sales departments can easily provide adequate estimates of future revenues and predict the losses due to missed early sales. Losses associated with lower peak market share and longer tail may be more subjective. If more data are needed, manufacturing, finance, and engineering can provide estimates of their respective costs, even in approximate form.

Smith and Reinertsen recommend a simple spreadsheet calculation, because it would be more easily accepted than a non-intuitive, detailed one (such as net present value, discounted cash flow analysis, or internal rate of return analysis), at least for short term calculations spanning five years or less. Models such as discounted cash flow analysis are sometimes attempted without fully developing the assumptions that go into it or the scenarios to be compared. Misapplication of DCF techniques can contribute to excess aversion to making long-term investments (Clark and Wheelwright 1995). A simple model will probably be more accurate than many assumptions and data that go into it, and may help reinforce that people make decisions, not analyses (Smith and Reinertsen 1991).

The simple model begins with the projected average sales price of the product, which typically starts at a predictable value and decreases over its expected life at a predicable rate per month. Market size and market share are then estimated over the product lifetime, yielding unit sales per month and dollar sales. Turning to manufacturing costs, unit costs are estimated at introduction, and a small decrease each month is applied to represent learning curves, which are of a typical value for a given industry or firm. More sophisticated cost models may also include price trends for materials, labor, and overhead. Then, one calculates the gross margin over the life of the product.

Operating expenses are next to be estimated. One-time expenses such as tooling may form a line item, with engineering expenses for development as another, and marketing one-time expenses and overhead as a percentage of sales as two more. General and administrative expenses are often calculated as a straight percentage of sales. This finally allows calculation of profit before tax and return on sales for each month, cumulative profit before tax, average gross margin, and average return on sales. This constitutes a baseline case. One way to graphically display such data is with the return map format, discussed in a later section.

The same people who prepared the above estimates are then asked to consider the impact of four generic, hypothetical deviations, such as a 50% development overrun, a product cost overrun of 10 percent for two years duration, a performance problem that cuts sales volume by 10 percent, and a delay of 6 months in product launch. These data comprise all that is needed to do all six kinds of trade-off cost-benefit estimates.

The adjustment for development expense overrun is the most straightforward. The most complex adjustment is the case of delayed market introduction. The effects will depend on the market elasticity of demand and on the degree of competition. In markets such as medical devices and many OEM markets, early entrants gain the benefits of customers' unwillingness to switch suppliers due to distributor contracts, a product learning curve, or having already designed an OEM component into their systems. A delay in market launch will cut deeply into the peak market share and quicken the drop-off afterwards.

Typically these trade-off calculations show a much higher value for time than most managers expect. Consider the common question of whether to add a feature to improve performance, taking a little extra time to accomplish this. Two months of delay, for instance, might be valued at $470,000 per month for a total of $940,000. The extra feature must be worth at least this to make the delay worthwhile. If we assume that the new feature adds 1 percent to the unit sales of $100 million over the six-year product life, then $1 million in revenue would be realized. But, profits before tax may be only 16% of sales, leaving only $160,000 profit impact. In this case, it would be a poor decision to delay two months to add this feature. A better alternative would be to add the feature during a model extension or future product.

Development cost might be traded off with speed if, for example, an outside drafting service could cut two weeks from the schedule. At $25 per hour for 200 hours of drafting, the cost of $5,000 is well worth the additional $235,000 in additional sales or $37,600 in additional profits by reaching market two weeks earlier.

Time-to-market is often referenced in literature as a primary competitive advantage. However, this is not to say that speed alone differentiates market leaders to the neglect of other considerations. Speed in development is rooted in the ability to do rapid problem solving and to integrate insights from engineering, manufacturing, marketing, and customers. Faster development allows better business decisions and speeds up tactical decision making. It allows more frequent product improvements and customer feedback, allowing products to develop more in unison with customers' needs and expectations. Although quality and manufacturing cost may be compromised temporarily to speed time-to-market, running improvements and successive product revisions can increase quality and lower costs. Companies that make swift, effective product development a way of life will consistently outpace others at providing customer-centered products, earning market share, profitability, brand loyalty, retention, leadership position, shareholder value (Smith and Reinertsen 1991). Products that are rushed to market prematurely often suffer from quality issues that damage the firm's reputation (Gupta and Wilemon 1990). Speed must be achieved intelligently and in balance with quality.

Many studies have claimed that companies that are first to market enjoy lasting dominance. However, a recent study by Tellis and Golder (Tellis and Golder 1996) disputes this conclusion, indicating instead that "early leaders" enjoy greater success as the market matures than do the “pioneers.” The authors performed historical analysis of fifty product categories, using a more specific and restrictive definition of “pioneer.” They found that true pioneers — those firms first to sell in a product category when the market is small and relatively unknown — rarely became market leaders. Pioneers failed at a rate of 47%; those that remained still hold the position of market leader in only 11% of categories, with a mean market share of 10%. On average, those in the “early leader” category entered the market 13 years after the pioneers. Many pioneers are often forgotten in hindsight (such as MITS, pioneer of personal computers, or Chux, pioneer of disposable diapers).

Tellis and Golder attribute the success of early leaders to having a vision of a future mass market, managerial persistence, financial commitment, relentless innovation, and asset leverage (this last one is particularly important for market extensions). As common sense would indicate, it takes a balanced strategic implementation to achieve and hold on to early leadership. In fact, followers often learn from the risks, mistakes, and hard-earned lessons of the pioneers. Initial innovations may appear too crude for a market to catch fire. Later entrants often better understand the market potential and are better prepared for a sustained attack, one product cycle after another. Being first does not automatically provide advantage; it only provides first opportunity.

Not all projects benefit from acceleration. Basic research is one example for which techniques for time compression are not effective. Large, complex projects, such as aerospace systems and power plants have high development and construction costs and suffer small losses for late completion. Such projects require complex organizational structures with diffuse responsibility in which coordination can be difficult, requiring complex control and reporting systems. If projects experience schedule overruns, the developers may be paid even more in some cases rather than suffering a loss. Time is not a priority, and workers are given multiple assignments to fill gaps in their activities.

Projects that result in products with a limited market life are the most in need of acceleration. Changing markets, demanding customers, developing technologies, and competition are driving forces for many products today. Just as with JIT techniques in manufacturing, accelerated development not only reduces the investment tied up in ongoing work, but makes the developer more responsive to the evolving needs and expectations of the customer. Accelerated development requires an integrated approach that encompasses development, purchasing, manufacturing, quality, marketing, and sales. Acceleration implies overlapping phases of development rather than distinct, sequential ones, requiring more communication and lower-level authority among the cross-functional team. Other methods that provide acceleration have more to do with the product design than with teamwork, such as modularity, commonality, standard interfaces, DFM techniques, agile manufacturing, and so on. Of critical importance is properly selecting and empowering the project manager. Conventional

PM techniques easily slow a project. Each of these approaches to accelerating schedules will be addressed in later chapters.

As companies grow larger, they have greater resources to apply to product development, but may become more bureaucratic, slower, and defensive. Larger companies are successful innovators, running contrary to the prevailing wisdom (Souder 1987). But, smaller companies may have an inherent speed advantage. Speeding up product development in maturing firms requires continuous assessment and change of the product development procedures and bureaucracy.

3. BUILDING PRODUCT DEVELOPMENT CAPABILITY

This chapter continues the investigation into the product development process with a focus on improving this capability within an organization. Common factors in project success or failure are found in the literature, including the influence of company culture and leaderships style. The metaphor of a product development "funnel" for project identification and selection is introduced, and several examples are described along with recommendations for improving the process. Objectives include speeding identification of market opportunities, selecting product concepts that can achieve commercial success, and learning from projects to continually improve product development capability. The importance of product strategy and the project portfolio is emphasized for leveraging a firm's capabilities, better satisfying customer needs, and capturing greater market share.

3.1. Common Problems in Development Projects

The environmental forces of technological change, demanding markets, and intensifying competition demand skill and creativity at managing development speed, efficiency, and quality. Why do some projects in some firms succeed while others fail? In a study of several hundred innovative development projects (Souder 1987), nine common barriers were identified:

1. Avoiding technologies that fail.

2. Designing the best organizational structure.

3. Developing organizational climates that stimulate innovation.
4. Picking projects that have the best chance of success.
5. Determining how much effort to spend on projects, and when to terminate unsuccessful ones.
6. Managing projects for timely completion.
7. Handling problems at the marketing / engineering interface.
8. Coping with uncertain technologies.
9. Transferring technologies and new products to other parties.

Common causes for ineffective management of development projects have been identified by a number of authors ((Clark and Wheelwright 1993; Laufer 1997; Souder 1987):

Multiple, ambiguous objectives and different functional agendas: These can lead to prolonged planning stages and conflicts throughout the project. Everyone should share an understanding of the project’s intent throughout the organization, in clear objectives. Conflicts must be resolved early and at low levels.

Focus on current customers and confusion about future target customers: By focusing on the present situation and on backward-looking market research, projects always aim at a moving target. Market tests later reveal surprises and disappointments, leading to late redesigns or poor market acceptance.

Future customers should remain the focus while providing a continuity of offerings.

Narrow engineering focus on the technical solution, to the neglect of schedule: Slips in schedules and compression in the final stages are the results. Time-to-market must remain a strong focus. This suggests a system view of the product concept with creative, cross-functional problem solving.

Reliance on later stages to solve problems: The focus should be on early development, testing, and validation of the product and process designs before ramp-up. The first design should be the right one in terms of anticipating and resolving downstream issues.

Narrow specialists in functional silos: Mismatched expectations and unspoken assumptions often result from functional organizational structures. Communication problems and misdirected effort can be avoided by use of cross-functional team structures, staffed by members with broad expertise in critical areas, using a functionally integrated design and problem solving approach.

Unclear direction and accountability: Strong leadership, shared vision of the product concept, and widespread accountability is recommended. False starts and dead ends must be avoided.

Common upper management mistakes can contribute to many problems in development projects:

Senior management attention is too late to influence the project: Typically, management pays the most attention to a project in the later stages when the expense burn rate rises and pressure to meet launch dates mounts. Unfortunately, management can have little influence then because most of the project has passed; the concept has long since been chosen, the specifications finished, and detailed design is well under way. Most of the costs in terms of development, materials, and manufacturing methods were committed to long ago. Management usually gets involved in a project reactively, “at the wrong time, and usually in the wrong way” (Clark and Wheelwright 1993).

Business planning does not precede product planning: Too often, the product plan is not connected to marketing, technology strategy, and other business issues (Clark and Wheelwright 1993).

3.2. Common Factors in Project Success

Project success or failures may have its roots in the process and strategy for selecting the projects as well as in their implementation. Souder (Souder 1987) found a constellation of factors that correlated with project success to the 95% confidence level. Combinations of factors correlated more strongly. Failure may be predicated on absence of only one key factor, listed below.

3.2.1. Factors for technical success:

- Clarity of problem definition.
- Perceived level of fit between company and technology: This factor allowed a better solution to market needs. Better fit was often found in conjunction with well-developed interfaces between marketing and R&D, another success factor.
- Perceived technical expertise in the project area.
- Quality of resources: This was found more often in larger firms, running counter to the perception that larger firms are not innovative.

3.2.2. Factors for commercial success:

- Clarity of problem definition.
- Clarity of understanding user requirements.
- Perceived technical expertise in the project area (goes along with good customer fit, and good R&D-marketing coordination).
- Degree of detailed planning and control applied: The degree of planning and control was not found to be significant for technical success, but it was for commercial success. Interviews suggested that this was because there was not enough information in the early phases of a project to develop a detailed plan. When close financial or activity control was brought to bear, it tended

to stifle the entrepreneurial spirit and motivation. Nonetheless, planning and control in later stages was helpful if not essential to keep the project on target.

3.2.3. Other commercial success factors

The following factors correlated with success, but below the level of significance:

- Familiarity with the technology.
- Familiarity with the markets.
- Fit to the company philosophy.
- Lean-money funding: This refers to a scenario in which project personnel, flattered by attention from top management, tend to be optimistic and protect upper management from bad news. To help the project, management authorizes additional funds. As a result, too much project time is spend deciding how to spend the additional funds, and some of the resulting activities detract from the original project, often delaying or disrupting it.

Internally generated ideas tended to have better success than external ones, and those from marketing and management had higher success rates than those from R&D, probably reflecting the need for a deep customer understanding.

Projects mounted in response to a threat to current market condition seemed to benefit from greater urgency compared to offensive product projects, which had the lowest success rates of all categories. Line protection projects — those launched in anticipation of changes in user needs or practices — tended to be disappointing due to smaller markets than anticipated and lower cost efficiency. Offensive projects succeed more often when a strategic expansion was being attempted rather than a tactical opportunity, due to the greater organizational commitment generated by strategic initiatives.

Projects based on well-developed science succeeded much more than undeveloped science or art, but often were disappointing nonetheless due to overconfidence and a tendency to gloss over details.

Eager customer attitude correlated with success, due to high customer involvement and good communication. This underscores the importance of knowing your customer well (Souder 1987).

3.3. Qualities of Successful Companies

In the same study, Souder evaluated qualitative or cultural factors of the most innovative firms. Innovativeness is the author's measure of a firm's ability to mount high-risk projects that are new to the firm and which the firm believes would significantly benefit its financial welfare. The following are qualities of the top one-fourth of the studied companies by this measure of innovativeness:

- Willingness to accept change and deal with disruptions such as responding to new ideas and conditions.
- Long term commitment to technology, which was exhibited in better management of high R&D costs and consistent commitment to projects.

- Patience in gestation and decisiveness in allocating resources to priorities. These firms had well developed project selection systems, fostered decisiveness in screening ideas, and avoided on-off commitments. Customer needs were well-known to the idea generators.
- Risk and uncertainty were willingly confronted and accurately assessed.
- Alertness in sensing environmental threats and opportunities through extensive use of external contacts, and met with a prompt response.
- Cross-departmental openness and a diversity of talents and cultures characterized these firms, which were more open to external sources of information as well.
- Acceptance of conflicts and fostering of resolution was valued. These firms seek out discontent and tap those constructive frustrations; conflict resolution leads to new ideas and a more receptive climate (Souder 1987).

The climate or prevailing atmosphere of the firms in the study were further explored. It is commonly held that climate is important; but, was this born out by research? The following characteristics of climate were found to be positively correlated with innovation:

- Role flexibility: Dynamic response to needs, wearing many hats.
- Openness and trust: High professional regard, confidence in superiors, peers, and subordinates.

- Managerial support: Interest in employees, awareness of attitudes.
- Communications: High in volume and frequency. Timely, accurate information from upper management. Dependable internal technical communication. Lack of misunderstandings or inconsistency.

In contrast, uncertainty and conflict in task assignment was negatively correlated with innovation.

The data were further analyzed to determine the factors responsible for the desirable characteristics described above. The following factors, which were found to be correlated with innovation, have one think in common — respect for management expertise and decision-making:

- Technical competency: Strong background, up-to-date information. First and second level managers have background in the field.
- Interpersonal competency: Styles that inspire trust and openness. Courses for managers show that the firm is concerned with motivation and management styles. Managers with poor styles were moved out of R&D.
- Sense of Direction, decisiveness: Managers appear to know where they are going and why, with free discussion about how.
- Decision process: Unpopular decisions occurred frequently, but acceptance was fast. This was due to respect for the expertise of the managers, the

participative process that led to decisions, and communication by managers of decision rationale.

Climates of firms can be characterized as either promotive or restrictive, according to Souder. He coined the phrase “promotive total organizational climate” to describe firms with the following characteristics:

- Citing growth and innovation as institutional goals.
- Top management is eager for new products.
- The company is in a growth and diversification mode.
- The company desires to be first in the industry in at least one technical area.
- Budgetary control is highly decentralized.
- No one department is perceived to be the major seat of power.
- Employees naturally perceive that the climate is non-threatening, but that there is a sense of urgency to develop new products.
- Decisions are perceived as being participative or decentralized rather than dictated by one level of management.
- There is a substantial amount of group-to-group cooperation, borrowing and lending of people and equipment, and pooling of funds.

Restrictive firms are the converse. They are interested in slow, solid growth and are production-volume oriented rather than sales or profit oriented. Decisions are perceived as coming from top-level managers. Sales or production departments are perceived as the seat of power. Management is perceived as aloof, formal, and impersonal. There is a perception of gamesmanship and politics, so managers guard their budgets and turf.

3.4. Organizational Principles that Favor Innovation

Souder makes a distinction between “classical” and “innovative” organizing principles of organizations, which research showed were correlated with successful product innovation.

Classical organizational principles are those based on rigidly specialized behaviors and rational economic decision making. The emphasis is on reducing the cost of performing repetitive tasks. Management focuses on directing and controlling others by rules and policies, with authority held at the top and delegated by chain of command. Functional specialties are separated which favors efficiency over integration.

Innovative firms, in Souder’s analysis, avoid bureaucratic rules and policies. The organization is horizontal, flatter, and colleague-based relationships are pervasive. Management’s role is to foster harmony and change, and to adapt the organization to evolving needs. Authority is decentralized, with many sources of power, and participation is encouraged. Cross-departmental teams, autonomous teams, and matrix structures are common. Sharing of responsibilities ensures synergy.

Table 1. Classical versus Innovative Organizing Principles (from Souder 1987)

Classical	**Innovative**
Jobs are narrowly defined and subdivided into rigid, small units	There is constant adjustment of tasks through the interactions of the organization members
A narrow definition of authority is attached to the individual's job	A sense of responsibility replaces authority and there is a commitment to the organization that goes beyond the individual's functional role
There are many hierarchy levels and a strict hierarchy of control and authority; the bosses order things to be done	There is a low degree of hierarchy of control and authority; things get done through a mutuality of agreement and a community of interest
Communication is mainly vertical, between superiors and subordinates; these communications consist of instructions issued by superiors	Communication runs in all directions between people of different ranks, and it resembles consultation rather than command
There are many rules and policies, requiring loyalty and obedience to superiors	Emotional commitment to the achievement of tasks and the expansion of the firm is highly valued
Economic efficiency is the goal	Newness and creativity are sought and growth is the goal
Top-down authority-centered management is the mode	Horizontal, expertise-centered influence is the mode; teams, task forces, and project management methods are used

Souder’s research then attempted to confirm that the above principles were indeed correlated with successful innovation, based upon surveys of participants. The following attributes were found to be correlated negatively with successful innovation to the 95% confidence level:

- Degree to which jobs are perceived to be narrowly defined.
- Degree to which authorities are perceived to be narrowly defined.
- Degree to which information flows and communications are perceived to be top-down only.
- Degree of loyalty and obedience to superiors perceived to be required.
- Degree to which rules, policies, and hierarchical organizational levels are perceived to characterize the organization.

Organizational goals were also found to be correlated with innovation. Goals that were negatively correlated to the 95% confidence level were economic efficiency (cost minimization, process optimization), annual profit maximization, and return on investment. Goals that were positively correlated were sales growth, market growth, and innovation (Souder 1987).

Organizational structures within firms and project teams are one way that these principles are manifested, and have a significant impact on success. Later chapters address organizational structure and team leadership during the implementation phase.

Product development can be made much more effective by involving management at the early stages, and by linking product identification and selection to the underlying business planning process (Clark and Wheelwright 1993). These front-end activities have a substantial influence on the speed and success of development projects. The project activity in turn lays groundwork, not only for future product generations, but for the processes, skills, and capabilities critical to the future of the company. Front-end improvements are the focus of the remainder of this chapter.

The importance of improving the early stages of new product development processes within organizations was the subject of an essay by George S. Day (Professor of Marketing at the Wharton School of The University of Pennsylvania, and member of the editorial board of the Journal of Product Innovation Management). He states that significant improvement efforts among top firms in the 1980s were focused on the latter stages of development and on market launch. Currently, returns are diminishing with further efforts, so our attention should focus on the front end of the process where tremendous opportunities still exist for most companies. The few most innovative firms are developing formal processes for the idea generation and screening process, but most other firms can be "charitably described as *reactive*," employing haphazard processes, emphasizing "catch-up" projects, and with no one taking responsibility for capturing knowledge or accountability for the results. Day recommends four broad areas for creating a directed ideation process:

- Provide a clear strategic direction.

- Manage ideation activities as an ongoing process.
- Undertake a directed search using multiple inquiry models.
- Classify, bank, screen, and monitor all ideas.

Day further urges development and dissemination of a statement of strategy for new products, addressing the objectives, roles, growth paths, and acceptable risks. Thus, all parties in an organization can function from the same strategy. Among the proactive concepts currently in use are continuous improvement, innovative imitation, lead user analysis, latent needs and life-style analysis, scenario development, technology forecasting, and business system reconfiguration.

Finally, Day states that firms must create a capability that is distinctive — a unique bundle of skills, knowledge, processes, and technologies that is difficult for competitors to understand or emulate (Day 1994).

3.5. Skills for Improving Product Development Processes

Development projects can be seen as the implementation phase of the larger product development process. The front end of this process, before a product concept has been decided, lays an important foundation for effective development during execution. Many opportunities exist in the front end to speed the development process, keep it on target toward satisfying customer needs, and avoiding lost time by changes in management direction and unanticipated technical problems. The implementation phase — the projects themselves — become powerful engines to drive the growth of skills and development capability within an organization. Improving this capability builds knowledge and skill within an organization, and simultaneously makes demands on those skills. Clark and Wheelwright (Clark and Wheelwright 1993) summarize those skills in technical, organizational, and commercial categories (see Table 2). Various of these roles, skills, and knowledge are explored in later sections.

Table 2. Skills and Knowledge required for improving product development performance (from Clark and Wheelwright 1993).

	Technical	Organizational	Commercial
Senior Corporate Managers	Understand key technical changes	Recognize importance of creating a rapid learning organization; lead and provide vision	Identify strategic business opportunities
Business Unit General Managers	Understand depth and breadth of technology	Train and select leaders; champion cross-functional teams; adapt career pathing	Target key customer segments; architect product families and generations
Team Leaders	Provide breadth of capabilities; comprehend depth requirements	Select, train, and lead development team; recognize importance of attitudes and secure functional support	Champion concept definition; competitive positioning
Team Members	Use new tools and apply technologies	Integrate cross-functional problem solving; create improved development procedures	Operationalize customer-driven concept development; refine concept based on market feedback

Project managers, in addition to their role during implementation (the focus of later chapters), also participate in the day-to-day decisions and insights that build the development process and strategy. Project managers must develop the capability to manage heavyweight teams. They should pay close attention to training and attitude within the team, particularly to interaction, customer orientation, problem solving, joint product-process design, and responsibility of members to achieve cross-functional two-way communication. Team members must be supplied tools such as CAD and DFM tools that make their work efficient, and groupware to make communication effortless. Many of the organizational issues will be challenging to team members, requiring new behaviors and attitudes. Project managers must set the standards for teamwork and conflict resolution, and work with upper management to provide correct and consistent rewards and incentives.

3.6. Functional Maps

Each functional group within a firm monitors the driving forces that define critical dimensions of competition. Frequently, these dimensions are captured and analyzed graphically or in summary form, both to produce communication tools that enable collective decision making, and to trigger the invaluable interactions that go into generating them. Usually, these functional maps display the critical dimensions as a function of time, and are used to help uncover trends and provide context to evaluate alternative decisions. Benchmarks from other organizations, particularly the toughest competitors, are used to gauge competitive advantage. The specific maps chosen by a functional group depend on the circumstances. Some common types have been found to be of value across a range of business functions (Clark and Wheelwright 1993):

- Marketing: Product profile (product attributes relative to competitors), Channels of distribution (sales and market by channel), Product generation (timing of new products, life cycle models, relationship to one another).
- Engineering: Critical skills (skill composition out of total workforce), Performance trade-offs (range of performance for various combinations), Component technology (performance using various component choices).
- Manufacturing: Process technology (degree of automation, fraction of output in different process types), Vertical integration (role of suppliers, internal operations by component), Cost structure (cost by volume levels, cost by factor of production).
- Integrative maps: Product / process matrix (process flow characteristics versus product structure), manufacturing / engineering (such as manufacturing cost versus product complexity), marketing / engineering (such as price versus performance of various generations).

3.7. Development Funnel

The number of product concepts that can be pursued in an organization is limited by resources and time. The notion of a development funnel is a graphical metaphor for the process of identification, screening, and convergence in selection of and commitment to a set of projects. Investigations or product concepts enter the mouth of the funnel, are successively screened and refined in the neck, resulting in shipping products that exit the tip.

The conventional notion of the development funnel is of a smooth, methodical gathering and narrowing of options and refinement of concepts by reasoned choice and structured interaction. But, in practice, case studies in which participants with in a firm draw a cartoon of their actual process reveal a variety of depictions that bear little resemblance to the ideal. Ideas from some sources may never reach the funnel, but those from others, such as upper management or marketing, may be injected around the initial filters. Chance is often depicted in playing a large part, and dog-legs and loops represent delays and diversions (Clark and Wheelwright 1993). Yet, the notion of a funnel remains popular. It focuses attention on the process for creating projects, achieving convergence on concept and design, and building commitment.

Several approaches to the funnel were found in practice by Clark and Wheelwright (Clark and Wheelwright 1993). These are quite common, relatively workable, and are sufficiently different to illustrate the nature of choices firms make:

3.7.1. Large Firms with R&D Groups

The first model is common of larger, technology-intensive firms with internal R&D groups. Ideas for new products and processes are generated by scientists and engineers charged with providing creative and innovative ideas. A series of screens are used to reduce the number of ideas, often using peer review processes. Initial screens are often based on technical feasibility, while later screens typically focus on manufacturing and economic issues. Concepts may then pick up ideas from others that are losing momentum or have been screened out. Resources become concentrated in those that appear most producible and cost-effective. Finally, products are screened before commercial introduction based on consideration of customer preferences, distribution channels, and expectations of financial returns. These products may compete with each other as well as with those from rival firms, in a “survival of the fittest.”

This first approach suffers the expense of parallel development efforts, most of which never become commercial products. Project groups become committed to keeping their pet projects alive, and resources become strained. Resistance to killing a project increases as commercialization approaches. Products that do reach the market may compete with each other for slow-growing markets, and few see adequate returns. Excess manufacturing cost and complexity can result, as can confusion in the distribution channel.

3.7.2. Smaller Firms

A second model is more typical of smaller firms that do not have the resources to follow the first model. A single idea is selected from a wide range at the advanced development stage, then backed by management all the way to market introduction. Ideas are quickly screened by top management for market potential and expected returns. This approach of “all eggs in one basket” is often followed by startups, many of which fail. Larger firms may have more than one product in the funnel at one time.

Frequent reviews and updates are used in an attempt to avoid surprises and to make mid-course corrections. Products are pushed to market quickly, often in not-quite-finished form, with upgrades being made in the field. Eventually, a successful product may be turned into a product line. Firms that succeed once may try the same approach again on subsequent generations.

This second approach has the advantage of focus and commitment. In larger firms serving many market segments, this process may lead to being too conservative, not innovative enough to lead the market. Too many mid-course corrections, delays, and compromises may result. Abandoning projects is highly resisted due to the lack of alternatives. In a changing and complex environment, the resulting product may be behind the times.

3.7.3. Recommended Model

A third model is proposed by the authors that combines the best of both. The first phase is an approach to concept generation that “expands the mouth of the funnel” by pulling ideas from a number of sources — customers, competitors, suppliers — not just R&D. Incentives, rewards, and a value system of responsibility in all functions are used to encourage inputs. Functional map methods may be used.

The first narrowing or screening is done by a peer panel of mid-level managers based on whether enough information exists to show readiness to proceed. It is an evaluation of readiness for advanced development. Proposals are evaluated based on fit with the aggregate project plan, relevance to technical and market strategy, fit with technical and process knowledge, and appropriateness to available resources. If the project is ready, it proceeds to the middle, advanced development phase where the project is bounded and any required knowledge is specified. Specific tasks needed to gain needed information are identified, and a new review time set.

The second phase consists of evaluation of competing concepts, defining them in terms of a set of platform and derivative development projects, and linking them to the stated strategies and objectives of the firm. This second phase may take only a couple of months, and aims to provide senior management with information to evaluate competing concepts, in terms of functional maps, the aggregate project plan, and available resources. It ends with a second narrowing or screen, a go/no-go decision to proceed with formal development projects, beyond which projects are staffed and funded with the expectation that products will result.

The final phase is formal development and project management, including additional reviews and monitoring. At this phase, all but the most promising concepts have been filtered out, so ramp up of the expense burn rate is incurred only for those projects expected to result in products. One or two platform projects plus a handful of derivatives and enhancements would survive, tied to business strategy and specific market objectives.

The process represented by the development funnel has lasting impact in an organization. It serves to train, develop, and identify people capable of generating product concepts, weighing the options, and facilitating decisions, and to focus the organization on continuing to build these capabilities. Clark and Wheelwright outline a method to audit and continue shaping the development funnel. In this method, the diverse team of managers and functional contributors who participate in the development funnel process meet to lay out the basic role of the funnel and elements of choice. Then, dividing into random groups, drawings of the process are made using the funnel metaphor but modifying it to reflect their actual experience of how the screening and narrowing occurred. This process is to be fun and creative. Rejoining the larger group, each smaller group presents their drawing. The insights from these drawings and the ensuing discussion leads to diagnosis of the process.

The outcome of this process by one medical electronics manufacturer yielded the following themes, commonly found in other companies:

- Ideas for new products and processes came from many sources, but tended not to be managed or guided.
- The start-point for projects was ill defined. The tendency was to move anything that looked good to the active list.
- During development, the funnel did not converge smoothly, but consisted of bulges and constrictions.
- A number of inputs that could have occurred early in the process actually happened late, causing recycling and iterations.

- Management pushed hard near the end of development for market introduction, often causing difficulties in other projects and pushing product out before it was ready.
- Many official projects died from inattention or lack of progress. Those that were completed did not usually match the intended product family.
- Subcontracted or OEM projects often came in very late, requiring iterations to fit with other products or were introduced without adequate fit with other products.

As part of building development process capability, performance measures should be established and employed to focus improvement efforts. These measures help steer the firm to higher profitability and impact on the market. Measures fall into three dimensions: time-to-market, productivity, and quality.

Time-to-market is a measure of the firm's responsiveness to customers and competitors, which impacts the quality of designs due to closer ties between shorter product cycles and the market, and the frequency of projects, which is particularly important for products with shortening model lifetimes. Measures for time-to-market include: frequency of new product introductions; time from initial concept to market launch; number started and number completed (actual versus planned); and percent of sales coming from new products.

Productivity enables a firm to have greater breadth and freshness of product line and a higher frequency of development. Measures include: engineering hours per project, and cost of materials and tooling per project (actual versus planned).

Quality is related to the firm's reputation and customer loyalty, to its market share, and to profitability. Measures include: yields; product performance; customer satisfaction; reliability, availability, and rates of failure and service (Clark and Wheelwright 1993).

Recommendations for improving the development process include:

- Have middle management do more of the planning and decision making on a day-to-day basis, because they have the exposure to needed issues and discussions. Senior management should set the agenda, determine the organization's focus, and provide incentives. They can use the development funnel to build the organization, people, and capabilities. The formal screens in the process serve to involve senior management in decisions.
- Competing projects can be good in the concept development phases, often into advanced development, when there is insufficient information to make technical and market projections. In formal development, competition makes no sense. Resources and loyalties become divided. Starting a project should mean a commitment to commercializing it. Rather than competing products, it is better to divide resources between projects that address different market segments.

- The mix of development projects should aim to build both market position and desired development capabilities in needed areas. For example, if software is becoming more important to a hardware company, it may chose to shift its focus to software more than the proportion of proposed projects would reflect.

3.8. Speeding Project Identification

Tremendous gains in time-to-market can be had by speeding the identification of projects. Unfortunately, management rarely gives as much attention to early development as it does to the implementation phases. There is not yet a plan to monitor. The burn rate is low, typically only the cost of a few people working on a given concept. A style of "management by exception" means that the project identification phase does not get much attention. So, time passes while the prospects for success of various proposals are considered and reconsidered, and this delay and associated losses are largely unnoticed by management.

Delays increase market risk and shorten the market life of any resulting product. The “fuzzy front end” presents the greatest opportunity for speeding development time with the least expense or effort. Furthermore, the invisible costs of delays from lost revenues is often hundreds of times that of the visible costs of personnel assigned to the projects at this early stage (Smith and Reinertsen 1991).

The focus during project selection is finding the right product idea to develop. This does not mean simply selecting the product concept most likely to win in the marketplace, but the concept that, given limited development time and the imperfect development machine at one's disposal, will be most successful. This is different from merely selecting the best engineering solution.

Common causes for delaying identification of a project include:

- A key element of the product is new to the company;
- Clear responsibility is not assigned for this element;
- No system exists to prevent a project from slipping into dormant state;
- No system exists to review dormant projects (Smith and Reinertsen 1991).

Annual planning is not frequent enough in today's accelerating markets. Also, members of standing committees often are distracted by other pressing issues. An alternative approach is to form ad hoc or task committees to fit specific objectives, and declare a clear deadline. Their mission would be to assess feasibility with a sense of urgency. This committee may include those who will have to execute idea.

Usually, a window of opportunity in the market exists before it is recognized and defined. Managers may assume that other firms are not as far along, and there is little sense of urgency, little pressure to apply resources. Conversely, after a competitor is identified, urgency is high, but the peak market opportunity may already be passing. Even after a need is identified, projects are often further mulled and reconsidered. Perhaps half or more of development time is consumed before the team has started work. This often goes unnoticed because there is no project to monitor and low burn rate due to the few assigned personnel. Proposals are often studied to death until it is too late to commit. Front-end studies often conclude that the best product is one that should have started before the study.

Organizational structure can strongly affects this phase. Firms that utilize new products groups in addition to functional departments have an advantage because full-time attention can be devoted to new proposals. Unfortunately, the group can become polarized by functional alliances among its members. Also, such a group may have to hand-off to the general practitioners to carry out project, which itself burns time, undermines ownership, and looses unwritten product information.

3.9. Separating Invention from Development

Because development speed is such an important factor in commercial success, technological uncertainty must be reduced before a product development project is launched. Development projects demand resources and commitment from throughout an organization, and have repercussions on organizational structure and strategy for future products and projects. This should not be undertaken until a promising product concept has been identified and the technology and marketing knowledge base is sufficiently mature. Otherwise, a feasibility study may be more appropriate to determine if the underlying technologies and methods are capable of achieving the desired goals within the capacity of the resources that can be made available in the project structure. Such research cannot easily be put on a timetable.

A top priority in development strategy should be to force clarification of the technology strategy. Defining a set of advanced technology projects ensures that required inventions precede their application.

One of Hewlett-Packard's major businesses created what they call the "pizza bin" approach. It requires explicit identification of the technologies required in each primary business function before proceeding with a development. Business strategy drives each function — marketing, engineering, manufacturing, and field support — to develop needed strategies, which then await use in development projects that "pull" them as if from pizza ingredient bins (Rothberg 1981).

3.10. Picking Winning Projects

Success in developing new products depends on developing and picking winning concepts. Of critical importance is the composition of the team that evaluates ideas and the management of the process. Various idea generation processes have become popular, such as brainstorming. Many methods are used for environmental scanning, competitive intelligence, technology forecasting, and technology assessment.

Often, many ideas exist within a firm, but the real challenge is to get the submitters to let go of the ideas. Typical fears are that the ideas will not be fairly judged, perhaps reflecting badly on submitters, or that the ideas will languish and not be acted upon, or that the submitters will not get proper credit. Systems for documenting and handling the ideas are important to help create an atmosphere of innovation. This usually involves working with the submitter to develop the idea and provide complete descriptions.

Idea judging often begins with an initial screening process, which both reduces the number that have to be evaluated in more depth and familiarizes the evaluation team with the ideas. Formal or informal processes exist to further eliminate, rank, and develop ideas.

Do firms with high success rates approach project selection in a particular way? Souder (Souder 1987) investigated this question using his database of nearly 300 development projects. He found five basic approaches to project selection, some of which were continuous processes, and others which were performed periodically. The categories he termed “reactive” and “campaign” are performed periodically, while “proactive,” “system,” and committee” are continuous processes. A firm may use more than one approach. Each approach can be characterized in terms of both the flow of ideas and they way they are judged. The style of decision making often reflected the style of the firms officers, and considerable variation among the firms was found.

In the committee approach, ideas flow from functional departments to committee representatives, who screen and develop ideas with the submitters before further presenting them. To stimulate ideas, ad hoc teams commonly performed technology forecasting and gap analyses to identify problems, opportunities, and shortfalls. Some firms emphasized environmental scanning and competitive analyses to provoke internal idea generation. External ideas were sought using commercial idea banks and consultants, and acquired by interaction with trade groups and professional associations. Procedures for handling ideas were the most sophisticated and formal in the committee approach, with ideas cataloged and tracked with periodic feedback to the submitters. Some documented the benefits in order to justify the expense of the process and boost morale. Idea screening methods were very detailed, progressing from a coarse initial screening to more detailed evaluation and rating.

The systems approach is similar to the committee approach, but uses more formal methods and integration with the planning process. The idea generation usually occurred during Management by Objectives (MBO) or other planning reports addressing objectives, goals, plans, and mission statements. Individuals were left to suggest ideas, but they were “expected” rather than rewarded, and suggestion committees were seldom used. Ideas were expected to meet established criteria before being submitted. Rather than ad hoc committees, standing planning committees would investigate external intelligence. Idea tracking was part of the planning process as well. Idea screening was therefore implicit and tied to the objectives.

The campaign approach emphasizes getting ideas for a particular need, such as to solve a customer or performance problem, or for an event such as an annual budget or planning session, or when the queue was running low. Sources of ideas and methods were of little concern. Sometimes, department staff or external consultants were used to instruct employees in the techniques, but usually there was no instruction.

Few procedures were used for handling ideas, and screening was unstructured, only sometimes leading to consensus.

In the proactive approach, one or more departments were charged with generating ideas, often the R&D department. Ideas were actively sought. Typically, a person in product planning or R&D was responsible to prospect, scan, and search inside and outside the firm. Many of the same techniques were used as in the systems approach, such as gap analysis, technology forecasting, and creativity techniques, but were not as sophisticated or tied to planning activities. Every firm handled and screened ideas differently, and in some cases ideas were shelved or lost with no follow up, while in others the first acceptable idea received was immediately selected.

The reactive approach is triggered by unexpected events or crises, such as a competitor’s new technology or product. In the absence of environmental scanning and intelligence, it was common for them to be totally surprised and even panicked. Such firms either saw themselves as the only supplier, were in a follower mode, or were waiting for clearer signals about trends. Varying techniques were used to handle and screen ideas. None used systematic idea screening, and most were spontaneous and extemporaneous. A popular method was to assign the most affected party to devise a defensive strategy, such as R&D for a new technology or marketing for a competitor’s new market strategy.

Souder’s research revealed no obvious best choice, but some guidelines became apparent for which is best in a given circumstance and organization. The committee and systems approaches are most sophisticated and the only ones suitable to large, decentralized organizations with matrix project management or new product development departments that cut across functional departments. The committee may be too cumbersome to manage for some firms. The systems approach assumes a highly developed strategic planning system that is integrated throughout the firm with MBO, project planning, operations planning, product planning, and forecasting systems. Campaign approaches can be used along with others when there is a recognized need that can be easily communicated. Proper handling and feedback is essential to prevent disillusionment of idea presenters. Proactive approaches are most suitable when management is highly specialized and innovation is concentrated among top management. To the degree that a company relies on regular innovation, it must move from the campaign approach to proactive to committee to systems. Thus, systems approach to project selection is ultimately the best approach.

The most effective approaches take advantage of the collective wisdom of organization to open dialogs and build consensus. This helps to retain the commitment of participants — managers are more willing to provide resources as needed, and departments cooperate and take handoffs from one another (Souder 1987).

3.11. Influence of Technology on Success

How does the nature of technology affect outcomes of various projects? How does one determine which technologies to pursue, or which technical approaches to undertake? Souder (Souder 1987) examined his database of development projects for patterns. He summarized the results by saying that the long-standing wisdoms in new product development are indeed confirmed empirically by the data. These generalizations include:

- A well-developed concept or theory of the technology should exist and be available to the innovating firm if it is to expect high degrees of success with that technology.
- Information about how to apply this body of knowledge must be available. Developing the original theory or basic application knowledge should be considered research, and outside the realm of a product development project. Time spend on such research has high opportunity costs. Most firms find their resources better spent on other new product developments.
- Research may be pursued in parallel using intermediary organizations, incubators, and technology developer organizations.

Organizations that do not have a high level of resident know-how in a technology are not very likely to have high degrees of commercial success with it. The optimum is a state in which all three above-listed conditions are met. Even the best management methods could not consistently overcome the disadvantages of poor theory, poor know-how about application of the theory, or poor internal expertise with a technology. A firm is best served to build upon its core competencies in product and process technology, and to develop that core of know-how in anticipation of future markets and technology trends.

On the other hand, innovation often implies exploring new areas of technology. Exceptions to the above generalizations can be successful, but some guidelines should be heeded for overcoming difficult or unfamiliar technologies:

- Select those projects that are a good strategic fit to the firm, due to reliance on a familiar raw material, product, process, technology, highly-technical market (such as a medical device niche), or distribution channel, or because of relevance to the firm’s long-range plan. The key is to leverage an advantage possessed by the firm related to the new technology, or to move in a direction the firm is planning to or needs to pursue. The fewer new competencies to gain, the better the chances. Still, expanding the firm’s strategic set of skills takes a huge commitment of resources away from other projects, and may put ongoing operations at risk.
- Provide the highest quality and amounts of resources to address these new technologies.
- Use strategies to isolate research from development projects and reduce drain on resources. These may include incubation strategies, co-ventures with other firms possessing the necessary competencies, funding of research at universities, subcontracting to independent labs, internal think-tanks or exploratory efforts, or limited R&D Partnerships.

3.12. Decision tools

A variety of project selection aids was found in the literature. These range from simple tools to formal mathematical decision systems. The intent is to model the preference of a given decision with regard to factors such as costs, resource requirements, sales forecasts, economic returns, technical and market risks, and patent potential (Shtub et al. 1994). Some examples of models include scoring, checklists, prioritizing models, benefit-cost analysis, cost-effectiveness analysis, discounted cash flow techniques, multiattribute utility theory, and other mathematical models.

Project selection algorithms evaluate projects in two steps. The first step quantifies the probability of technical and commercial success based on subjective estimates from the technologists and potential implementers. The second step quantifies the benefits of the project, if successful, based on estimates from financial and marketing staff. The algorithm then multiplies probability and benefits, subtracts costs, and yields an expected net present value.

Complex multiple-criteria methods for evaluation can be fairly accurate when uncertainties are minimal and the data are reliable. Supporters of formal mathematical models hope they might become the ultimate devices for decision making, eliminating subjectivity. But decisions, particularly for changing, competitive markets and developing technologies, are based on opinion-gathering and thus are subjective by nature. Project selection algorithms are only adequate for those evaluations for which the quantification of success probability and benefits is particularly straight-forward, in other words, for the easiest kinds of decisions (Bordley 1998).

Surveys typically report very low usage of such models (Souder 1987). Initial enthusiasm for the model drops as increasing amounts of subjective data are required, some of which is little more than guessing or is suspected of being biased by the estimator to achieve a particular result. However, other benefits of attempting to use such models include sensitizing the participants to those business issues with greatest impact on probabilities for success and financial return, encouraging communication about strategic intent and implementation issues, and thus stimulating researchers to develop better proposals (Bordley 1998).

Making the decision process more systematic is a more realistic goal than the dream of eliminating subjectivity. The simpler models are based on relatively apparent logic and are more trusted. Using models involves much discussion, resulting in a more complete airing and evaluation of the issues. Alignment on appropriate goals for the firm develops as these discussions progress; because goals change, the initial implementation of decision support systems may not produce satisfactory results. Prolonged use of a decision system as it becomes accepted builds a record of use and a tradition of record keeping that makes the models more effective, and builds the personal judgement of individuals involved. Alternatives can be evaluated on a more consistent basis and consensus becomes easier to build once a set of decision models gains acceptance.

A typical approach is to use checklists, at least in the initial screening before moving on to more sophisticated methods. Checklists are popular in proactive and campaign approaches. They can introduce some rigor into discussions by focusing on advantages, requirements, implications, or other attributes of an idea, perhaps ranking each as good, fair, or poor.

Scoring models are often used in proactive and committee methods. Scoring requires more time and effort to construct and apply. A system of criteria and weights may be used to arrive at a score for each alternative.

Prioritizing models may be used in committee and system approaches. An example might be to assess priority for a project based on a formula containing the product of various estimates of success probability for various stages or aspects of a design. Other attributes might enter into the equation, such as estimated profit, cost factors, and customer preferences. As with scoring models, a single number represents the outcome for each proposal.

Portfolio models are the most sophisticated, and may be used in the systems method. In the rare situations that employ portfolio models, they are typically used to explore alternatives, conduct simulations, experiment with budget allocations, and provide a learning experience to help arrive at a set of actions to be taken. Examples include mathematical programming and operations research methods.

The evolution of screening systems among firms that increasingly rely on innovation is from simple initial techniques such as checklists to scoring models or other prioritizing methods to portfolio models. For an in-depth treatment of new product forecasting and decision support systems, the reader is referred to *New Product Development: Managing and Forecasting for Strategic Success* by Robert J. Thomas (Thomas 1993).

3.13. Selecting the Project Mix

A variety of interrelated tools are often used to evaluate the mix of present or proposed product offerings. Several concepts are described below, ranging from broad initiatives to focus development efforts to simple matrix tools for evaluating types of projects in terms of technology, resource allocation, and markets.

3.13.1. Aggregate Project Plan

Most firms engage in multiple simultaneous projects. Increasingly, firms arrive at the list of “active” projects through a systematic process and review. The concept of an aggregate project plan begins by specifying the types and mix of projects that the firm plans to undertake. The intent is to balance and prioritize the resource demands of individual projects with existing capacity over time. The sequence of projects and target dates for market introduction are mapped out. Avoiding over-commitment and enhancing common focus can result (Clark and Wheelwright 1993). Interrelationships are highlighted, which serves to enhance cooperation among projects and their shared resources and enables shared and synergistic activities to be identified. The process also focuses attention on developing a coherent market strategy, resulting in a more integrated attack on intended markets, fewer surprises from the environment, enhanced commitment, and less redirection of efforts.

Steps in developing an aggregate project plan (Clark and Wheelwright 1993) are:

1. Define the types of classes of development projects that are to be covered. Typically, these are the five categories described below under "product maps."
2. Define for a representative project of each type the critical resources and cycle time required for its complete development. This usually focuses on human resources, and often includes dollar cost.
3. Identify the existing resources available for development efforts and currently active projects, with their requirements for completion.
4. Compute the capacity utilization implied by this.
5. Establish the desired future mix of projects by type. Here, strategic plans confront harsh realities. Trade-offs are inevitable, and time-to-market is often of great importance. Strategically critical projects receive priority. In established firms, half or more of the resources may be directed to next-generation platforms developments.
6. Estimate the number of projects of each type that can be undertaken with existing resources or those that can be made available. This involves trade-offs between development time, cost, and resources.

7. Decide which projects to undertake, including both ongoing and new projects. Some ongoing projects may be dropped or resources reduced; others may be accelerated.

3.13.2. Product Portfolio

The “product portfolio” concept recognizes that the competitive value of market share depends on the structure of competition and the stage of the product life cycle. One of the earliest methods of evaluating product portfolios is a two-by-two matrix, categorizing projects by market share and growth (Rothberg 1981):

- A product with high share of a high-growth market may be termed a “star” and may yield high profits but with a high influx of cash to finance growth. Strategies include reinvestment of earnings in cost reductions, efficiency increases, product improvements, and better market coverage, particularly in gaining a large share of new users or applications that are growing in the market.
- A product with high share in a slower market is a “cash cow” because of the low investment needed. Strategies are aimed at maintaining price leadership and market dominance, including investment in technological leadership. Excess cash is invested in growth elsewhere in the company.
- A Product with low share in a slow market may be called a “dog.” Since there can only be one market leader and since many markets are mature, this

category is the largest of the four. Strategies include focusing on a niche that can be dominated; “harvesting” or cutting back of support costs to a minimum; divestment, such as a sale of the business; or abandonment.

- A product with low share may be called a “problem child” if the market shows growth. Rapid growth but poor profit margins create a tremendous demand for cash. Either heavy investment should be made in getting new users, or the firm should buy existing share by acquiring competitors.

3.13.3. Project Portfolio

Projects are often considered together as a “project portfolio,” particularly when referring to them in strategic overview, such as when evaluating future growth of the firm, looking at issues of product-market mix, or leveraging commonality and synergy among the projects.

3.13.4. Product Maps

A “product map” is a visual tool to categorize the product development projects, evaluate the mix of projects, estimate and prioritize resource allocations, and avoid over-commitment. A typical breakdown is to chart the process change vertically versus the product change horizontally. The primary purpose of this chart is to distinguish among derivative projects, new platform projects, breakthrough projects, and advanced development projects, listed in increasing order of degree of change, risk, and resource needs. Each type of project has different characteristic resource requirements:

- Advanced development projects aim to invent or capture new know-how so that it can be available for future projects. Such efforts are more creative and uncertain in outcome, so they are usually given relatively few resources and management attention. Often they are conducted by an organization other than the development organization, or by a separate team within it.

- Breakthrough development projects create a first-generation or a significantly changed product or process. The core concepts, processes, and technologies may be new to the organization and perhaps the industry. They require the greatest organizational commitment, resources, and development of manufacturing processes.

- Platform or next-generation products establish a new architecture for future products using relatively established technologies and processes, and have a design life of several years. They offer fundamental improvements in cost, quality, and performance over previous generations. Considerable up-front planning is needed, with considerable involvement from engineering, marketing, manufacturing, and senior management. Often, new platform projects target a core group of customers and are part of an aggregate plan that allows for derivative products by addition, substitution, or removal of features or modules.

- Derivative development projects are of relatively narrow scope and resource requirements and represent evolution of previous products. They may be cost-reduced versions or enhancements of existing products. There may be little or no manufacturing process change, or incremental process changes, like lowering costs or improving reliability. Usually, such projects complete more quickly than other types.

3.13.5. Product-Market Matrix

Product-Market Matrix is a tool used in evaluating market strategy and cash flow, and has been adapted and extended by many authors (Cardozo et al. 1993). It displays present or proposed products in a two-by-two matrix, charting current and new markets on the horizontal axis and current or new products on the vertical. Products are thus categorized by their purpose: penetration, line extension, diversification, or market expansion.

Although the unique competitive environment of any firm is the greatest factor in determining the product mix, research suggests that some generalizations can be made (Cardozo et al. 1993) about how to achieve greatest sales growth. The product mix will depend strongly on the age and environment of the firm, indicating, for example, whether the goal is for growth, entrenchment, or defense:

- Young firms (less than 6 years old) are often best served to focus on their original product line and markets, or in some cases to change the products in those markets where they have built or can readily build relationships. The latter situation reflects those firms that are seeking their niche in the early years.

- Next-youngest firms (6 to 9 years) who have satisfactorily performed in their target product-market combination may achieve improved performance by developing at least one major new product/service line.
- As the firm grows older (over 9 years), market expansion appears to hold a greater payoff than product-line extension.

3.14. Return-On-Investment

Evaluation of return-on-investment is key to screening projects and allocating resources. One tool for evaluating and tracking ROI, developed at Hewlett-Packard, is the return map. It graphically presents curves representing estimates of investment, sales, and profit (difference between investment and sales) as a function of time. Key measures indicated on the return map are:

- Time to market (TM): Typically, this is measured starting from the end of the investigation stage, by which time some investment has already been spent. Given that the duration of the investigation phase can vary and indeed delays market launch, it may be more appropriate to refer to the entire duration.
- Break-even time (BET): Break-even corresponds to the time at which investment and profit are equal, where the curves overlap.
- Break-even after release (BEAR): This indicates the time elapsed between market launch and BET.

- Return factor (RF): the ratio of profit to final investment at a given time after release.

The return map stresses execution speed and helps keep the team focused in the face of new marketing information, management redirection, or feature creep. Because it shows investment, sales, profit, and cost (implied by the difference between sales and profit), it can be used by various groups within the firm to discuss the impacts of development timing and strategy. This one tool shows the influence of each functional group on the overall goal (Clark and Wheelwright 1995). The impact of missed forecasts and slipped milestones can be seen, and future development decisions can be influenced. Return maps can help make the increasingly important trade-off between market share and profit margin by illustrating the cumulative impact on profits. After the product is released, estimates are replaced with real data, providing a check on the accuracy of sales forecasts, and prompting the team to make late changes to address unreliable performance, poorly prepared sales force, or inadequate production capability.

A weakness of this tool is that it does not provide much feedback to the development team early in the project when the market has not fully been defined and revenue streams may not have been predictively modeled. Furthermore, as real data accumulate, the return map can reveal which functions are failing to meet their projections, resulting in apprehension and fear of punishment. Also, it fails to capture the cumulative effect of what HP calls the “strategic cycle” of three or so product releases — the time it takes to develop a new and significant technology and then exploit it by rapid development cycles that address specific markets. However, it remains a useful tool to conceptualize the interplay of time and financial return. Used retrospectively, it allows comparison of projects and capture of lessons for future project management.

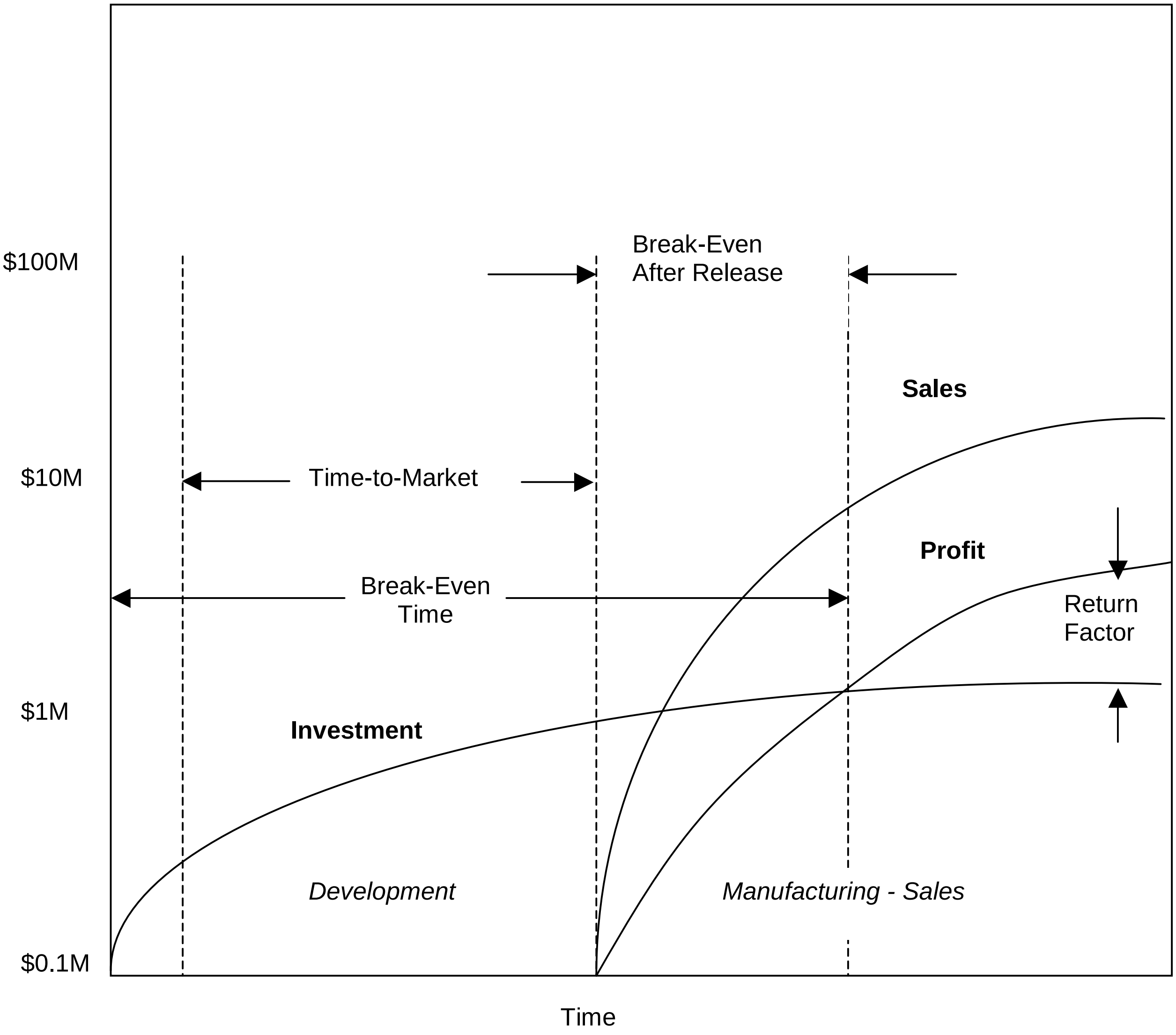


Figure 4. Return Map shows cumulative investment dollars against cumulative sales, yielding profits. This one tool illustrates the relationship of each functional group's contribution to returns and highlights the importance of elapsed time.

3.15. NPD Strategy and Organizational Learning

Product development strategy impacts the internal growth of an organization, in addition to the already discussed intent of shaping the external identity and product offerings. Clark and Wheelwright refer to development projects as the “engine of renewal” that builds new skills, knowledge, and systems within the organization (Clark and Wheelwright 1995). The development project is a microcosm of the entire organization and its interaction with suppliers and customers. The intense time and budget pressures intensify the strengths and weaknesses of a company and test its systems, structures, and values. Both the results of the project and how it is achieved shape the firm’s distinctive capabilities and its future.

People learn from previous projects and apply what they learn to renew the company’s capabilities. Going beyond the development and leverage of experienced individuals, organizations can make a practice and policy of supporting learning that cuts across projects and functional boundaries, capturing and embodying this knowledge in new procedures, policies, strategies, training programs, and reward structures. The concept of continuous, institutionalized capture of knowledge about core competencies is termed the “learning organization.”

Categories of learning include recurring problems and their solutions, critical factors in performance, working-level linkages between engineering and manufacturing or engineering and marketing, prototyping, management processes for making decisions and allocating resources, and the product development process itself (Clark and Wheelwright 1993). Organizations must develop a culture that values capturing and sharing such knowledge, and mechanisms for doing so. People should be asking:

- Do we have the skills we need?
- Do we have the right people involved in tasks?
- Do we have the right tools and supporting resources?
- What methodology and discipline can prevent recurring problems?
- Do we measure and track the right information about tasks?
- How do we capture solutions and make them permanent?
- Do we have a process and framework for functional integration?
- Do we have the skills, attitudes, and values that drive this integration?
- Do we have the right number and type of projects?
- Do we have a continuously improving process for creating aggregate project plans?

The Manufacturing Vision Group, a coalition of nine manufacturers and universities, studied the most successful projects to identify the factors that lead to success and continuous learning. They found seven key elements which, when applied holistically, initiated change, fostered learning throughout an organization, and optimized development. Those projects that succeeded mastered all of them; those that failed lacked one or more:

1. Core capabilities: This refers to the distinguishing attributes that enable a company to serve its customers in a unique way. These include knowledge and skills, management systems, manufacturing processes, physical systems, and values (attitudes, behaviors, and norms). In the best-managed companies, core capabilities grow stronger with each project and are leveraged to do what competitors cannot. If not updated and tied to strategic planning, they can be come "core rigidities" that can thwart needed change. For example, the highly-regarded "H-P way" has led to the tremendous growth of Hewlett-Packard over recent decades, but is now under scrutiny by management and consultants, and a reworking of the company culture to improve agility and speed is expected.
2. Guiding Vision: Successful companies articulated a clear image of the future that focused daily work. Rather than a specific goal, the guiding vision is a general direction or destination that described what must be done and why, and leaves individuals room to determine how. The best companies create a synergistic guiding vision for products and processes that are intended to fulfill customer expectations, build lasting capabilities, and support their business strategy.

3. Organization and Leadership: The best companies develop a customized system for promoting teamwork and supplying managers to lead projects with a clear concept of the project. Managers ably provide direction and decision-making authority. No single organizational structure or leadership style is appropriate for all projects, so a range of approaches is needed, as is the judgement to apply the approaches that best suits the project, the environment, and its goals.
4. Ownership and Commitment: Team members have a sense of devotion toward a project. Managers and company practices can help build this spirit among employees.
5. “Pushing the Envelope:” Top companies make a practice of constant improvements to products, processes, and capabilities. This imperative creates the awareness and pressure in daily work needed to achieve improved performance.
6. Prototypes: To help employees solve problems and learn faster and better, and to help build a common language within a team, prototypes of all kinds are used. These include models, mock-ups, and computer simulations.
7. Integration: Joint decision making among all functional units is essential for optimum development speed, efficiency, and quality. More than coordination, integration refers to a redefinition of task roles and work content to leverage the cross-functional development team.

Post project reviews or “learning audits” are settings in which lessons can be extracted from development teams. The degree of success in meeting objectives is assessed in various dimensions: schedule, market acceptance, technical objectives, and business objectives. Few companies are far-sighted enough to endure the time and expense of such reviews. But the Manufacturing Vision Group points out the benefits in captured experience leading to future savings and speed far outweigh the cost. A tradition of post project reviews sends the message that management places a premium on learning and cross-project support.

Projects also serve as settings to cultivate managers and leaders. The heavyweight and autonomous team structures are particularly oriented to developing leaders able to integrate business strategy, product concept, and project activities. Leadership and team structures will be discussed in later chapters.

Creating great products on time and within budget is very difficult. Doing so while building long-term capabilities and effectiveness in an organization is a great challenge. But it is worth the time, cost, and effort if it results in a consistent stream of great products.

3.16. Creating a Development Strategy: Case Study

Medical Device maker Physio Control was pressured into creating a development strategy by its growing problems in the early 90s. The maker of cardiac defibrillators and heart monitors had held a strong market position in the mid-1950s, but found its position challenged by small niche competitors taking advantage of new markets. Legislation mandating use of portable defibrillators in all emergency vehicles, combined with new technology in electronics, software, displays, and batteries, had led to a growing number of product categories, doubling between 1985 and 1990. Product life shrank from 14 to 5 years during that same period. Physio Control was challenged to become more responsive and productive to cope with growing development bottlenecks and resource limitations.

Senior management chose to develop a capacity plan and development strategy. Functional managers led data collection from functional groups involving all levels. Senior management listed current projects to consider a coherent strategy. After a daylong meeting, consensus emerged around the strategy for the next-generation platforms. Over the next few months, heads of marketing, R&D, and manufacturing reevaluated the platform strategy and developed better estimates of needed resources. Crucial bottlenecks existed in the model shop, testing, and quality assurance.

A further series of senior management discussions resulted in a detailed sequence of projects to achieve the strategy. To transition from present projects, ongoing activities had to be cut back, not just from ongoing product enhancements, but responding to customer requests, problems, and crises in the field. Rather than prioritize ongoing activities, they started with the question, “given our strategy, the nature of our business, and our short- and long-term objectives, what is the appropriate mix of projects to pursue?” They determined the fraction of resources to devote to new platforms, smaller projects based on existing platforms, and ongoing support. Based on this, priorities were given to projects in each category. In this way, a cleaner break was made with prior activities in line with the business plan for the next five years.

The number of projects was sharply reduced, and a much higher degree of communication and understanding resulted (Clark and Wheelwright 1993).

3.17. Demonstration Project: Case Study

Another method for building development capability was used by Hewlett-Packard's Vancouver, WA, division in the mid-1980s to develop the inkjet printer (Clark and Wheelwright 1993). A need in HP was recognized to develop a new mode of development and teach it to the rest of the organization. The project involved new markets and technologies to HP, and management wanted to break with the engineering-dominated culture by having early and continuous manufacturing involvement, with a goal to attract stronger people to manufacturing (Clark and Wheelwright 1995). The team for this ambitious project, developing an innovative laser-quality computer printer priced at under $1000, was given the mission to reduce development time and lower manufacturing costs.

The team was organized according to the heavyweight team concept (discussed in an upcoming chapter), managed by the head of R&D, staffed from all major functions, and moved to a single location. Significant integration of product and process development was necessary to create a low-cost printing method. Tooling design was integrated with parts design. Design for manufacturability (DFM) was a critical theme. The number of parts was substantially reduced; in one extreme example, thirty parts were combined into one. Early and frequent prototypes were scheduled to give prompt feedback. The strong leadership and team approach, as well as significant technological development, were credited with the project success, including a twenty-two month cycle and more than double the margins on earlier products. The project became a model for subsequent developments, having demonstrated what was possible (Clark and Wheelwright 1993).

3.18. Benchmarking

Benchmarking is a way of building awareness of the competition by comparing measures of key capabilities. At its best, benchmarking is a proactive, continuous process of measuring products, services, and practices against the toughest competitors or those companies recognized as industry leaders (Kolarik 1995). Without such external comparisons, a firm may tend to overrate itself or underestimate competitors' capabilities. "Best practices" may be found inside one's organization, in another organization in the industry, or in another industry that has a comparable practice. Benchmarking identifies performance gaps and methods that may be adopted to build efficiency and competitiveness. Emulation of these practices may include copying of competitors, or creative swiping from other markets or industries, perhaps from organizations that were not successful in their attempts. Benchmarking also has the benefit of creating rivalry and motivation for making changes to the way of working.

4. PROJECT MANAGEMENT PHILOSOPHIES

In the remaining chapters, the implementation phase of a development project is discussed, the phase during which a formal team is assembled and begins development of a promising product concept, beginning with requirements definition and conceptual design. Rather than review basic teachings in project management methodology, this paper discusses some perspectives and approaches specifically aimed at speeding development and improving responsiveness to customer needs. These include:

- Short, overlapping project phases
- Early and continuous cross-functional collaboration
- An ever-deepening understanding of customer needs
- An approach to planning that postpones detailed planning in order to get a quick start.
- Team organization and leadership
- Risk assessment and management

Many excellent texts in traditional project management are available to the reader. Some recommended texts are:

1. Duncan, William W., ed. 1996. *A Guide to the Project Management Body of Knowledge*: Project Management Institute. This book provides a comprehensive breakdown of all project management responsibilities and

activities, along with a glossary of terminology and acronyms specific to project management.

2. Shtub, Avraham, Jonathan F. Bard, and Shlomo Globerson. 1994. *Project Management: Engineering, Technology, and Implementation*. Englewood Cliffs, NJ: Prentice Hall. This textbook provides in-depth and comprehensive instruction in project management and related tools, with exercises.

These texts provide excellent training in the traditional roles and responsibilities of a project manager, and describe methods for structuring, scheduling, budgeting, managing resources, controlling, and completing a project. This paper will not attempt to summarize that massive body of knowledge, but instead will refer to and critique many of the concepts, techniques, and tools. Many such texts in project management offer a perspective to structuring projects that does not seem relevant to rapid product development. Issues of time-to-market, competition, changing customer expectations, product strategy, team collaboration, continuous improvement, organizational learning, and cross-project synergy are not addressed. Unwritten assumptions seem to lie behind the traditional methods that are dangerously wrong for product innovation projects.

For these reasons, other references were sought to discover how project management is actually carried out in competitive industries. Many useful references were found under the category “product development” which rely heavily on case studies and research of industry practices to identify trends and make recommendations. Some were quantitative research articles; others were extended essays with recommendations; still others provided case studies and examples of various principles in action.

The juxtaposition of these two sources of reference material — traditional project management and new product development — confirms that important differences exist between traditional methods and those used in time-based competition. The traditional methods are still fully relevant for many projects, such as architectural construction, civil engineering, aerospace projects, or other large and complex system development, particularly for a single sponsor or customer. Plus, a large subset of the methods of traditional project management remain relevant in the fast-paced world of product development. However, traditional methods alone are incapable of guiding a project manager in product development to the goal of commercial success, and may be disastrous if followed literally.

The goal of this paper is to identify the most important factors that make projects successful. A spectrum of techniques, tools, styles, and team structures are presented, looking for those factors that make the difference. While some general recommendations can be made, many methods depend on the specific project, industry, degree of technological maturity, marketplace, organizational structure, and culture. A set of skills that successful project managers should possess is outlined. In this chapter, we begin by exploring the basic philosophies and perspectives the underlie both the traditional approach and the newer variants.

4.1. Why Focus on Project Management?

Project management, defined simply, is a framework for structured planning and control of an effort that is specific in its objectives, limited in time, and conducted by a temporary project organization that will disband upon completion (Shtub et al. 1994). Project management is a model that is increasingly relevant in a time of increasing change, market fragmentation, and customization. Project structures are often used for system, product, or process design efforts and for production jobs with low volumes or small batch sizes. Project methods are also applied to other types of one-time initiatives besides those focusing on production. As technologies, markets, and organizations change at increasing rates, project methods are used with greater frequency to enhance structure, efficiency, and accountability of the work. Particularly as organizations become flatter and leaner, management activity is increasingly about getting temporary efforts completed, and less about controlling permanent structures of work. Functional departments are increasingly sharing power as cross-functional teams and task forces become more common. “Projects are the future of all work,” according to Jim Kouzes, Chairman and CEO of Tom Peters Group / Learning Systems (Laufer 1997).

"There's been a tremendous increase in business organizational change and interest by a lot of institutions reorganizing around projects," reports Virgil Carter, executive director of the Project Management Institute (Carrillo 1998). This is shown, for example, by growth in the market for project management software, both the small web-enabled packages for managing smaller projects, as well as the larger, more sophisticated programs for managing portfolios of projects and tied into enterprise-wide information systems.

A worker's ability to coordinate effectively across many functions has come to be expected. Project management is becoming an important skill, particularly for senior engineers in product development, and essential for those moving into management. Yet, the literature provides a model of project management that is increasingly outdated. Engineers become managers by promotion, armed with on-the-job experience but relatively little training. Some engineers may dread the vagaries of management assignments, or denigrate management as "soft" or "people skills." For such individuals, project management may bridge the perceived gap between the methodology-based world of engineering and the judgement-based world of management.

The period of relative job security during the past 100 years or so is an aberration — the exception rather than the rule — and one that is ending for good, according to William Bridges, author and executive development consultant. "The conventional job is no longer the most efficient way to get things done" (Cabanis 1998). Work is increasingly done by temporary project teams, and the current trend of "dejobbing" can be seen as a consequence of the shift to "projectizing" of work. Organizational structures are redefined with increasing frequency; even employers and employees come and go more frequently in a trend toward "free agents" with "portfolio careers." As organizations focus more on core competencies, they use partnerships, subcontractors, and vendors to expand their product offerings while reducing internal headcount. Jobs are steadily shifting from within large organizations to smaller firms, startups, and one-person shops. Because of increased outsourcing and variable staffing strategies, there is a brisk and growing market for project managers (Fleming 1998). According to Bridges, traditional management roles are disappearing; in the future, we will all live on “Planet Project” (Cabanis 1998).

New product development projects and project portfolio strategies are increasingly the focus of competition, with dedicated project teams becoming a more common organizational principle. Project management talent is further in demand as firms pursue all kinds of business initiatives to cope with increasing change, such as supply chain synchronization, the integration of information systems, improved financial controls, expansion overseas, pursuit of state-of-the-art manufacturing and certifications, or compliance with stiffening regulations (Fleming 1998). Every one of these entails project management.

In addition to speeding product development or bringing structure to one-time initiatives, project management is increasingly central to building a firm’s development capability and organizational learning. Projects are seen as the school and proving ground for new leaders, and a primary source of organizational learning (Clark and Wheelwright 1995).

Particularly in the United States, workers lack awareness of functions other than their own or of the value of collective contribution. Several factors may contribute to this. The American culture holds the individual as the fundamental kernel of society and commerce, emphasizing individual rights, freedoms, competition, and accomplishment. Individuals immigrated to the U.S. for freedom of religion, or ventured westward to establish homesteads. In design and production, the role of the individual has been emphasized over the team or the organization. The Industrial Revolution of the early 1900s introduced the assembly line, which standardized products and processes and broke down production into linear sequential steps, each independent of the others. There was no advantage to understanding the bigger picture; each worker could focus on his or her specialization and ignore other functions on the line. In fact, production workers were often paid according to their own productivity, putting them in competition with their peers. Overall productivity was not the concern of individual workers.

Modern products, based on rapidly changing high technology and with short product lifetimes and fragmented markets, are most effectively developed during intensive interaction among a dedicated team. But, the U.S. culture does not resonate with these emerging values. In contrast, Japanese culture emphasizes consensus among the collective — family, firm, institution, and country. Production workers there never experienced individual incentives and competition, so there are no bad habits to unlearn, unlike U.S. workers. The average Japanese worker makes more than 150 improvement suggestions each year compared with less than ten for American workers. Teamwork, continuous improvement, quality circles, and the like were more thoroughly and quickly adopted in Japan because the culture already valued team collaboration and consensus. This resulted in Japanese leadership in quality and time-to-market that is still being emulated by the west (Breen 1996).

A need exists for a modernized curriculum in project management for competitive product development projects, one that emphasizes these elements that are less than natural to most Westerners. It was with these motivations that research for this paper began. According to William Bridges, what we are “badly in need of is a curriculum for the new workplace self-management, intrapreneurship, taking responsibility for outcomes. Project management is a ready package of such new skills.” The mindset of a project manager, aware of and the business goals of the organization and responsible for outcomes, is a skill of growing importance (Cabanis 1998).

As Alexander Laufer writes in *Simultaneous Management*, “competent practitioners usually know more than they can tell.” Can project management be taught effectively? Experience, of course, is the most practical education available. Nonetheless, the student can achieve a high degree of competency by combining study of project management methodology with coaching in the observational skills and judgement needed for effective application. This paper attempts to address the latter — to explore the perspectives and methods used by the most successful project managers in the field of product development.

4.2. Related Concepts

Project management shares much in common with the discipline of systems engineering. Both use a similar phase-based breakdown of activities and emphasize a systems-level, complete-life-cycle view. Systems engineering differs in that it focuses on engineering methodology, including requirements definition, architecture definition, functional allocation, analysis of system performance, system integration, deployment, operation, and logistics throughout the life cycle (Blanchard and Fabrycky 1990). The emphasis is on design methods and system performance. One aspect of systems engineering that is particularly valuable to project managers is the comprehensive checklisting of all imaginable system functional requirements. In contrast, project management is concerned with cross-functional coordination rather than engineering methods, and on more general managerial concerns such as business objectives, competitiveness, and team dynamics. Project managers may not be engineers at all, and project management methods may be applied to efforts that do not include engineering activities.

Operations Research is another related, complementary field. Operations research grew out of efforts to support complex military operations by providing scientific methods to analyze problems, operate large systems, and optimize efficiency. It has since expanded to support the operation of large corporations and government systems, with management science as a major thrust. The term operations research is often used to refer to this body of established models and techniques. But, the

Operations Research Society of America defines it as any activity “concerned with scientifically deciding how to best design and operate man-machine systems, usually under conditions requiring the allocation of scarce resources” (Phillips 1986).

Many systems engineering and operations research methods have application in project management, and all three have some parallel aspects. However, as with traditional project management, they all have as their roots the development and operation of large, expensive systems and have limited applicability to development of products for competitive marketplace. In particular, questions of competitiveness and time-to-market are not addressed and call for other resources.

4.3. Traditional Project Management

A deeper look at the origins and methods of traditional project management is helpful to recognize its strengths and weaknesses, particularly any blind spots or gaps in its application to product development for increasingly competitive and time-driven markets.

Project management, as this author first learned it at NASA’s Jet Propulsion Laboratory, was a highly formal structure of task planning and monitoring, tied to organizational policies and government regulations. Indeed, project management developed as a professional discipline in large efforts such as the Manhattan Project and the Apollo program (Shtub et al. 1994). Gantt charts were first used prior to World War I, and PERT/CPM networks were developed in 1957 and 1958 (Frame 1994). These tools have become synonymous with project management. The kinds of efforts most benefiting from traditional methods are those with high technical and organizational complexity, high cost, heavy regulation and basis in policies and procedures, and frequent budget review cycles. During the author's work on Congressionally-funded NASA projects, it was common to have over a dozen reviews in a single year during which funding might be cut or authorization might be withdrawn. Demonstrating control, efficiency, and progress were top priorities to the project managers that regularly reported to sponsors at NASA.

The project management body of knowledge tends to reflect these early military and authoritarian roots. In the arsenal of terminology, tools, charts, and procedures, most seem designed to monitor budget, resources, and subcontracts with emphasis on controlling technical risk, but neglect market risk and the importance of time to market. Top-down project definition, planning, and control is the norm. Leaders of fast-paced product development find conventional project management teachings anachronistic, aside from a few basic tools such as Gantt charts.

Project management emphasizes a linear sequence of phases, reflecting the dependence of downstream phases on information from upstream phases. In traditional project management, planning of work elements, often down to the level of individual tasks, must be completed before work can begin. Downstream phases must wait until all necessary upstream information is "fully" available before commencing (Haddad 1996). Phases are punctuated by formal phase reviews that often mark the transfer of a project from one function to another, such as engineering "release" to manufacturing. Communication between these functional silos is typically very limited, and attention is spread thinly across many projects. Phase reviews become bottlenecks as managers of the function inheriting the project skeptically examine project work output, with which they are relatively unfamiliar, to evaluate whether they are willing to take on the problems and risks. This can be problematic enough between functions of equal power in the organization; but if design engineering has more power than manufacturing, for example, the project may be "transferred" or “thrown over the wall,” problems and all.

This sequential mindset and activity-planning framework can contribute to excessively long development times. If a phase is only allowed to proceed when all questions from the preceding phase are answered, it slows rate of progress to that of the slowest element, and creates downtime while bottlenecks are addressed. In traditional projects, schedule is considered important but secondary to controlling expense and technical risk. Traditional methods do indeed track schedules; but a project manager, in balancing costs, schedule, and performance, tends to ignore the economic impact of delays, aside from resource costs. The risk of missing market opportunities and the costs due to lost sales and market share are ignored. Traditional methods do nothing to prompt a project manager in product development to recognize the value of time, and no tools are provided to evaluate trade-offs between time and cost, resources, or performance. In fact, many traditional projects are funded in such a way that the developer benefits financially from delays (such as cost-plus-fixed-fee contracts).

The traditional phased design review process defines specific points for upper management to become involved, particularly at later stages of the project, with little management attention in between. Technology transfers are traditionally viewed as a one-shot hand-off, a clumsy, “low-bandwidth” process compared to the alternative: early cross-functional involvement and continuous upstream and downstream information exchange that enables fast, effective product development.

To be fair, no one advocates blanket application of traditional methods to all types of projects. In fact, the Project Management Institute (PMI) states (Duncan 1996) that methods should not “be applied uniformly on all projects; the project management team is always responsible for determining what is appropriate for any given project.” Recent revisions to the PMI text, *A Guide to the Project Management Body of Knowledge* include the generalization of project phases to reflect the variety of numbering and naming schemes appropriate to any given organization, removed the focus on functional organizations, and given greater emphasis to the integrative nature of project work. Management processes in that text have been broken out to better show the inputs and interactions among various knowledge areas and to make the generic structure more robust and applicable to a variety of project types. These recent changes underscore the evolution, broadening application, and recognized importance of project management methods. This chapter will delve more deeply into many of these evolutionary changes in the context of product development where time and customer orientation are priorities.

4.4. Accelerated Project Management

To address the emerging environmental forces and competitive imperatives of new product development, as discussed in the preceding chapters, project management practice must recognize the growing priorities of speed and customer orientation. The new project management is based on a reduced preoccupation with project phases, new ways of structuring and leading teams, new tools for planning and breaking down tasks, new approaches for control, and new cultural values. The combination of rapid change, increasing complexity of products and markets, and the greater depth of specialization in the workforce requires a strategy of collaboration and collective, ongoing planning, replacing the traditional top-down direction and up-front planning.

Actually, some of these elements were recognized and described in literature as long ago as the turn of the century, such as the need for simultaneous development of design and manufacturing process, and the importance of cross-functional integration in addressing customer expectations. However, only recently have these elements been perceived as essential, practiced in a coherent way, and adopted widely (Smith 1997). Furthermore, the need for overlapping phases and shorter, incremental product cycles is not readily found in historical literature, and may be a truly new element. Improvements by Japanese firms in time-to-market by adopting these techniques has triggered worldwide emulation since the 1980s, similar to the way that quality management became a worldwide trend a decade earlier.

More recently, Tom Peters, among other authors, has been touting the importance of project management and cross-functional collaboration, particularly in those organizations increasingly adopting “projectized” structures. Project management methods are increasingly finding their way into the functional setting for a variety of executive initiatives, even when project structures are not used (Dinsmore 1996).

To adopt these newer methods and achieve their benefits requires us to re-evaluate traditional methods and overcome the associated assumptions and habits. The priorities of the traditional approach were to be *efficient* at structuring large efforts, allocating massive resources, controlling expenses, and managing technical risk. Priorities of the new approach are to be *effective* at rapid development of products for demanding, competitive markets, and managing market risk. Strategic elements of this new approach include:

- Compression of time-to-market
- Shorter and more iterative development cycles, often with running cost reductions
- Overlapping or simultaneous phases during each cycle
- Greater integration of functional resources
- Emphasis on collaboration rather than top-down direction
- Team management and motivation

- Passionate customer focus and ongoing interaction between the development team and customers
- Ongoing tracking of the competitive environment
- Anticipation and management of technical and market risks using contingency planning and parallel development of alternatives
- Early and rapid prototyping
- Assuring quality throughout the design cycle
- Leveraging new information technologies and tools such as DFM, CAD, and CAE, and the emerging category of collaborative tools
- Continuous improvement and organizational learning.

This calls for greater entrepreneurial leadership, orientation to business objectives, collaboration, and focus on the customer from the project manager and team members. These new strategies, tactics for achieving them, and required skills are the focus of the remainder of this paper.

4.5. Incremental Innovation

Traditional project management emphasizes efficiency, resulting in a long-term view of product development in which large projects are attempted in order to achieve all the technical objectives in the most efficient manner. This typically American approach of concentrating all improvements into one project is undeniably appealing — not only does the firm hope to catch up to the competition in one step, but the new product can be put into production in a single, efficient switchover. Unfortunately, in such a large, ambitious project, the sheer number of new requirements and untried innovations increases complexity and risk (Smith and Reinertsen 1991). This complexity appears in both planning and design, and leads to a dangerous compounding of risk that virtually assures schedule slips if not outright failure.

An analogy with systems engineering may help frame the problem of large projects. System engineers are familiar with the compounding mechanism by which a complex system design may become unreliable due to the large number of otherwise relatively reliable components, all in series or with complex and difficult to predict interactions. In system design, reliability is improved by techniques such as redundancy, substantial component quality improvements to achieve vanishingly small failure rates, and using standard interfaces and modularity to reduce unknowns and risks. In a similar way, management of complex projects with many technical and market unknowns leads to high risks and low confidence in the schedule. The complexity of up-front planning invites errors because many assumptions must be made due to inadequate information. The complexity of precedence relationships among the many tasks, each with its own substantial risks, causes compounding of schedule uncertainty and confusion. Management overhead increases but management effectiveness decreases.

A large project sets up conditions that lead in turn to subsequent large and ambitious projects. Consider a firm that attempts an ambitious project to catch up all at once with the competition. They know it will be many years before they can bring another upgrade cycle. Consequently, the pressure mounts to get the present project right so that it might have a several year market life. This pressure of “all eggs in one basket” leads to greater analysis of the requirements, possibly leading to disagreements and paralysis due to the staggering complexity. The project’s importance leads to greater control and management involvement in project reviews and decisions. Progress is further slowed, and by the time the project is complete, there is once again pressure to catch up in another massive project (Smith and Reinertsen 1991).

The alternative is to take smaller, more frequent steps, an approach that has many benefits. Larger projects can be broken into smaller sub-projects, and long-term development strategies that would have been attempted in a single megaproject are parsed into several shorter, incremental development projects. Priorities are established among them, and the challenges are framed in a compelling, inspiring way. Collaboration is more productive by focusing on small, urgent opportunities, rather than becoming paralyzed by the sheer size and complexity of problems and the uncertainty of solutions. Technical innovations are then tested more quickly and phased into production more predictably, so schedule risks become much more manageable. Massive, all-at-once information and technology transfers between functional groups, such as between marketing and engineering or engineering and production, are smoothed and reduced to a prolonged or continuous exchange of manageable parcels. Communication is frequent and multidirectional, rather than one large, unidirectional data dump. Process development and quality improvements proceed in parallel, with design improvements made in incremental cycles to help smooth resource requirements and produce. A continuous stream of improvements can reach the market more frequently, starting with the most important ones.

Furthermore, incremental development allows more frequent market introductions and faster feedback from customers, so that product strategy can be tested and refined. Incremental innovation reduces the chances that one's product "aim" is wrong, and reduces the amount of the deviation. Smaller development projects can more quickly respond to, and better parallel, trends in customer needs and competitive products. Knowledge of customer needs increases dramatically, so product concepts are of better quality, and alternative technical approaches to achieving them are tested more quickly. If technical problems arise, there is much less waste of design-work-in-progress, management overhead, and investment dollars (Smith and Reinertsen 1991). The chance of project failure is dramatically reduced, the financial impact and delay caused by any failure is reduced, and more is gained from each development dollar. No longer can a single failed project sink the entire company.

Another benefit of shorter, incremental projects is that experimentation and rapid prototyping are facilitated. Smaller improvements can often be tested quickly by modifying existing products or processes, but larger technology leaps may require lengthy development before the first chance to test it or put it in the customers' hands. Often, unintended outcomes in early prototypes turn out to be desirable features, or at least are instructive in unanticipated ways. Later sections will explore these approaches in more detail.

Several projects that might have been conducted in parallel are typically shorter and more successful if done in series. Consider three projects that might be done either in series or in parallel over the same time period by sharing resources. In the series approach, projects complete in a shorter time after their concept phase, assuring that customer needs have changed as little as possible. Each release produces feedback that will improve the concept of the next project. Management overhead is less for three projects in sequence than in parallel over the same total time period. Later starts on two of the three projects means that less cash is tied up in development and invisible inventory. Shorter developments also reduce the window for scope or design changes that can derail a project or escalate costs. And, with the series approach, two of the three projects will have reached market sooner and thus provided greater financial returns, particularly if price erosion and early capture of market share are considered. Of course, some limitations may be present that prevent a halving of development time by a doubling of resources, as is often the case in software development or where fundamental inventions are required. But, even with the costs of additional resources so that such projects might proceed in parallel, the greater returns often more than compensate. For example, an unnamed high-tech company implemented such approaches, and was able to reduce time between product introductions from 133 weeks to 57, shorten order fulfillment cycles from 77 days to 32, boost productivity per employee from $55k to $83k, reduce inventory from $124M to $70M, and increase net income from a $147M loss to a $16M gain (Hanson 1999).

An example of the success of incremental innovation is the Sony Walkman, introduced in 1979. At $200, the original model was not a success. But Sony introduced many small changes incrementally, including manufacturing improvements to cut production costs, feature changes, and performance improvements. Mechanical components were made lighter and more rugged, some being replaced with cheaper electronic components. The price dropped, increasing the number of potential customers. Countless varieties were introduced to test the marketplace, leading to a more stable product strategy and better coverage of various market segments. This success could not have occurred by planning or studying the market, particularly given the newness of the product concept, but could only have resulted from "learning by doing" (Smith and Reinertsen 1991).

Techniques that support incremental innovation (Smith and Reinertsen 1991) include:

- Take quick, frequent steps. Each cycle leads to greater technical and process knowledge and customer understanding, with a sharpening of product strategy.
- Learn from customers. Market research, prototyping, and visits with customers in the factory and field help to understand evolving customer needs, trends, and openness to change and new technology.

- Make technology transitions incrementally and transparently. Both the technology and customer preferences about its implementation may provide surprises. Restraint and taking small steps will smooth the transition.

- Freeze the concept early. Short time horizons make for better market forecasting, and freezing the concept early allows implementation to complete before the target moves. The tendency for scope, features, and technology to “creep” must be resisted in favor of earlier completion of a smaller upgrade cycle.

- Have a long-term product strategy. Smaller steps need to add up to a larger strategy to cover all the necessary markets and product variations, be they derivatives, enhancements, new platforms, or breakthroughs. Otherwise, efforts become fragmented and wasteful. A coherent strategy empowers employees to create and make local decisions that accelerate development further and sharpen its focus.

- Take sales away from your own products before competitors do. By speeding development, a firm can afford to stay in the lead even if it means obsoleting one of its own products that much sooner. In this way, the firm can increase performance, market share, pricing premiums, and profits over many cycles at a much greater rate than the competition.

4.6. Overlapping or Simultaneous Project Phases

The focus of incremental innovation is to limit the scope of any given project and bring the most desirable product advances to customers as quickly as possible. In terms of project management, the main strategy for speeding development is to use short overlapping or simultaneous project phases.

Common to all project management methods is the subdivision of work into phases. Names for these phases and granularity of the breakdown may vary. A highly generic breakdown is as follows:

- Concept phase
- Definition phase
- Implementation phase
- Manufacturing phase
- Commercialization phase

The traditional, sequential phased approach is conceptually simple and therefore attractive — the purpose of each phase, its start and end points, and responsibilities are all well-defined. The dependence of downstream activities on information and other deliverables from upstream activities is assured by the serial performance of phases. However, sequential development takes longer because of the strict grouping of tasks within parent phases, and the rigid ordering of the phases. Furthermore, the sequential model does not capture the iterative and cross-functional nature of development work at successful companies.

To speed development, waste and unnecessary delays must be reduced. One approach is to shorten and overlap the development phases, a metaphor for making the handoff between phases more efficient and the delays between them as small as possible. Pushing this philosophy further leads to making sequential activities parallel wherever possible. The extreme of this philosophy is a breakdown of phase boundaries, using smaller granularity in the planning process so that individual tasks do not have to wait for the start of their parent phase.

A popular term for this philosophy is “concurrent engineering” or “CE.” Fundamentally, concurrent engineering refers to the use of overlapping or parallel activities as a strategy to shorten development time, and the early involvement of functional groups to allow this strategy to work. The term implies early and simultaneous attention to all life-cycle issues, including producibility, reliability, and serviceability. The implementation of concurrent engineering typically includes other related approaches discussed in this paper, such as integrated cross-functional teams and focus on customer needs with tools such as quality function deployment, in addition to that of overlapping phases. The term, as it has gained popularity, has come to imply different things by different authors, similar to the way the term “total quality management” has expanded to encompass virtually all management activity (Blackburn et al. 1996).

Concurrent engineering replaces the traditional sequential model of development phases with an overlapping or, at the extreme, parallel execution of phases, as a response to the imperative of fast time-to-market. The technique of overlapping phases is analogous to just-in-time methods in manufacturing that include a “pull” system and use of small batch sizes. In concurrent project management, information needed by a task is “pulled” as needed in small increments from previous tasks, rather than waiting for availability of complete information in one phase to be compiled and “pushed” into the next.

A limitation of terms such as "concurrent engineering" or "simultaneous engineering" is that it seems to imply that only engineering functions are performed in parallel. Ideally, all functions, not just engineering, work together in parallel, including purchasing, finance, marketing, quality, reliability, and field service. Perhaps "simultaneous management" would be a more inclusive term. However, in practice, many firms do not achieve such broad cross-functional integration, but instead focus on integration of engineering disciplines only to achieve parallel development of product and process. New product teams often contain core members from engineering disciplines, such as software, electronics, mechanical, and industrial engineering, plus manufacturing participation that starts with part-time members and transitions to full-time by pilot production. This is a major improvement compared to the classic "over the wall" hand-off from engineering to manufacturing, but it misses some opportunities to sharpen business and customer focus that a true, fertile cross-functional team can provide. The appropriate degree of concurrency and team integration should be determined for each project and organization, and no single approach is best for all projects.

In CE, the traditional notion of project phases is still present, but de-emphasized somewhat, with greater attention going to the individual tasks and their dependencies. Tasks are planned, not around the generalized concept of rigid phases, but around the specific logical inheritance among tasks and the objectives of the project. Plus, a greater sense of risk in this inheritance is accepted, accompanied by a more flexible risk management strategy. Any task can begin as soon as adequate information is available, or if assumptions can be made about what the missing information might be and what risks might result if the assumptions were wrong. A phase boundary is not a distinct moment in time, unless there is a clear and compelling need such as a review to determine readiness to proceed with clinical trials. Work in each phase is allowed to deeply overlap that of other phases. This flexibility allows the project’s most pressing questions to be explored first, often in parallel, so that overall risk in the project is reduced more quickly. While there may be some loss of efficiency due to greater chaos or more backtracking, these can be minimized by careful team coordination and ongoing planning. Any loss of efficiency and increase in risk is more than made up for in other ways.

For the most part, the overlap of tasks and phases is not confusing because the same individuals are involved in nearly all the phases. Typically, cross-functional heavyweight or autonomous team structures are used, and assignment of core functional members may occur at the start of the project. By use of cross-functional teams, the people performing any one task are mostly the same ones performing the next task. Boundaries are broken down and information flows more freely at the lowest possible level.

In concurrent engineering, not all tasks are done in parallel, but the members of various departments can begin communicating and make their contributions in parallel. Because all the functional skills are represented from the outset, consideration typically begins quickly on many fronts: marketability, requirements, specifications, design, testing, prototypes, manufacturability, process development, test methods, service, and support (Hull et al. 1996). Suppliers are often integrated into the development team depending on the importance of outsourced components in the product and the willingness of the supplier to dedicate resources (Haddad 1996). Teamwork and information sharing, both upstream and downstream, are central to the CE approach. By working in cooperative, parallel fashion, the likelihood of misunderstandings or oversights is reduced, leading to an overall reduction in redesigns, better match to customer needs, higher quality, earlier market launch, and greater organizational learning. The implementation of CE often combines early simultaneous involvement with use of information systems to share design information, and utilization of CAD/CAM systems (Hull et al. 1996; Shtub et al. 1994).

In traditionally managed projects, a PERT/CPM diagram of tasks may come to a choke-point for each merge node that represents a design review, while one for a CE project will have complex splits, interdependencies, and merging of lines. Gantt charts will show significant overlap of tasks. Because precedence relationships are de-emphasized by performing activities in parallel, Gantt charts are more commonly used than network diagrams.

Sports metaphors are often used to characterize the CE approach. The traditional phased program planning method is described as a relay race, in which each runner represents a phase of the project lead by the relevant functional group, passing the baton of information to the next phase and group. The transfer of ownership occurs at a phase review culminating in management’s declaration of completion of the phase and authority to proceed with the next phase. In contrast, the CE approach is often described as a rugby game. Rugby often appears chaotic, with everyone on the field at once and little apparent distinction among the player’s roles. Tactics are worked out on-the-fly collaboratively, based on the talents of the participants and the weaknesses of the opponents. Speed, cleverness, initiative and skill are more important than strategy (in contrast to American football which is highly structured). The important thing is for the “scrum” of players to move the ball downfield by whatever means are available. The emphasis is on spontaneous teamwork among hand-picked members rather than on a sequentially structured process of individual achievement (Clark and Wheelwright 1995). The rugby metaphor emphasizes the all-at-once collaboration of a fully-integrated team on all aspects of the problem, responding as needed rather than in a planned sequence.

In some industries and firms, accelerated projects retain a sequential phased structure, but the phases are accelerated and shortened, often overlapping each other. This approach is compared to soccer, as opposed to rugby (Rosenau 1990). A cross-functional team uses the phase structure to focus its efforts, improve comprehension over time, and reduce of risk, often using design reviews as check points. A structure of short, overlapping phases aids in sharing of resources if several projects must be done in parallel. It also limits the commitment of funds until uncertainty is reduced, and allows filtering out of less-promising efforts. The choice of structure along this continuum from a sequential relay race to a parallel rugby game is determined by the relative need for top-down control compared with the effectiveness of cross-functional collaboration in dealing with complexity and uncertainty.

By early staffing of the project with dedicated personnel from key functional groups, the communication and creative process is started early and given continuity, and the team is virtually forced to act cooperatively and in parallel. Everyone begins operating and collaborating across functions much earlier and with little bureaucracy. Taking initiative to find ways to overlap and accelerate the process becomes the responsibility of each person on the team and part of the culture. When working on a task, needed bits of information are “pulled” by the party in need, rather than “pushed” from phase to phase in large batches as in the traditional phased approach. This gives everyone something to do from the start, and builds awareness of the interrelationships among tasks and functions, building collaborative momentum within the team. A dedicated team working in parallel tends to make the participants less specialized as everyone pitches in to do what is needed. Because the team is aware that information is changing, they develop a sense of cooperation and joint responsibility for results in all functions. The formal procedures and informal guidelines within the company begin to reflect this joint responsibility. Organizational structure of the team will be addressed in a later section.

Overlapping of phases relies on each individual having both an overview perspective to identify major opportunities, and a microscopic search for small ways to make progress. Team members begin to make a habit of asking questions (Smith and Reinertsen 1991), such as:

- What is the minimum of information needed to start the next step?
- When is the earliest I can produce this information?
- Is there anything that can be done to reduce the required information?
- Are there possible assumptions I can make that will have a high likelihood of being accurate enough to move forward without waiting for confirmation?
- Are the likely consequences to making a particular mistake large or small?
- Can I still finish early by starting early with limited information, even if assumptions are wrong?

- What information would allow taking another step?
- Who might be enabled to take another step by the information that I have?

Adoption of the CE approach requires reconsideration of nearly every aspect of project structure. Managers must be much more participatory, hands-on, and skillful at facilitating group processes and conflict resolution. Managers and team members typically put in longer hours, because there is little down-time between tasks or while one functional group performs their assignment. Careful consideration is required of everyone regarding impact on others. For example, design engineers must consider the capabilities of a manufacturing process group so that their designs are “downstream friendly.” This implies attention to issues such as design for manufacturability, value engineering, failure modes and effects analysis, and Taguchi Methods, which are designed to prevent problems and make improvements as early in the design process as possible, and to give product engineers the tools to balance product quality with manufacturing costs. Conversely, downstream groups can pull information from upstream groups to forecast needs and anticipate problems and capabilities that must be developed, as well as provide early advice and feedback. Risk management, cooperative problem-solving, and the ability to respond to unexpected changes are critical skills.

The term "concurrent engineering" sometimes implies the use of certain tools and tactics that make overlapping tasks more efficient, such as modular architecture to make future changes easier and commonality and compatibility across multiple projects and products. Tighter integration of teams is often achieved by strengthening the team structure and accountability, weakening links to functional group structure, and locating members of the core group within feet of each other to increase the frequency of interaction. Communication networks may allowing access to a common database to enable concurrency.

4.7. Project Planning Philosophy

Planning and control are significantly altered in the concurrent engineering approach compared to traditional project management. In the traditional approach, detailed planning is completed early in the project. Planning may be rolled up from the bottom up, estimated from top down, or both; however, collaboration is not traditionally part of the process. The approach is reminiscent of the authoritarian military model. Control is emphasized over speed. If information is limited initially, the planning phase may become prolonged as the project manager solicits and analyses data and develops a detailed plan. All of this delays the start of the design phase.

Once design work commences, newer information is often gathered, and the original plans begin to show their age. But, the formal plan-implement-control philosophy and phase-review authorization process, with its associated delays, creates great resistance to modifying the plans despite the new information. In many projects, plans are changed anyway, causing some repetition of work already completed, demoralizing some team members. Ironically, team members who complain that the changes caused their efforts to be wasted may be the same ones saying “I told you so” that the need for change was apparent for some time and inevitable. Factions may develop arguing for and against a new proposal given the partial completion of the original one. Monitoring and control is done against the detailed plan, with deviations considered undesirable, drawing management attention (Clark and Wheelwright 1995; Smith and Reinertsen 1991).

In the CE approach, responsibility for planning, monitoring, and control is more organically shared among the team members. Detailed planning is likely to slow product development (Peters 1994). The project manager recognizes that not all the planning output is needed at the outset of the design phase. Initially, the project is framed and kept within boundaries for meeting market opportunities. Planning is typically done only to the degree needed to proceed with the available information and to plan long lead-time tasks. Basic timelines are blocked out for major objectives, but the means for achieving them may be undetermined. Information is limited at the outset, but is gathered, developed, and refined by the entire team during the various phases of the project. Collaboration is the norm, with ideas and information being generated by the process of team interaction over a period of time. The objective of the project manager is to help the team identify the critical unknowns and long lead-time items, and begin activities to address these as soon as possible. Further planning is contingent upon what is learned while investigating these key questions, often using fast prototype iterations (Clark and Wheelwright 1993; Peters 1994). Plus, the target is often a moving one, so continuous planning helps the project converge on the best outcome rather than on a pre-determined one.

Further planning is distributed throughout the project and continuously refined. Operational decisions are made incrementally, and important strategic decisions are delayed as much as possible to allow more flexible approaches and last-minute feedback. As uncertainties are eliminated, information is gained, or alignment on objectives evolves, the plans are made more detailed (Clark and Wheelwright 1995; Smith and Reinertsen 1991).

4.8. Limitations and Pitfalls of Concurrent Engineering

In the practice of concurrent engineering methods, pitfalls are numerous. Because downstream development phases begin before the product or market information required is available from earlier phases, it is inherently risky. Tasks may be overlooked unless the team is truly integrated across functions, communicative, and experienced.

Overlap of phases must be undertaken deliberately and selectively, with risks from concurrency weighed carefully along with the likelihood of change and the consequences of waiting for final information. The sensitivity of downstream tasks on incomplete upstream information is a key variable, as is the rate at which upstream information is developing (Krishnan 1996). Creative alternate approaches that reduce sensitivity and risk can often arise among a well-functioning team. Careful management is needed to assure that the assumptions made in lieu of complete information are reasonable and that the consequences of error are acceptable. Alternate scenarios should be anticipated so that changes are anticipated and not resisted.

Multiple scenarios may be pursued to maintain flexibility, while information is being developed that eventually will lead to the choice among the scenarios. Redundancy or iteration may be deliberate tactics, both to manage risk by providing alternatives, and to generate early learning experiences. However, resources can be spread too thin. Furthermore, once evaluation of multiple scenarios has begun, the engineering team may feel committed to completing them so a rational comparison among them can be made, even though the original intent was simply to provide back-up alternatives. Managers must balance contingency plans to manage risk with the benefits of focus on one approach.

This type of contingency planning may require a new perspective on change, particularly regarding design iterations. In the traditional sequential mind-set, information flowing downstream is assumed complete, so iterations are considered wasteful and undesirable under any circumstances (Krishnan 1996). However, in the CE approach, information is not assumed complete, so uncertainty and risk are carefully managed in anticipation of new information or developments. Change is not necessarily avoided and is often desirable. To develop products quickly, one must act quickly without the delay of detailed planning; this implies that management must support "fast failures" as inevitable and necessary for building knowledge. At first, this seems in conflict with "do it right the first time," but the two philosophies are complementary rather than contradictory. We need to experiment to develop *new information*; by which we can recognize the possibility of improvement in present products and processes. The notion of "doing it right" simply means that we use our *present knowledge* and analysis capabilities to their potential, and consider downstream impacts up front; we do not cut critical activities in our zeal for speed (Peters 1987). So, the best approach is to quickly implement a partial solution, usually through early prototypes, and solve problems iteratively through successive approximations. The goal is to arrive quickly at an answer, not to avoid mistakes along the way (Reinertsen 1992).

This iterative process must be cut off at some point and a product released, often followed by running cost reductions and iterative product improvement releases. The timing of this cut-off decision is often hotly disputed. A balance of product quality and timeliness must be achieved, and trade-off analyses may help in reaching alignment.

Great success with concurrent engineering has been reported among many types of hardware projects, with high correlation between degree of phase overlap and shorter development cycles. But, software development remains largely sequential, particularly in the United States (compared to Japan), and concurrency is often limited to within phases rather than across phases because managers are unwilling to assume the risk. Typical problems include changing requirements and postponement of integration between hardware and software. This is changing as structured software development becomes more widely implemented, and the belief that “software is different” is challenged under pressure of increasing competition. One example is Microsoft, which has largely abandon the sequential waterfall model in favor of a management practice of “synchronize and stabilize” that consist of parallel specifications, development, and testing phases which are synchronized by daily builds (Blackburn et al. 1996). Active project management is needed to coordinate hardware and software at an early stage, driving early information exchange and front-end tools like quality function deployment. Architectural modularity is a critical enabler for managing concurrency within a project and promoting reuse of code between projects.

Not all projects are suitable candidates for acceleration by shortening or overlapping development phases. Breakthrough projects that require revolutionary innovation may not be appropriate candidates for the CE approach due to the uncertain creative process of developing fundamental science, such as biotechnology and chemistry breakthroughs. The CE approach does not apply as easily to mammoth projects such as aerospace vehicles or system development, where project size limits face-to-face teamwork. Nonetheless, Boeing used CE approaches to reduce development time of the model 777 by 1.5 years (Clark and Wheelwright 1993). Small, “one-man show” projects, where a single inventor drives the development, may show little benefit due to lack of resources to commit to concurrent tasks (Smith and Reinertsen 1991).

Projects with a high level of concern for technical quality or with high burdens of regulatory control and documentation may not be easily accelerated. The medical device field is one example of both high level of concern for quality and high regulatory burden. Furthermore, regulatory approval delays are often unavoidable. It is tempting to accelerate product development all the more to compensate for such delays. However, many firms still lack adequate product development processes and design controls, so quality and market fit may become casualties of acceleration attempts (Sahni 1992).

To make decisions about an accelerated development process, it is important to understand the firm's present process and its strengths and weaknesses. Success depends on a combination of factors, such as cross-functional team structures that promote early simultaneous influence, effective information technologies that enable collaboration rather than slow or overburden the team, and team-member training in CE methods.

Acceleration methods are likely to cause unpredictable problems when applied over troubled existing processes, resulting in mistakes and redesigns. Merely attempting to use overlapping phases without addressing the entire development system is likely to lengthen development, not accelerate it (Hull et al. 1996). Before deciding to cut cycle time, the focus should be on eliminating waste, bottlenecks, and weaknesses in existing processes. Many firms claim to have systematic product development processes in place, but some are found upon audits of project histories to have significant gaps and deficiencies. Some important or critical activities may be skipped and others undertaken superficially. One study showed that only 34% of companies performed all the activities called for, and found that better completion of these design activities correlated with higher success rates (Gupta and Wilemon 1990).

The single greatest contributor to acceleration is simply to start early — to recognize market opportunities and define product concepts without excessive debate and changing direction. Another is to commit to projects that employ technologies, processes, and markets most familiar to the firm and that match its distinctive strengths — its core competencies — leaving only a manageable few unknowns to overcome. Adequate product definition is critical to assure that the path being accelerated is one worth taking. Many firms do not adequately link specifications to customer needs, which tools like quality function deployment are designed to accomplish (Sahni 1992). Project managers and teams need to be able to make effective trade-offs among product schedule, development cost, product cost, and product performance. Weighing the effects of process changes requires competent value analysis.

Success with concurrency is critically dependent on the quality of interaction among the team, and realistic assessment of this quality by the project manager is needed. Clark and Wheelwright (Clark and Wheelwright 1993) define four dimensions of communication between upstream and downstream groups, such as engineering and process groups:

- Richness of media: Are documents physically and electronically distributed, or is there rich, face-to-face communication and discussion of models?

- Frequency: Is information offered in batches or one-shot transfers, or is there frequent transfer of small amounts, with real-time on-line communication and shared databases?
- Direction: Is transfer of information a one-way monologue, or two way dialog?
- Timing: Is communication late, occurring at the completion of work, or early, setting the stage for the start of the process?

Failure may result if the overlapping of tasks is not combined with effective breaking down of functional walls and with proactive quality tools and training (Kolarik 1995). If the cross-functional team structure is not supported by the culture and values of the firm and by measurement and reward systems, or if the necessary interaction does not materialize for any other reason, concurrency is likely to fail. Firms need to learn to support, recognize, and reward collaborative accomplishment as successfully as they have done so for individual accomplishment in the past (Schrage 1995).

Innovative solutions, in particular, depend on collaboration among the relevant specialized contributors. Simple communication or coordination of activities is not enough. Managers must learn how to frame opportunities or challenges in a compelling way that elicits commitment to working together on a solution. Collaboration further requires development of a shared context for the problem and understanding of proposed solutions, which depends on rich interaction and use of prototypes and other models (Schrage 1995).

Many barriers exist to cross-functional integration. For example, differences between engineering and manufacturing working styles, pace, language, job descriptions, rewards, compensation, and locations can make cooperation difficult to establish and maintain. Particularly in the U.S., a caste system exists in which engineering is viewed with more prestige and is charged with product performance and features, compared to manufacturing which addresses the gritty details of producing what engineering designs for them. This is not the case in Japan, where functional members work side-by-side in product teams, and designers typically start their careers in manufacturing (Clark and Wheelwright 1993). This may be an important reason for Japan’s head-start on issues of quality and time-to-market.

Senior management must establish the context in which functional integration and problem solving can occur. This includes formal policies and procedures such as job descriptions, criteria for performance reviews, reward systems, and training programs to help workers develop the needed skills and attitudes and stay focused on customer needs. But, it also requires a formulation of values and beliefs that is articulated and modeled in a consistent way by senior and functional management.

A sense of mutual trust and shared responsibility is essential to integrated problem solving. Upstream and downstream functions must see themselves as committed to, and their performance measured in terms of, each other’s success (Clark and Wheelwright 1993). Successful integration requires functional groups to anticipate each other’s needs and make efforts to address them, often increasing their own workload and expense in the process. Collaboration often exposes one’s work and methods to criticism from other functional groups. The climate must support experimentation, cooperation, making mistakes, and constructive criticism. Negative inter-departmental politics can destroy collaborative efforts.

5. ORGANIZING FOR SUCCESS

Organizational structures can and do strongly influence behavior, in terms of both individual interactions and group dynamics. How influential is the structure of the organization as a whole on product development effectiveness? Designing organizational structures is not a simple matter, requiring a balance among ongoing operations, project needs, company history and culture, questions of employee development, incentives and rewards, and costs.

On the project level, much attention has been given in the literature to the use of so-called "heavyweight" or "autonomous" team structures. The concept of teams has become a fad. There is substantial justification for this, given the success of teams in speeding development of innovative products under conditions of uncertainty. Teams are widely recognized as highly effective at accelerating product development by promoting cross-functional interaction (Clark and Wheelwright 1993) and by giving the team control over product design decision and resources rather than the functional group managers (Smith and Reinertsen 1991). Yet, the word "team" has become over-simplified and dangerously ambiguous. Implementation of teams varies considerably, and no single structure seems best. Some of the more thoughtful research has explored variations of team structures, and structures of the organization as a whole, and studied their effect on project success. Such research can help management understand team dynamics and apply this understanding to diverse situations.

Fundamentally, teams are a way to create new relationships among colleagues and customers, with several intents: to reduce rework by early communication from downstream functions, to coordinate simultaneous activities by enriched interactions among participants, and to enhance innovation by creating an environment that supports collaboration. But, are team structures always better? What are the drawbacks? Project structures should be tailored to the type of project and its relative needs for cross-functional communication of information, coordination of activities, and collaboration in creating innovative solutions, while taking into account the higher costs of team structures, the needs of functional organizations, and the overall organizational culture.

In practice, project managers do not often have much ability to influence organizational structures, which typically evolve over long time spans and require widespread support within the organization to implement. However, when opportunities occur to influence organizational structure, project managers can serve as change agents and internal entrepreneurs, using their insight about project needs and problems and the dynamics of informal networks to help shape the formal structure. More frequently, a project manager is able to shape the structure of the project team. However, project team structures must be consistent with the overall organizational structure and management philosophy.

5.1. Organizational Structures

An organization tends to evolve into a basic internal structure that best addresses the fundamental issues of the business. Firms differ regarding which issues are most important to organizational structure (Shtub et al. 1994), including:

- Functional skills
- Products and product lines
- Customers and markets
- Processes and raw materials
- Geographic territories or languages

The chosen structure must be appropriate to the goals of the business, the market in which it operates, the number and nature of project s, the kinds of technical expertise needed, the depth and rate of change of market and technical knowledge, communication, lines of authority, responsibility for results, financial and accounting systems, and development and retention of resources.

In most organizations, some degree of functional structure coexists with a project structure. Each will play a role in the functioning of the team and the career paths of individuals within a project, not to mention the interplay among projects within the business. The relative balance between functional and project dominance of the organizational structure will depend on the number and relative importance of project work, level of uncertainty, commonality of technologies, complexity, duration, resource needs, overhead cost, and data sharing (Shtub et al. 1994). Functionally-dominated structures will tend to concentrate technical expertise, enabling fundamental advances in narrow specialty areas, while project-dominated structure will tend to concentrate project-specific information, enhancing cross-functional coordination and speed. The management challenge is to find the most effective hybrid structure.

To achieve success in product development, many elements must interact: customer needs and expectations, market dynamics and distribution, product strategy, economic evaluation, technological expertise, and manufacturing process capabilities. These elements must come together in a coherent, dynamic way if superior quality and rapid development are to be achieved. Because most organizations are based on a functional structure, it is usually left to the project to achieve this cross-functional integration and strategic direction.

Large, mature firms with ongoing operational concerns often have strong functional groups within engineering (such as software, electrical, mechanical, service, test) as well as in marketing and manufacturing. People are grouped by discipline, working under a specialized sub-function manager and a senior functional manager. This structure has a clear career path within each function, until one reaches the general management level. Evaluation of individual performance is made by sub-function managers who themselves are highly skilled in the technology. Members of a specialty can collaborate on designs, bringing to bear the best expertise of the group, and can share resources and training. Senior members can serve as mentors to junior ones, further strengthening the firm’s functional expertise.

New product development projects in a functional organization are often charted as “horizontal” structures cutting across “vertical” functional groups, usually described as a “matrix organization.” These projects may be part of a portfolio of projects, managed through a product development process (as described in an earlier chapter). Projects may be coordinated within these organizations in a number of ways, depending on the organization’s need to balance ongoing and routine operations with innovation.

Souder (Souder 1987) examined data gathered on 256 innovative new product development projects in terms of organizational structures, finding four basic types:

5.1.1. Classic Functional Structures (Type I)

Souder defines Type I as those that are completely functional, broken down into engineering (or R&D), production (or operations), and Sales / marketing. Such organizations contain mostly specialists, possibly with deep technical expertise, and career paths are typically bifurcated into technical or management roles. This type of organization is well suited for mass production (Shtub et al. 1994) and can be extremely efficient and cost effective for civil, aerospace, or military development under lump sum or fixed price contracts (Heisler 1994). In developing new products, they are strong at handling routine problems and well-characterized technologies, and are appropriate for stable environments and low product evolution rates for well-defined markets (Souder 1987). Such organizations epitomize what Souder characterizes as "classical" operating principles (discussed in an earlier chapter). The functional separation makes it hard for personnel to appreciate the concerns of other functions, and creates an obstacle to interaction and collaboration for new product developments. Workers typically have multiple assignments, and prioritization can be a problem, leading to schedule uncertainty.

5.1.2. Functional Structure Within Divisions (Type II)

Type II structures are broken down into divisions, each of which focuses on a different market, product technology, or product line. Each division may have its own market research function to guide development of its product line, and its own functional groups. Growth may be achieved by adding more divisions. As with type I organizations, they lack the ability to adapt to changing environments or handle radical innovations other than incremental changes to their current line. The focus is on profits from their narrow product lines, so proposals to develop new technologies or products cannot find a home.

5.1.3. Matrix Project Management with Long-Range Planning (Type III)

Type III structures attempt to improve on type I and II by adding a long-range planning group (LRPG) that reports to top management, a divisional research and development (R&D) group that reports to the division, and a projects manager function (or a corporate R&D function) that leads projects across the functional groups in a matrix fashion. The LRPG conducts market intelligence, environmental scanning, and other activities to evaluate new opportunities and threats, giving new product concepts to R&D. The project manager leads the division-wide development of major new products efforts that require cross-functional and perhaps cross-divisional resources. Projects may be passed to an existing division or new product division upon readiness for commercialization.

Advantages include better interdepartmental openness and ability to handle innovative ideas. However, such structures often create problems such as constrained resources, impacts on ongoing operations, and high management time to balance short and long-range efforts and mediation. Also, the corporate projects management function may become relegated to fire-fighting problems on existing products rather than strategic initiatives. There is also no mechanism to fund and protect new innovations until they are commercially viable.

5.1.4. New Enterprise Division (Type IV)

Type IV structures add a new enterprise division (NED) to the type III approach. The NED provides a home or incubator for developing innovations between the projects manager stage and adoption by a division once they have achieved break-even profits. This structure balances the efficiency needed for ongoing operations with the need for innovation. But, considerable cooperation among the various units is still required, which can be derailed by political, technical, or personal issues (Souder 1987).

One variation of structure not directly addressed by the Souder study is the so-called Project Organization (Shtub et al. 1994). At the other extreme of the continuum of organizational structures from the classical functional organization, a project organization is characterized by the virtually complete breakdown of work into specific projects, with little or no remnants of functional groups remaining. Each project manager reports to top management and contains its own appropriate set of functional contributors. Some degree of functional staff may exist to coordinate among and train functional members across the projects. This type is similar to the type II organization which is broken down into divisions to address specific product lines or markets, except here the divisions are replaced by temporary project structures rather than ongoing business units. Such an organization might staff a project from scratch when a contract was obtained, or try to staff new projects from ones that are ending. It would provide little career continuity as project work phases in and out, and may have little focus on a coherent product or technology strategy.

Recently, organizations are tending toward a more flat, flexible structure to deal with rapidly evolving change. These “leaner and meaner” structures trim costs and speed communication by reducing middle management layers by up to 50% and numbers by up to two-thirds. The customer is brought as close to the development team as possible. Professionals are “empowered” with greater delegated authority and expected to perform more creative and dynamic roles in the pursuit of higher levels of quality and customer satisfaction. Accomplishing this change can be painful and disruptive, and can be helped by proactive emphasis on project management methods, product development process, norms for individual and organizational behaviors, and total quality management methods (Dinsmore 1993). The use of cross-functional teams give companies much added flexibility to organize and reorganize around shifting markets and segments.

5.2. Team Structures

Accelerated product development using a concurrent engineering approach makes much greater demands on cross-functional communication, because work often begins with relatively little up-front planning and transfers between functions that traditionally occurred between phases are lengthened into continuous interaction. Constant upstream and downstream flows of information are needed. Motivations of managers of functional groups or product divisions can hinder or cripple the process. This compels organizations to develop new structures that enhance the product development process, provide concentrated and continuous project communication, and reduce traditional barriers and disincentives.

Furthermore, some projects require extensive creative collaboration among the various contributors. Examples are projects that require fundamental technological innovation, combinations of technologies, or creative solutions to improve performance, customer acceptance, or costs. Collaboration is made more necessary in modern product development by the increasing depth of specialized knowledge, which means that no single person can master all the technical skills required. The fast pace of development and increasing competition makes further demands on creative problem-solving. Collaboration requires more than mere communication of information and coordination of activities; it requires collective creation of new information, a process that relies on shared environments (real and virtual) and interaction among collaborators in the presence of diverse kinds of models, including prototypes, mock-ups, sketches, computer simulations, theories, and linguistic metaphors (Schrage 1995).

Many authors have described various types of project team structures (Clark and Wheelwright 1993; Heisler 1994). Those most commonly found are variations of the following four:

5.2.1. Functional Team

In this approach, responsibility for a project is held by one function at a time. Work is managed by functional line managers, who make decisions unilaterally about the project. Once the phase is complete, the project is transferred between functions; for example, the design phase ends with an “engineering release” to manufacturing. Often, development is slowed by limited communication between upstream parties, such as design engineering, and downstream parties, such as production. Transfer is often not smooth due to lack of coordination between functions. But, the process can work for projects which are easily defined at the outset, have stable customer needs, require only incremental technology changes, and have little sense of urgency.

5.2.2. Lightweight Team

In this structure, the project manager serves as coordinator across various functions in a matrix structure, usually with little or no authority other than being an “internal customer” or “coordinator” (often referred to as “dotted line” reporting). Staff in the functional groups work on the project, but may interact with the project manager through a functional group liaison rather than directly. The project manager oversees, monitors, and documents progress, but has little power to make changes or reallocate resources. The functional mangers retain power over the people and the design choices, and communication is often just as circuitous as in the functional team structure (Clark and Wheelwright 1993). This is probably the most dangerous form of project structure in that the appearance of a project structure exists without the effectiveness of one (Smith and Reinertsen 1991). Responsibility and authority of the project manager are poorly matched.

5.2.3. Heavyweight Team

In heavyweight teams, the functional manager retains responsibility for “line management,” that is, for evaluation and long-term development of workers. The project manager controls all project issues, including design trade-offs, and directly interacts with the all the workers, not just a liaison. This team structure avoids much of the conflicts and ambiguity of the lightweight and functional team structures, and gives the project much more visibility and status in the organization. Interaction among the team is frequent and dynamic, and the team may be collocated with the project manager (Clark and Wheelwright 1993). Some firms attempt to find a “balanced matrix” structure between lightweight and heavyweight structures in order to enhance quality and serviceability across a product line. Unfortunately, it is difficult to manage because the multiple sources of authority may make decisions politically difficult and time-consuming. Upper management has to actively set priorities and provide support (Smith and Reinertsen 1991).

5.2.4. Autonomous Team or “Tiger Team”

This team structure is truly independent of functional management. Functional groups surrender resources to the project manager, who becomes the sole manager for each person during the duration of the project. The project manager can foster a more entrepreneurial environment among the team, establish norms, and set up team rewards and incentives. Members are fully accountable for the project results, and work full-time on it. Specialists may be added to the team on a part-time basis for various phases, but the majority of participants are full-time and stay with the project for most of its duration. This structure provides the best way to respond quickly to needs and to focus on accomplishment. An extreme of this form is a venture group, which can become a business unit spin-off.

One potential drawback of the autonomous team is that communication with other members of the same functional specializations is reduced. The project team may operate with little connection to the rest of the organization, possibly overlooking shared resources, materials, or expertise. The resulting products and processes, and even the team members themselves, may not integrate well with the rest of the organization upon completion. Products from different teams may risk incompatibilities or inconsistent user interfaces. A project team may tend to expand the scope of the project in their enthusiasm. The project manager must work with other project managers and senior management to create synergy among projects and to maintain connection with the parent organization and its goals. Success is highly dependent on quality of the project manager and the way senior management interacts with the team.

Cost effectiveness is also a factor. Projects that are routine and have small payoffs may neither need a strong project team approach or justify its expense. Career continuity may be a concern because team members will need to find new projects once the present one is complete. A culture that emphasizes the value of team members is essential if voluntary participation within teams is expected. Assurance of a successive, interesting project assignments and career development should be a central theme in human resource management.

5.2.5. Evolution of Organizational and Team Structure

Most larger firms resemble one of four types of organizational structures studied by Souder (Souder 1987), and use one or more of the team structures described by Clark and Wheelwright (Clark and Wheelwright 1993). But, small firms or start-ups can be seen as a “degenerate” case in which there is one product line and perhaps only one project. Small organizations are often committed to a single development project, and the above analysis does not apply. The environment is essentially that of a tiger team, with its small size, physical co-location, and commitment to a single activity. The firm’s newness allows extensive leeway to define performance evaluation and reward systems and to create procedures they believe most effective.

As start-up firms complete initial projects and begin to grow, the organization may change to one resembling a heavyweight team. Due to the small size, managers generally recognize the need to shift the balance of power back and forth between functional and project approaches. At some point, firms may face the need to develop multiple concurrent projects and support multiple product lines. If a firm is not acquired by a larger one, it may tend toward a functional structure, particularly if a large proportion of the projects are derivative or sustaining in nature. For such projects, the functional structure is comfortable and effective. But, those firms engaged in innovative product development may find the structure too slow, too costly, and not sufficiently customer-focused to compete with smaller organizations. Attempts to use a lightweight structure that end poorly may be followed by the more substantial step of implementing heavyweight structures. The continuum between lightweight and heavyweight approaches allows adjustment appropriate to the needs and pace of any given project (Clark and Wheelwright 1993).

5.3. Success Rates for Various Structures

Souder (Souder 1987) studied organization and team structures used in innovative projects, including the methods described above, as well as others such as formal committees or initiatives led by individuals and dyads. He evaluated success rates for these structures (whether projects exceeded or met expectations) as a function of the market and technology environments and organizational dynamics, revealing the following insights:

5.3.1. Top-down Structure Led by Commercial Line Management

A top marketing person is responsible for the project life-cycle, and managed within the marketing line management structure. This approach was often not successful due to technical deficiencies in their designs. Poor communication with, and participation of, R&D personnel were often reported. Long wait times for decisions often distorted information flows. Those projects that required few technical inputs worked out well, however.

5.3.2. Top-down Structure Led by Technical Line Management

In this approach, R&D proposed, defined, and managed the project. Even lower success rates were found with this approach than with commercial line management, but for the opposite reason: lack of marketing involvement in defining customer expectations and product strategy. Those projects that were completed were shelved due to marketing indifference for the resulting product. In some cases, marketing did not understand how it might fit into the product line, or how it would help the customer. In several cases, performance did not even match that of existing products. Commonly, information as to the customer requirements was lacking, and, when tried, technical personnel did not succeed in gathering customer input.

5.3.3. New Product Departments

These efforts reported to division or corporate management, and were average performers. Comparing the subset that were well received with those that were not led to some suggestions for helping make such structures work. The successful ones were usually led by technically trained and experienced people from R&D. Also, the leaders often were radical thinkers and change agents within their firms with many underground partnerships that spanned the organization. These leaders had high power and stature, and were familiar with their end markets and customer needs. Leaders often visited customers together with R&D and marketing. In some cases, this caused conflicts with sales personnel for those accounts because upcoming products were seen as discouraging current product sales. Conflict resolution was important given the power sharing and cooperation necessary to make this approach work.

5.3.4. New Ventures Departments

These did not perform very well, despite other empirical evidence that these structures can be highly effective. Data from the study showed that most projects suffered from being either too small or too big. Small ones did not get enough attention and were assumed by division managers to be well in hand within their own organization. Even if top management believed strongly in the project, they had trouble overriding the other managers' objections when trying to allocate budget and resources. On the other hand, big new venture projects were viewed as too risky, large, and uncertain. These often involved significant departures from firms’ core technologies or pushed into unknown market areas. Despite the fact that risk taking is the reason for founding new ventures departments, managers were unwilling to accept such risks when faced with them. It was difficult to watch the negative cash flow, knowing that most new project ventures will fail anyway. This seems to contradict the earlier claim that new venture structures in type IV organizations performed well; but the type IV structures combined new ventures with project management and other highly effective methods, discussed below. Here, they are analyzed separately, revealing weaknesses specifically in the new ventures approach.

5.3.5. Project Teams with Commercial Project Manager

Projects that were managed by a commercially-trained manager had the highest success ratings. Project managers were appointed from the marketing department, such as a brand manager, product manager, area manager, or product planner. Their leadership was legitimized from top management, which is an influential factor in itself. Projects drew members from several departments, returning to their home departments when done. These marketing-based project managers caused the right things to happen within their organizations such as rallying support and raising visibility. Not only did they know the end markets and customers well, but they were technically competent and well-known to the R&D members of the team. They were tough minded and kept tight control of budget, but maintained a participative spirit. Personnel from all levels typically attended high-level meetings and visited customers. The commercial project managers were good people managers — they spread credit around, and openly resolved conflicts when they erupted.

5.3.6. Project Teams with Technical Project Manager

Project mangers drawn from Engineering had among the lowest success ratings, in contrast to marketing managers. The main reason was that marketing personnel did not feel involved when the project was led by an engineering manager and did not contribute. There was no joint agreement about how engineering and marketing might divide roles. Often, marketing was not involved in development of specifications, and they often rejected the completed project. Top management was not as involved in selecting and legitimizing the engineering manager as for the commercial manager case; rather, the source of the project idea often became the project manager with no official announcement, much less endorsement. Top management ultimately viewed R&D as having strayed from the intended project path or having taken tangents. The R&D teams had isolated themselves.

Souder argues that these results should not be interpreted as suggesting that the project leader should not be from R&D or engineering. Rather, an analysis of the successes among them indicates that technical managers need to be legitimization by top management, and need to have a personality profile more like the successful commercial project managers. The person should be able to motivate others, use tight control and yet not be aloof, be seen as tough but participative, and stay informed about customer needs. To have status across departments, the project manager must have support of top management, not just department management. Successful engineering project managers were typically 30-45 years old, with 5-12 years in a technical function and 4-10 years in marketing function. Often, they had worked for another firm, broadening their approach. The problem with some technical project managers was that they did not have the requisite managerial talents or enthusiasm for management.

Given the poor success rates on average for engineering project managers compared to the much higher rates of those with management skills and attitudes, a strong case is made for providing engineers with management training and for selecting those with a flair and background for project management. The data also underscores the need to stay close to the customer, to have good engineering-marketing cooperation, and to have top management endorsement of the leader.

5.3.7. New Product Committees

Projects that were created and guided by some variation of a standing committee or ad hoc task force were highly effective, comparable to the success rates of commercial project managers. These councils developed strategic plans, and coordinated efforts across department boundaries. They often contained top level managers, department managers, and R&D and marketing task force leaders, and met monthly plus more frequently when decisions were needed. Membership in the committee often changed as projects evolved. For example, an engineering task force leader replaced an R&D one later in the project to facilitate internal technology transfer. These structures were used mostly when a project was considered costly, risky, radical, or time consuming. They were also adopted when customers were resistant to the new technology or their wants were ill defined. Other reasons include project needs which were highly interdisciplinary or when failure was perceived as unacceptable.

These new product committees were used only on selected projects, and were cumbersome, effortful, and expensive. Failures were often big ones, due to expanded budgets intended to recoup delays, leading to overlapping roles and confusion due to addition of new people. Fractions can form in such committees, and decision making can exhibit conflict at multiple levels. Also reported were technical confusion, interpersonal upset, and lack of direction, leading to products not suitable for customer or with high warranty costs. The large structure made changes in course difficult, so response to problems or new information was sluggish.

5.3.8. Dyads and Counterparts

This describes scenarios in which two senior contributors work together to create promising ideas that earn senior management support. The contributors carry forward their proposals and see their careers as benefiting from management attention to the project. The examples in Souder’s database were not highly effective and suffered from a variety of problems. Often, the dyad members were too friendly to challenge each other’s ideas. The power of the dyad was not sufficient within the organization to engender buy-in and participation in all departments and levels needed. Typically, such projects were relatively small.

5.3.9. Commercial One-Man Shows

In these cases, an individual from marketing or sales proposes an idea and contracts with an outside firm or customer. This approach worked only when the technology and customers were familiar and the development effort was small. Often, the leader told the outside contractor exactly how to produce or develop the product. In successful cases, the leader was nearly always a known powerful force in the industry. Failure resulted when the end product was not well defined and needed more research, and where the customer needs were not well understood. So, such a person must have organizational power, command of significant resources, and the trust and esteem of customers if the project is to succeed, as well as a good understanding of customer needs and relevant technologies.

5.3.10. Technical One-Man Shows

In this case, the project principal is from R&D, engineering or another technical function. These projects were the least effective of all. Like the earlier case of technical line management, technical one-man shows did not have mechanisms for researching users needs and perspectives and placing products in the marketplace. Lacking marketing input, they produced products that often were too sophisticated for the customer, products that failed to perform, or no product at all. Successes were marked by top management commitment and by a principal who was a prominent technical expert, competent in business functions and marketing, and had a good understanding of users requirements and market dynamics.

5.3.11. Situational Application of Team Structures

The results of the 256 projects studied by Souder were summarized in terms of whether the technology, the market, or both were well understood, yielding some generalizations. Commercial project manager and new product committee structures were the only two to perform highly under a variety of conditions. Commercial line mgmt and commercial one-man shows only performed above average when the technology was understood. Technical line management and technical project manager only performed above average when market was well understood, but neither performed very highly. Thus, it appears that leaders must have the skills appropriate to the important unknowns of the project, and that commercial managers were more skilled at rallying functional contributors from within their organizations. New product and new venture structures only performed above average when both technology and market were well understood. But, project management teams and new product committee methods were better able to handle uncertainty, and were very effective and powerful under a variety of conditions (see Table 3).

Souder emphasized that, when both technology and market are poorly understood, it is not enough to assemble one team each to analyze these factors. Rather, they need to be the same team, "working together in a totally integrated fashion, combining their data, impressions, and perceptions." Synergism is the key to success. Because the more effective structures are also the more costly, the type of structure should be selected based on cost effectiveness. As the project scope expands, the structure can grow, finally settling into a less-powerful structure as the uncertainties are resolved. For example, a technical one-man show can evolve to commercial project manager structure, to new ventures mode, and finally to a commercial line manager mode.

Of course, a team structure must be consistent with the overall organizational structure and philosophy. Referring back to the parent organizational structures, we can see that the type III structure was a combination of project management, task force, and top down structures. The type IV structure included addition of the new ventures method. Both of these organizational structures are highly effective regarding innovation and project success. Management may find that existing functional staff do not have enough depth in multiple functions or the general management breadth or team experience to function well in a team structure, at least without significant training or job rotation (Clark and Wheelwright 1995).

Because of the power and flexibility of project team structures, either heavyweight matrix or autonomous “tiger team” structures, the rest of this paper will focus on management of such teams. The principles discussed will apply, for the most part, to other structures in which time-to-market and customer-centered designs are top priorities.

Table 3. Successful methods under four environmental conditions (adapted from Souder 1987). A question mark indicates that many other factors must be present for success, as discussed in the text.)

Project Structure:	Market and technology well understood	Market well understood	Technology well understood	Neither well understood
Commercial Project Manager	•	•	•	•
New Product Committee	•	•	•	•
Dyads and Counterparts	•	•	•	•
Technical Project Manager	•	•		
Technical Line Management		•		
Commercial Line Management	•		•	
New Products Department	•			
New Ventures Department	•			
Commercial One-Man Show	?		?	

6. LEADING DEVELOPMENT TEAMS

Rapid product development increasingly makes use of teams. In various projects and organizations, these teams may be more or less cross functional, and more or less dominant compared to the power of functional groups. Nonetheless, the way a team is founded, organized, and led can have a profound influence, particularly on those aspects of a project that require creative collaboration. Many new project managers, particularly those from engineering backgrounds, may view teams as merely an assembly of contributors without recognizing the synergies and sensitivities of teamwork, or may dread "people management" issues and the need to learn "soft skills." These skills are not as subjective or vague as they may first appear, and can be learned. This chapter outlines some aspects of forming and managing teams that can be critical in accelerated product development but are not typically addressed by conventional project management training.

6.1. Project Manager responsibilities

A project manager, in the traditional sequential project framework, has responsibilities that are well delineated. These include defining the project scope; creating some sort of work breakdown structure, schedule, and budget; and, coordinating, monitoring, and controlling execution of the project phases. In the context of rapid new product development for a competitive market, some roles are de-emphasized and others become more important. The project manager becomes less of a coordinator and monitor, and more of an initiator and participant. Because of rapid change and the limited amount of information held by the project group at initiation, boundary management is a primary responsibility. Facets of the job include product champion, technical generalist, entrepreneur, leader, catalyst, facilitator, mentor, supervisor, politician, and protector. In both the traditional and newer roles, a tremendous amount of situational judgement and flexibility is needed.

6.1.1. From Engineer to Manager

Many firms maintain separate career paths for engineering and management. In the author's work experience at NASA/JPL and two medical device firms, this separation was present to varying degrees, and pay curves for each track were comparable. Senior engineers earn about the same as project managers and enjoy relatively less stress, visibility, and demand on their time. Hours may be shorter and control of one's work and environment is greater. Pay for a "technical fellow" or top-level technical contributor was comparable to line management. This split in career paths has the effect of delaying acquisition of management skills by engineers until their success in leading technical tasks eventually lands them in management roles. The step from engineer to manager is a big one, and many engineers feel little incentive.

Often, engineers find the adjustment painful, as many old habits must be broken. New management knowledge must be gained, new perspectives must be adopted, and new motivations and rewards must be found. The prospective manager must be willing to give up the relatively solitary and clearly-bounded life of an individual contributor and the security of having an identity as a technical specialist or expert. The demands of old projects may continue to distract one from day-to-day management activities (Dinsmore 1993). Project managers must be generalists in terms of technology, and cannot be “loners” but must deliberately inject themselves into the work of others. The focus is on people, not things, and on authority, not expertise. Management requires the enjoyment of leadership challenges, detailed planning, staffing, helping others, taking risks, making decisions, accomplishing through the work of others, and using the organization.

In some ways, these roles seem at odds with the habits and perspectives of an engineer. Engineers tend to avoid bureaucracy of an organization in order to focus on his or her work. But, managers must work through the organization’s policies and procedures and be responsible for creating and improving them. Engineers strive to minimize risks, relying on mathematical precision and accuracy. Managers take calculated risks, relying heavily on intuition and business judgement. While an engineer applies established scientific methods based on reproducible results, managers must make decisions under varying conditions and based on limited information. One must learn to give up control to the team and become even more involved with them, yet stand accountable for their result. Solving technical problems based on one’s individual skills is replaced by solving business problems based on the integrated talents and behaviors of others. A project manager succeeds through his ability to catalyze the activities of others rather than one’s own abilities (Shtub et al. 1994).

6.1.2. Traditional Project Manager Responsibilities

According to the Project Management Institute (Duncan 1996), project management is "the application of knowledge, skills, tools, and techniques to project activities in order to meet or exceed stakeholder needs and expectations from a project. Meeting or exceeding stakeholder needs and expectations invariably involves balancing competing demands among: scope, time, cost, and quality; stakeholders with differing needs and expectations; identified requirements (needs) and unidentified requirements (expectations)." They also distinguish a second term, "management by projects," which refers to the application of project management methods to aspects of ongoing operations. This aspect of project management — application of methods to general management practice — represents a rapidly growing aspect of project management in organizations. Project management skill sets are becoming more common and even expected (Dinsmore 1996).

The responsibilities and methods of project management are usually broken down in one of two ways. The first is according to the aspect of the project managed:

Integration Management: Project plan development, project plan execution, and overall change control. Tools include policies and procedures, design reviews, drawing and sketch control, documentation control, and project planning and resource management tools listed below.

Scope Management: The processes required to ensure that the project includes all the work required, and only the work required, to complete the project successfully.

Consists of initiation, scope planning, scope definition, scope verification, and scope change control. Tools include statement of work, requirements and specifications documents, technical scope description, work breakdown structure, master project schedule.

Time Management: Ensure timely completion of the project. Consists of activity definition, activity sequencing, activity duration estimating, schedule development, and schedule control. Tools include PERT/CPM network diagrams, stochastic or parametric techniques, linear programming, hammock activities, Gantt charts, master project schedule, milestone tracking.

Cost Management: Ensure that the project is completed within the approved budget. Consists of resource planning, cost estimating, cost budgeting, and cost control. Tools include economic evaluation methods (such as equivalent worth methods, break-even analysis, and utility theory), top-down and bottom-up budgets, iterative budgeting, slack management, crashing, and PERT/Cost.

Quality Management: Ensure that the project will satisfy the needs for which it was undertaken. Consists of quality planning, quality assurance, and quality control. Tools include quality function deployment, quality standards certifications, robust designs, statistical process controls, failure mode and effects analysis, acceptance plans, designed experiments, total quality management.

Human Resource Management: Make the most effective use of the people involved with the project. Consists of organizational planning, staff acquisition, and team development. Tools include organizational breakdown structure, work breakdown structure, resource allocation subject to constraints, resource leveling, linear responsibility chart, facilities and space requirements.

Communications Management: Ensure timely and appropriate generation, collection, dissemination, storage, and ultimate disposition of project information. Consists of communications planning, information distribution, performance reporting, and administrative closure. Tools include computer information systems, intranets, email, groupware, document distribution lists.

Risk Management: Identifying, analyzing, and responding to project risk. Consists of risk identification, risk quantification, risk response development, and risk response control.

Procurement Management: Acquire goods and services from outside the performing organization. Consists of procurement planning, solicitation planning, solicitation, source selection, contract administration, and contract close-out (Duncan 1996; Shtub, Bard, and Globerson 1994).

Some texts emphasize the “triple constraint” of performance specification, project schedule, and project budget as a focus of management attention (Rosenau 1981). For example, a desired increase in product performance (or response to a performance problem) will impose an additional cost or delay or both. A desire to speed up the project (or response to a slip) can be accomplished by reduction of performance specifications or allocation of additional funding, or both. Cost overruns can sometimes be compensated for by performance reductions. In the planning stage of the project, an over-optimistic or unrealistic plan may cause cost and schedule overruns unless performance reductions are accepted. One story from the author's work at NASA exemplifies this. A huge cost overrun went undetected by project management for many months. Upon discovery, the project manager requested additional funds from the sponsor at NASA headquarters, who responded by cutting the scope of the flight hardware by half, removing one of two experiment modules that were to fly aboard the space shuttle.

Missing from most discussions of the triple constraint is any recognition of the cost of delays in terms of shortened product life, and reduced market share and cumulative returns. Most texts focus on systems for which development cost is the primary constraint, and concern for schedule overruns typically focuses on the increase in expenses from extending the development schedule or missing a target deployment date.

Often, project management is taught by spelling out responsibilities for each phase over the project life-cycle. Or, the flow of management activities may be used as a structure to discuss responsibilities:

Scope the Project: State the problem / opportunity, establish the project goal, define objectives, identify success criteria, list assumptions, risks, and obstacles.

Develop Detailed Plan: Identify project activities, estimate activity durations, determine resource requirements, construct and analyze the project network, prepare the plan / proposal.

Launch the Plan: Recruit and organize the project team, establish operating rules, plan and level the work packages, schedule and level project resources, document the project plans.

Monitor and Control Progress: Establish progress reporting system, install change control tools and process, define conflict resolution and problem escalation process, monitor project progress against the plan, revise project plan.

Close Out the Project: Obtain customer acceptance, provide deliverables, complete documentation, complete post-implementation audit, issue final report (Wysocki et al. 1995).

Other responsibilities (particularly relevant to construction projects) include contract administration, safety, regulatory compliance, environmental compliance, public relations, site operations, labor relations, housing, automotive equipment, and security (Heisler 1994).

6.1.3. Additional Responsibilities in Product Development

The above breakouts of project manager responsibilities reflect both the framework of systems and tools for coordinating widespread activities and the presumptions that underlies the framework. The emphasis is clearly on efficient use of budget and resources against a comprehensive initial plan prepared with the approval of a specific customer or sponsor.

The rest of this section suggests many roles and responsibilities particular to product development projects for which rapid development and competitive markets are primary factors. One place to look for guidance is to question in what ways product development projects stumble. Investigating the problem of late market introduction, Gupta and Wilemon surveyed managers in the product development organizations of 12 large technology-based firms, and identified five main causes for delays (Gupta and Wilemon 1990):

1. Poor product definition (71%). This includes poor understanding of consumer requirements, and insufficient knowledge of the technology and market forces such as competitors, suppliers, and distributors. These led to frequent changes. Poor cross-functional relations contributed significantly to the difficulty in defining requirements and agreeing on specifications. This suggests the need for early integration of R&D, engineering, manufacturing, marketing, suppliers, and the customer to help achieve clarity before too much time has passed and opinions have been formed.
2. Technology uncertainties (58%). Delays often allowed enough time for new technologies to become available, leading to creeping elegance and further delays. Other uncertainties related to compatibility with existing components, impact of new technologies on strategies for incremental

improvements, uncertain benefits to marketability, questions about ensuring quality and reliability, and unknown time needed to develop or acquire the technology.

3. Lack of top management support (42%). Problems included low priority given to development projects, unrealistic expectations, short-term orientation, risk-aversion, lack of strategy, and lack of learning from past failures. Senior management attitudes about new product development and innovation were often at the source, and issues cited included lack of common vision, lack of project support by top management, and overburdened resources due to lack of prioritization. Possibly related to lack of top management support is the difficulty of assessing market potential, reported as the most difficult activity; if potential is uncertain, managers may find new product development too risky.

4. Lack of resources committed to new product development (42%). Part of the problem was lack of genuine senior management support for innovation. Assignment of inexperienced people was another.

5. Poor project management (29%). Failure to monitor progress, lack of control systems, poor team and cross-functional meeting management practices, complex matrix structures, and undefined or conflicting roles were cited. Some respondents reported their own resistance to controls, such as PERT or Gantt charts or to frequent management demonstrations. Some firms had

> committed to project management methods without obtaining buy-in from new product development personnel, leading to resistance. Tangible benefits were not made visible to them.

Management and organizational style was the number one frustration reported, reflecting a lack of willingness to take appropriate steps to facilitate innovation efforts. This included bureaucratic red tape, organizational inertia, risk-aversion, and conservative attitudes. Current products often consumed disproportionate amounts of time and resources. Organizations often did not have the right mix of people to carry out projects effectively. The second frustration commonly reported was lack of attention to details during product development, including poor market research, frequent and unnecessary changes in requirements, making decisions without forecasting their impacts, and inefficient use of resources. Examples typically focused on the product definition phase (Gupta and Wilemon 1990).

All of the above factors could be reduced by project manager leadership in the areas of early cross-functional involvement, customer orientation, innovative problem-solving, and commitment to development speed. In cases of risk-averse senior management failing to support projects, the project manager has the opportunity to sell them on the project and its benefits, acting as an internal entrepreneur.

A modern project manager in product development must be more rounded than a traditional project manager. Product development is a multi-faceted problem that requires more than administration skills and detail orientation. It is a business endeavor that requires a breadth of skills in four major areas (Smith and Reinertsen 1991):

1. People leadership: The team is faced with a difficult and relatively undefined task, requiring the most out of everyone in the team and those helping elsewhere in the organization. Teams have a life and development cycle of their own, which benefits from a strong example and gentle guidance. Morale is likely to waver as organizational changes and product difficulties are encountered.
2. Vision: An overall product strategy and specific product concept involves leadership of an evolving collective vision. Ideally, an organization embraces visioning from the very top, including all levels in the creation of a firm's vision, mission statement, values, and beliefs. The product concept comes to life first in the vision of those charged with carrying it out. Knowledge of user needs, competing products, and the wider product strategy is critical. From this vision comes the ability to inspire the team and guide them through uncertainty and tough decisions. As we have seen from Souder's research, a manager from a commercial background is often much more successful than one from an engineering background because of better leadership of business issues and participation across the organization.
3. Technical understanding: A team manager is intimately involved with myriad trade-off decisions, many of which involve technical factors. Products

are increasingly dependent on combinations of advanced technologies, so technical problems and their solutions are likely to require in-depth knowledge. Technical competence scores highly among project success factors, and many projects are led by their concept originators.

4. Project Management: The ability to handle tremendous amounts of detail while setting priorities and breaking down activities into tasks and phases remains important to a team project manager, although relatively less compared to a traditional project. The traditional project management body of knowledge remains a source of valuable techniques, but which must be applied with an understanding of the needs of product development. The methodology of systems engineering is highly valuable in structuring the engineering tasks and providing checklists to assure all requirements throughout the product life cycle are addressed.

A project manager serves many roles that draw on and combine these skill sets. Some of the roles that fall outside traditional project management are outlined below.

6.1.3.1. General Manager

The modern project manager must have strong awareness of the business environment and objectives of the organization, and the relationship of the particular product to the overall product portfolio. He or she must have concern with profit/loss responsibility, create dynamic strategies to lower costs, improve quality, collapse schedules, and gain market share and customer retention via a portfolio of successive, overlapping product releases, all in the face of growing competition committed to doing the same and who compete for skilled workers (Frame 1994). The project manager balances ideal technical approaches and the project scope against business deadlines and priorities, and works with financial management to understand financial implications of the project (Wysocki et al. 1995).

6.1.3.2. Intrapreneur and Change Agent

Implementing this general manager’s perspective does not come from structure-driven traditional project management, but by the ability to cut through bureaucracy, redesign business processes, and create and lead evolution of a dynamic organization consisting of creative, communicative knowledge-workers (Souder 1987). New policies and operating procedures must be authored and old ones modified or eliminated. Organizational competencies must be developed, including the development process itself, new process technologies, and functional coordination among marketing, manufacturing, and engineering. All this must be managed the midst of downsizing and flattening of organizations, transformation of job definitions, increased use of outsourcing, and development and implementation of quality systems. The project manager becomes an internal entrepreneur, taking initiative to lead organizational change and build support for new and perhaps risky proposals.

In innovative organizations, upper management may deliberately foster intrapreneurs by providing enough autonomy, authority, and financial discretion to an idea proposer to perform the first phase of an investigation. If it succeeds, the intrapreneur’s autonomy can gradually be extended. Each phase is accompanied by extending license to the intrapreneur. This bounded autonomy may be further supported by other “angels” within the organization that can provide support by way of funds, equipment, or manpower. The intrapreneur is free to combine these creatively to give birth to new projects (Souder 1987).

Greater creativity is needed to develop novel products that respond to increasing customer expectations. As institutions and traditions fall, people live in new ways and have evolving expectations and needs. New market niches arise and evolve. Competitors leapfrog each other, and project requirements at mid-project do not match those at beginning (Frame 1994). Project managers must be alert to these changes and creative in developing solutions or extracting them from the team process.

6.1.3.3. Product Champion

Accelerating development means that the fuzzy front end of a project has to be shortened, and a project often begins without a clear definition of the product concept. Rapidly evolving market and customer information means that the product concept develops on-the-fly. The project manager can carry the flag of the evolving concept, harnessing input and opposition to further sharpen the concept even after work on long high-risk and lead-time items has begun. Of critical importance are the project boundaries — the project’s mission, business purpose, and scope. A product champion preaches the product mission daily, making the product vision accessible to all, and rallies the entire organization to its development.

In addition to representing the product, the project manager also is ambassador for the team, representing its commitment, its capabilities, and its needs throughout the organization.

Leadership from a product champion is the key to distinctive products with integrity. Product champions focus the organization on customer satisfaction and devise processes, formal and informal, for channeling this into product concepts, designs, and production methods. Having been deeply involved themselves in generating product concepts, they then serve as guardians of them, talking to engineers, integrating details, keeping the concept fresh in people's minds (Clark and Wheelwright 1995). The project manager must be skilled at persuasion and be credible to management and workers of the parent organization.

6.1.3.4. Leader

Project managers are not mere implementers, but are initiators. They lead the drive toward customer satisfaction, managing risk and complexity, coping with issues of empowerment and communication within an organization while managing external contractors (Frame 1994). Heavyweight project managers are hands-on examples of cross-functional integration and are deeply involved in product design and optimization decisions. They know that product concepts cannot be refined and communicated by written documents alone. Project managers take the lead in customer involvement and participation with marketing to gather all the research and feedback needed to assure quality. They work with production to make sure that all opportunities for upstream input have been leveraged. They talk to engineers, assemblers, technicians, and testers to strengthen communication and demonstrate the importance of each role to the overall project (Clark and Wheelwright 1995). The leader draws the best contributions from the team members.

Team leadership is of primary importance in starting on the right foot, and starting quickly. A new project may call for a new type of team structure and management style. Flexibility in management style is needed depending on the situation and the participants. The project manager sets the initial tone for team culture, behavior norms, and communication modes. Creation of these team fundamentals is most successful when sourced from the team members themselves, and alignment is reached as a team. The same applies to any measures of team performance that may be used for tracking progress, calculating incentive compensation, and deciding individual and group awards for cost-saving or quality-enhancing contributions (Clark and Wheelwright 1993).

6.1.3.5. Supervisor

As functional line management recedes in importance, the project manager becomes the primary personnel supervisor. One drawback of projectized organizations is that technical specialists may feel insecure in their careers or cut off from functional mentors. Career development responsibility falls to the project manager, as does definition of incentives and rewards. The project manager must find ways to build motivation and urgency, while at the same time managing stress levels. He or she serves as coach to team members in building their careers and finding their roles in the organization and team. If the concept of empowerment is to succeed, that is, if delegation of additional roles and responsibilities to the team is to have the desired effect of faster decisions and better quality, then the team must also receive the information and training they need to get the job done. The project manager can authorize rotation among other functional roles (such as an engineer spending a month in residence at manufacturing), conference travel, in-house training, professional courses, and trade association participation. Hiring and performance reviews should be based on a consistent set of dimensions.

6.1.3.6. Technical Scout and Strategist

Rapid technological change quickly renders technical knowledge and information systems obsolete or inadequate. Decision points come long before adequate information can be obtained, so we must steer as we proceed rather than aim and fire. The project manager scouts for developments outside the organization, marshals internal specialists and external sources to assess technologies and develop the necessary computational tools and equipment. Tools include expert systems, decision support systems, and intelligent agents. Also, team members in various specializations are charged with keeping abreast of relevant technologies and maintaining contacts with experts outside the company.

Decisions about product architecture are increasingly important to speeding development of present and future releases, such as use of modular components, reusable components, and miniaturization. To produce a product that is truly user-friendly requires increased complexity in development in design. Complexity should be hidden in the software and technical sophistication, leaving a simple user interface. The project manager takes the lead in developing alternative architectures, defining the criteria for deciding among them (Smith and Reinertsen 1991), and providing trade-off analysis skills and tools (Shtub et al. 1994).

6.1.3.7. Protector and Politician

Support from upper management is critical in project success. Project managers can make this partnership succeed or fail by representing the project to upper management and making sure that it receives the right amount of attention — not too much or too little. As we have seen, too much management attention, or of the wrong type or at the wrong time, can slow progress. The project manager both provides a communication link to upper management and serves to buffer and protect the team from distractions and political disturbances.

The project manager promotes interactions and alliances among the various functional and senior managers, utilizing both formal and informal networks to influence and lobby. Various sources of funds may be found within an organization during financial lean periods and keep it going when official support is at a low point.

6.1.3.8. Mediator/Facilitator

Conflict resolution becomes critical in teams and cross-functional relationships. Issues that are not resolved early and at the lowest levels possible can fester into serious political struggles and roadblocks. Project managers also serve as facilitator of numerous meetings within the team and in various other settings. Leadership in meetings sets the tone and provides examples of expected behaviors such as cross-functional respect and concern with the project mission and organizational objectives rather than empire building. The project manager seeks out and mediates among various formal and informal roles outside the team, finding assistance wherever available from technical experts, idea creators, and idea carriers. One important such role is that of “angel” that can shoulder risk among upper management and provide official sanction or informal clout, and help the project find an official place in the organization.

Project managers have mixed feelings about their roles, particularly if they are moving out of a more stable and comfortable role as senior engineer or line manager. The project manager is a focus of pressure from all sides and subject to high expectations. Former line mangers find the number of subordinates is smaller and authority is significantly reduced, particularly for matrix organizations with strong functional managers. Former engineers find the duties excessive and without clear criteria for success. Financial rewards may be no more than in easier roles, while the personal visibility and risk are much greater. Inadequate breadth of technical competence can lead to problems if the manager does not find ways to provide scrutiny of and feedback for the efforts of particularly specialized team members. Project managers have limited control over their teams, and must carefully evaluate how to balance trust with prudence and supervision. Picking top performers for the core group with the right technical skills and a team track record is critical (Clark and Wheelwright 1993).

6.2. Team Formation

The evidence suggests that heavyweight or autonomous teams managed in the above manner can bring significantly improved development. Advantages include improved communication, stronger identification with and commitment to the project, and a setting for rich cross-functional problem solving (Clark and Wheelwright 1993). But, there is more behind the effective performance of teams than simply selecting a leader and picking some members. And, there are drawbacks to be aware of.

For example, the sense of ownership and commitment can also lead to pursuit of tangents or expansion of scope. It can also lead to a sense of self-importance compared to which the rest of the organization is "second class." Support activities, for which full-time resources may not be assigned, are particularly susceptible to conflicts should the team feel it is entitled to first priority access to these resources or to a commensurate level of commitment from them.

A working definition is offered by Clark and Wheelwright (Clark and Wheelwright 1995): "A team is a small number of people with complementary skills who are committed to a common purpose, set of performance goals, and approach for which they hold themselves mutually accountable." Teams differ from other types of working groups in that a team emphasizes collective work product, while working groups compile individual contributions. Teams have mutual as well as individual accountability. Interaction is thus more intense as decisions are debated, and even the debate process of a team is determined jointly. The team comes to have a strong identity, direction, and momentum as a unity, which has positive and negative aspects. Challenges in managing teams center around how the team manages itself, how boundaries are set, and how upper management relates to the team.

6.2.1. Project Charter

One way to clarify the mission of a team is to define a specific, measurable charter. The charter sets broad performance objectives, and may be created by senior management before the team is selected. Joining the team implies acceptance of the charter. Wording of the charter may cover the product's market, the scope (whether it is next-generation platform or derivative, for example), the time-frame, and measures of success such as gross margins or cost reductions (Clark and Wheelwright 1993). The charter provides bounds on a territory within which the team is free to create solutions. The project manager works with upper management to make sure the group does not succumb to creeping elegance and let the project expand beyond the original scope, except by deliberate agreement.

6.2.2. Contract Book

The goal stated in the charter may be achieved by a plan documented in a contract book, created by the core team and project manager soon after they are designated. It may take many forms, and contains detailed work plans by which the team will conduct the project, estimates of resource requirements, and results that are intended. The contents are typically negotiated between the team and senior management, commonly culminating in signatures to signify acceptance. It may take one to several weeks to construct, and may be 25 – 100 pages long (Clark and Wheelwright 1993).

6.2.3. Staffing

Core teams usually contain one team member from each primary function of the organization, such as design engineering, marketing, quality assurance, manufacturing, finance, and human resources. These members individually provide functional contributions while collectively serving to manage each function under direction of the project manager. In addition to functional skills, core team members should be selected based on problem-solving and decision-making skills and interpersonal styles. Other participants often are assigned, and the numbers may change with time; for example, more design engineers may be assigned initially, with more from manufacturing later. Often a difficulty is how to manage the non-core members to fairly give rewards and status compared to the core team. A spirit of parity and equality is ideal, and rewards should at least be perceived as fair.

Care should be exercised in selecting core team members who are able to understand and act upon business issues, not just narrow functional concerns. Team members should have generalist skills in addition to the critical technical specialties. Ideally, the organization recruits volunteers, at least for the key functions of engineering, marketing, and manufacturing. This may be difficult, since projects involve longer hours and more visibility, unless the perceived rewards of team experience, freedom, and compensation outweigh the pain of added responsibility. Engineers asked to list preferences for their work environment rank teamwork in last place, and independence is third behind interesting work and salary. Most prefer working on their own ideas and on diversified tasks. So, working on a single project and getting it done on time is not especially appealing (Smith and Reinertsen 1991).

Teams operate best with about ten or fewer full-time members. Larger groups compound communication time and hinder the process of group alignment. The meeting burden becomes a full time chore in itself, and no one is able to get work done. Finding space and free time to meet is a problem. Large teams often have trouble creating more than a superficial alignment on purpose and structure. If the project is bigger than 10, cross-functional sub-teams of this size may be used (Smith and Reinertsen 1991). Clark and Wheelwright report a range of from 2 to 25 members among all the successful teams they have studied, and the majority were less than 10 (Clark and Wheelwright 1995).

Suppliers should be considered as potential team members, particularly for critical technologies in which the company does not have expertise. Early supplier involvement can provide a source of new technologies that may affect product formulation. A suppliers' representatives may participate in team meetings or visit a few days per month. Core team members can catch up to suppliers' knowledge by working closely with them. However, suppliers do not have the same motivations and organizational commitment, and they can be more reactive than employees if these differences are not respected.

The team may be collocated to help development of ownership and frequent communication, but this is often decided on a case-by-case basis depending, in part, on the relative benefits of team communication versus functional group communication (Clark and Wheelwright 1993). Firms with separate locations for design and manufacturing, for example, face a difficult balancing act, often resulting in the minority team members travelling to the majority location several days per week.

Typically, core members of one heavyweight team cannot also be members of another core team. Otherwise, dilution of focus and slowing of activities can result. In the extreme of autonomous teams, all core members are full time. In heavyweight teams, core members may also serve as contributors to other projects. However, full-time is recommended, because members tend to work first on the most pressing issue, on what is urgent rather than what is strategically important. Advocates of the dedicated team approach preach 100% involvement, but this is not frequently done in firms that have many concurrent projects at different phases. Personnel from quality are reliability are often on at least two teams, perhaps occupying two desks at different times of the week (Clark and Wheelwright 1993). Participation of manufacturing members, for example, may begin at a low level but ramp up as the project moves through the design phase, perhaps reaching only 30% for minor enhancements, or up to

100% for major platform projects. Process-intensive projects, such as disposable medical devices, require dedicated manufacturing support much earlier. The risk with part-time participation is that members may not be available when their inputs are most needed or not aware of developments in their absence.

Staffing a new team invariably goes too slowly, particularly if the organization is slow to identify and commit to a concept. Often, there is a backlog of work, and no one is available, which may particularly be a problem in manufacturing. At some point, it is necessary to cut off old responsibilities (Smith and Reinertsen 1991).

6.2.4. Initial Project Manager Roles

Among the first roles a project manager must attend to are:

- Provide the team with direct interpretation of the market and customer needs, including gathering of market data and analysis in conjunction with the marketing organization.
- Translate market information into terms understood by various functions. Early steps include generation of requirements definition document based on customer needs and translation into product specifications. The product architecture should receive careful attention due to the subtle and long-reaching impact it can have.
- Orchestrating, coordinating, and directing the various engineering sub-functions on a day-to-day basis, to ensure that their work is integrated and

mutually supporting. Of particular importance are initiating effective marketing-engineering linkages to ensure customer needs are optimally addressed, engineering-manufacturing linkages to verify that processes are developed jointly with designs, and relationships with providers of support services. Project managers should make sure that teams identify various sources of downstream input and upstream information. Important decisions include use of consultants, whether to bring capability in house, and make-versus-buy decisions.

- Staying in motion, conducting face-to-face sessions, and identifying and resolving potential conflicts at the earliest moment before they become chronic (Clark and Wheelwright 1993). Project managers can do much to enhance cross-project cooperation, inheritance of experience, and commonality of designs and processes, as well as coordination among projects that use common organizational resources.

6.2.5. Team Member Roles

Members of heavyweight or autonomous teams have responsibilities beyond their usual functional tasks and coordination of those tasks with other functions. They also help manage the team’s activities, including the list above, and share responsibility to ensure that commitments in the contract book are met. Shared leadership is fundamental to teams.

Like the project manager, team members should think like general managers. Bracketed by their overall mission and timeline, the team should reach its own consensus on interim milestones and schedules, and tries to beat the target timeline provided for them. The team structure itself and its mission are flexible to some degree, allowing the team to respond to changing markets, organizational issues, and technologies by creating alternatives and proposing changes to the initial project profile. Teams create internal structures and select sub-project leaders to focus their efforts in each phase of the project. Tasks must be continually redefined, subdivided, assigned to relevant team members, and coordinated, and results measured. Sub-project leaders often call working group meetings and at regular team meetings may present results and draw input from the wider team. The team process of goal setting, progress reporting, and maintaining project direction is everyone's responsibility. This process gives members more decision-making authority and autonomy to direct their own work and help others on the team do the same. Core team members often credit these new responsibilities as being important contributors to their career development, particularly their management skills, and to their enthusiasm and sense of contribution (Clark and Wheelwright 1993).

6.2.6. Launching the Team

Teams develop direction, momentum, and commitment by working to shape a meaningful purpose. Initial objectives usually comes from outside the team, but direction and purpose arise in the response to that challenge. Management is responsible for clarifying the charter, rationale, and performance goals for the team, but must leave enough room for them to develop their own initiative and interpretation of that purpose. Teams often spend much up-front time coming to grips with their assignment and forming their own process, culture, and approach to achieving it (Clark and Wheelwright 1995). This process may begin in a structured set of exercises, possibly during an intensive meeting or off-site retreat. A solid foundation might include:

- Vision and Values: This refers to a philosophical perspective on the intended future and the behavior guidelines that help steer the team. End-user orientation often figures prominently in the values, or patient benefits in the case of medical devices. Later decision-making finds a basis in this foundation.
- Mission: This defines what the team is supposed to focus on and accomplish, the business of the team. This may be a specific product concept or enhancement with performance goals defined by management, or it may have resulted from a product development process drawing upon the entire organization.
- Decision-making: Teams develop, either deliberately or accidentally, a process for making decisions, and team members tend to hold strong expectations that this process be followed. Often, greater commitment to the

project is accompanied by stronger feelings of entitlement to participation in decision making.

Consensus is often a desired principle, but in practice this can be slow, drawing out disagreements. Teams may rely on voting for some decisions, while others may be made by the project manager or senior manager.

The author’s work experience suggests that a more practical principle can be described by the term “alignment.” In this approach, all suggestions from the team are aired, but not all decisions are made by the group. A spectrum of decision-making processes (consensus, alignment, unilateral) is utilized, appropriate to the situation (discussed in a later section). Often, the choice is made by one or a few individuals who are best in a position to synthesize various inputs, assess buy-in of members, and formulate a single direction. Team members are asked to back this decision for purposes of speedy progress, even when they hold opposing opinions; in fact, their opposition is respected and utilized as a check on the aligned-upon decision.

- Norms: In addition to decision-making processes, norms are guides to behavior in the team setting, often on an unconscious level. Norms are the habits and expectations for team interactions, including showing mutual respect, full airing of issues and opinions, decision-making styles for various situations, encouragement to participate, negotiating styles, keeping of commitments, expectations of budgetary restraint, and having fun.

- Coordination: This describes how the team manages its boundaries, its "public relations" with management and other teams and functions. Individuals within the team take on roles such as scouting for information and technological developments, ambassadorial relationships with other functions and management, and task coordinators.
- Roles and Responsibilities: Who does what within the team is worked out initially based on functional skills, motivations, experience levels, and time availability, and evolves as the project proceeds.
- Goals, Milestones, and Action Plans: These are often done too soon, without the foundation of the prior steps. Consequently, the plans are not built upon adequate team inputs, good will, cooperation, and commitment, often leading to ineffectiveness and replanning (LaFargue 1999).

Team members often receive documented procedures and training to aid in their new roles. A product development process handbook is often provided that outlines the overall product development process, the stages of a project, roles within the organization, design review requirements, responsibilities, required training (such as FDA Good Manufacturing Practices), goal generation and documentation, and progress reporting. The team and project manager often negotiate specific procedures for the development phases, testing, and design reviews appropriate to the product concept. This keeps excessive requirements from slowing development and keeps the team from losing respect for management and the requirements they impose. The PDP handbook serves as a mechanism for continuous improvement of the product development process for the organization as a whole, as well as for keeping the team aligned on a single path and making use of the organizational resources and experience available (Hanson 1999).

Team performance depends on early establishment of direction in several respects. Members need to feel a sense of urgency and value in their purpose. Often, the greater the challenge, the better the performance; this relates to earlier results from Souder showing strong performance by teams responding to an external threat (Souder 1987). Initial meetings and first impressions can make a big difference in setting expectations for performance ethics and team behaviors. Early meetings should focus on providing a clear signal from management and the project manager regarding the specific project mission and expectations of the team. Rules for behavior should be established early and exemplified by managers and core team members. Defining a few immediate performance-oriented goals and tasks can set the team into early effective action and set a pattern for the future. Plenty of time spent together and early mutual accomplishments tend to solidify the team. Positive feedback, recognition, and reward are managerial approaches that greatly enhance performance (Clark and Wheelwright 1995).

6.3. Meetings

Since decision authority and project planning is distributed among the team, it is vital to keep everyone aware of project status and new information. Regular team meetings are a primary way to force everyone to think about progress and issues and to short-circuit misdirected activity. This may include many types of meetings: purpose-oriented meeting, sub-group meetings, cross-functional meetings, company-wide meetings, and management meetings. These are frequent, brief, and informal, with team information sharing and problem solving preferred over individual progress reports that may put people on the spot. Rather than focus on efficiency, team meetings encourage open-ended discussion and active problem solving.

For those meetings that call for team collaboration to create and evaluate new ideas, many techniques are recommended to keep people participating and interacting (Schrage 1995). Meetings are often staged around circular or rectangular tables to keep everyone facing each other. More than about 12 people can be too much if participation of everyone is desired. The project manager often serves more as facilitator to encourage participation than as a leader to control the process. Too much direction from the project manager, or even control of computer augmentation or scribe duties, can suppress participation; the manager may be seen as judge and jury rather than participant. In brainstorming sessions, it is useful to have a neutral party as facilitator for the same reason. Agendas are commonly recommended, but in practice they are not often provided or used. Conditions often change, rendering a pre-defined agenda obsolete as developments dominate the discussion. A close-working team usually knows what needs to be done, and an agenda declared by an authority figure might discourage initiative and participation. Agendas should avoid allocating time to specific topics, but rather to processes, such as “for 15 minutes, we’ll discuss criteria, then for 20 we’ll list ideas, then we’ll connect the ideas for another 15, then debate them for 20 minutes.”

Meetings to develop project schedules often benefit from participation. Planning often requires team input first to map out the objectives and then to discuss what it will take to meet objectives. The group process also serves to remind members how interdependent they are. This encourages communication of relevant details and identification of timesaving measures. The entire team becomes aware of the schedule as a whole and focuses on the critical junctures (typically, the major merge and burst nodes of the network diagram). Using software to plan the project schedule makes for easier evaluation of what-if alternatives, encouraging such speculations. One drawback of scheduling during meetings is that people may be hesitant to commit publicly to a timeline (Schrage 1995). The manager may sometimes prefer to meet with sub-groups for this. The manager may have to watch out for members who pad their schedules, or who commit to a tight timeline due to peer pressure.

Electronic communication such as email may be used to supplement, but not to replace, verbal communication. Although Email and document networks may help link teams in disparate locations, they suffer from the same drawbacks of any written medium — time may be wasted by going into unnecessary detail, and positions may be solidified by the act of describing them in writing. The face-to-face process of questioning and speculating, so important to plumbing new problems or creating novel solutions, is not present.

6.4. Group Decision Making Methods

One principle benefit of teams is that cross-functional expertise is brought to bear intensively and continuously. Decision authority in teams is much more distributed among the members than in functional organizations with a clear hierarchy of authority and expertise. The advantages of team decision making include a greater accumulation of knowledge and facts, broader perspective, identification of more alternatives and factors, and greater acceptance of a decision when it is made.

However, group decisions are often slow, and over reliance on the team for decisions will prevent quick and decisive decisions. When speed is of the essence, discussion may have to be cut short, which can cause conflicts. Compromises among the team may result in less-than-optimal decisions. Some team members or cliques may dominate the process, both negating some virtues of group decision making and discouraging participation and acceptance of other members.

The process of making decisions in a team is often a source of much frustration within teams. If too many decisions are made by management, team members may feel neglected, helpless, and lose motivation to participate. If group decision making becomes the norm, many decisions may become bogged down or lead to lasting conflict among the members.

How is a project manager to choose which decisions are best made by the group, and then to lead the process? It would be beyond the scope of this paper to go into group decision-making process in detail. Yet, some basic principles are worth addressing given the importance of teamwork in product development. New project managers often find group process to be the most troublesome aspect of their jobs.

Research suggests that group participation in decision making can be very beneficial in some stages of the process as opposed to others:

- In *establishing objectives,* groups are typically superior to individuals due to greater cumulative knowledge.
- In *identifying alternatives,* individual efforts are important to ensure that different and perhaps unique solutions are identified from various functional areas that can later be considered by the group.
- In *evaluating alternatives,* group judgement is often superior to individual judgement because of the wider range of viewpoints.
- In *choosing alternatives,* involving the group often leads to greater acceptance of the decision.
- In *implementing the decision,* individual responsibility is generally superior to group responsibility in carrying out decisions (Steers 1994).

The project manager is therefore faced with evaluating which phases of a decision making process should involve group participation. The tendency in leading teams is to avoid top-down decisions except where management perspectives or timeliness is paramount. It is often difficult for a project manager to resist making top-down decisions. But, decisions by group process can result in better attainment of goals as well as individual satisfaction and acceptance. Group decisions result in improved understanding by members of relevant organizational contingencies and of what is expected of them, increases their sense of control, and makes it more likely that members will be working toward outcomes and rewards they value.

These benefits often result even when the process is chaotic. One recent model describes many group decision processes as "organized anarchies." The so-called "garbage can model" describes decisions made under high uncertainty, such as unclear or disputed problems, alternatives, preferences, technologies, and solutions. Participation in described as fluid, with members coming and going in accordance with their time and interest. The model is named to suggest the random mix of problems, solutions, participants, and opportunities that, depending on timing, may result in a quality decision (Steers 1994).

Group decision-making procedures have been the focus of a growing body of literature. Various techniques for group decision making have been forwarded, each with its own strengths, weaknesses, similarities, differences, and situations in which they are applicable or effective. Adoption of any specific technique can bring specific weakness and pitfalls inherent in that technique. Rather than recommend a single approach, the following outline is offered of a few techniques and underlying factors to highlight some of the considerations and dynamics.

Norman R.F. Maier (Maier 1963) was one of the earliest researchers of group process, pointing out the improvements that could be made by including participation of workers in democratic decision-making. His studies and experiments focused on the aspects of (1) solution quality, and (2) solution acceptance by the group. Although his approach focused largely on groups directed by an authority, rather than empowered teams, his conceptual framework still applies:

1. Choosing the objective or problem to be solved. The most important step is identifying the problem. The symptoms of problems are much more apparent than the sources. The group must clearly analyze the foundational problem and define it.

2. Formulating the problem for group discussion. An accurate opening statement of the problem reduces ambiguity and helps to specify objectives. Framing the problem in a compelling way can motivate enthusiastic participation. Two rules in this respect are important: The leader needs to avoid statements that imply criticism or threat, and should avoid statements that imply a preconceived solution to the problem.

3. Exchanging and developing ideas. It is the leader's intent to have the group discuss freely. This means that he or she must stop talking after posing or clarifying the topic and seek responses from each individual.

4. Selecting a solution. After the group has listed a number of alternative solutions on the blackboard, and can no longer respond when asked for more ideas, it is then appropriate for the group to proceed with evaluating, consolidating, and organizing the proposals.
5. Follow-up. The solution is implemented and results are observed. Problems can be reopened and analyzed in a continuation of the process.

Maier's body of work focused extensively on the types of leadership needed, depending on the needs for high acceptance or high quality in the decision outcome. Leadership may be directed (1) toward persuasion approaches, in order to gain the needed acceptance, or (2) toward open discussion where group interaction is needed to achieve high quality, or toward both, depending on the needs of the particular decision. Those that require both require great managerial skill (Maier 1964). These points foreshadow the “situational leadership” techniques later popularized by Vroom and taught in many organizations. Maier developed a number of useful principles for leaders of group problem solving, including:

- Available facts should be used even when they are inadequate.
- The starting point of a problem is richest in solution possibilities.
- Problem mindedness should be increased while solution mindedness is delayed. Do not move too rapidly to the solution. The atmosphere of

selecting choices or alternatives must be delayed in favor of exploring the problem.

- The "idea getting" process should be separated from the "idea valuation" process because the latter inhibits the former.
- Disagreement can lead either to hard feelings or to innovation, depending on the discussion leadership. The leader of the group must create a climate where disagreement is encouraged, and use his position in the group to protect minority individuals.
- Groups have a tendency to focus on the first solution; the problem evaluation process should be prolonged. Studies reveal that a second solution to a problem actually tends to be superior in quality to the first.
- Solutions suggested by the leader are improperly evaluated, due to position power. To illustrate this point, a study has shown that when a discussion leader did not have a chance to study a problem beforehand, the results were superior.

One theory of participation in decision making is based on a long-term research project by Vroom, Yetton, and Jago (Steers 1994). They forward a model called the “normative theory of leadership and decision making” which can be used to recommend on the extent of participation and type of management for various situations. Management style is viewed as flexible according to the situation, ranging from autocratic (manager makes the decision alone) to consultative (group discusses and makes the decision). One intermediate style, for example, calls for group discussion followed by a decision by the manager; another suggests meeting as dyads, not as a group, before making a decision.

In the normative theory, the decision being sought is first evaluated in terms of the need for decision quality, acceptance among the group, and timeliness of reaching a decision. The model provides a decision tree for selecting one of five management styles based on the decision quality desired, problem structure, congruence of goal among the team, conflict among the team, commitment required, and amount of information possessed by the team or manager. The model is meant as a training device to show how leadership style can be adapted to various situations, rather than as a process to apply when decisions are needed (Steers 1994).

In general, there are two types of formats for conducting group decision-making: live sessions and some form of written correspondence. Some procedures for group decision making include elements of both formats. The following are some common group decision-making procedures:

6.4.1. Ordinary Group Procedure

The Ordinary Group Procedure represents the most common type of decision-making meeting, a relatively unstructured process. A group is called together, the problem is presented and members are asked for their comments and discussion. These meetings tend to be open ended and free flowing, and the only control may come from occasionally following Robert's Rules of Order. Few alternative ideas are suggested, and often the first satisfactory idea is chosen. Discussions can become long and fatiguing, and any solution can seem acceptable. Only if the group is already a team, working well together, and the members know and respect one another, will this technique yield quality decisions.

6.4.2. Brainstorming

Brainstorming is usually chosen when a group needs to generate solutions to a difficult or multi-dimensional problem, and acceptance is a factor. It is intended to increase the number of good ideas by building on the ideas of others, while minimizing the negative effects of interaction. No attempt is made at first to evaluate the quality of the ideas generated. Members are encouraged to build on other's ideas. These meetings tend to be fun, members feel like they've accomplished something, which can build camaraderie. But, research indicates that these sessions are not as productive as previously thought. More ideas can actually be generated by these same individuals working alone (Taylor, Berry, and Block 1958).

There are four basic rules for brainstorming sessions:

- Criticism is not allowed. Evaluation of ideas, positive or negative, is withheld.
- Freewheeling is welcomed - the wilder the better.
- Quantity is encouraged - the more ideas, the better.

- Combinations and building on others' ideas is encouraged.

In the brainstorming process, all members ideas are recorded, one at a time, on a flip chart or board so all members can see the list as it evolves. Typical brainstorming sessions last 30 to 40 minutes. This is nearly always more time than the group requires to exhaust themselves of ideas. Only clarifying questions are allowed during the session to ensure everyone present understands the idea. No questions or comments are allowed that criticize, evaluate or even compliment the idea.

However, these rules do not fully remove peer pressure and self-censorship. Assertive members can still dominate the session, and some members may not participate. Much time is wasted recording poor ideas. And, research shows that brainstorming in groups leads to lower productivity as compared to the combined productivity of a similar number of people working in isolation. Experiments showed nominal groups (a set of people whose individual work was gathered together after the fact) produced nearly twice as many different ideas as groups who met to brainstorm together (Diehl and Strebe 1987).

Many experimenters since have tried to identify why there is this loss of productivity when brainstorming in groups. Diehl and Strebe proposed three mechanisms for the loss in productivity:

Production Blocking is caused by the rule that only one member can speak at one time. This blocks others from speaking, reducing the time they have to speak, and potentially causing them to forget their ideas or to suppress them because they seem less relevant or less original at a later time. Time constraints were determined not to be a factor, but the inability to speak (waiting for others) was confirmed to have a detrimental effect on the quality and quantity of ideas produced by the group.

Evaluation Apprehension is the fear of negative evaluations from other group members, particularly when it is perceived that experts were present. When facing a highly controversial topic, members tended to self-censure which resulted in a significant drop in idea productivity. One technique that helps avoid this is to break the group up into smaller subgroups according to perceived level of expertise or stature, and each subgroup can discuss ways to contribute to the problem from their own area of knowledge.

Free Riding. Since members know that their ideas will be pooled, they assume others will propose the same ideas, or are tempted to free ride on the efforts of others.

In an experiment where the subjects were told an extremely high number of ideas was the "norm," they did succeed in reaching the same number of ideas as the nominal group. And, when a team was continuously prodded for more ideas and allowed to continue for an extended time, they also were able to generate as many ideas as the nominal group. Brainstorming, because it involves the entire group and gives the impression of contribution, tends to increase the buy-in of any resulting decision (Diehl and Strebe 1987).

6.4.3. Ideawriting

Ideawriting is useful for generating, developing, and exploring ideas, but does not result in a decision. The process is simple, consisting of four steps:

1. Divide the group into small working groups.
2. Write individual responses to a problem on a pad.
3. Write reactions to the other initial responses.
4. Read the comments, discuss the principle ideas that have emerged in the writing, and meet in the larger group to summarize the findings.

Ideawriting is based on the presumptions that:

- Writing is better than discussion for certain purposes.
- Writing in parallel is efficient and productive.
- All group members should be encouraged to contribute.

Some advantages are that one leader can oversee a large number of participants, and sessions tend to be very short, on the order of an hour. However, it is not in itself a decision-reaching method, but can be used in conjunction with other techniques.

6.4.4. Delphi Technique

The Delphi Technique uses a series of judiciously constructed questionnaires and controlled feedback to arrive at group consensus or to share information among individual, anonymous experts. The controlled feedback is achieved using a version of the first questionnaire's results along with a second questionnaire. This questionnaire / results cycle continues until the degree of convergence is satisfactory or enough information has been exchanged. A report is then written by the Delphi moderator.

This method is time consuming, and typically is not used in a small, collocated team. Delphi is best suited for situations where there are difficulties bringing the members of the group together due to geographical dispersion, interpersonal conflicts, desire for anonymity, or lack of a common organizational framework. Delphi is used to make decisions that require expert opinions from a heterogeneous group regarding a complex subject.

6.4.5. Nominal Group Technique

The Nominal Group Technique is a middle ground between brainstorming (in which participants meet and discuss) and ideawriting or the Delphi technique (in which experts write separately but never meet). Individual ideas are developed from members (as in brainstorming), ideas are discussed (ordinary group procedure), followed by a formal restrictive process (like statistical aggregation) and written feedback (as in the Delphi technique). Nominal group technique mixes structured decision making with interpersonal face to face groups. It is much less costly and faster than the Delphi technique, but the interpersonal interactions open the group up to conflict and social pressure.

6.4.6. Quality Teams

Quality Teams (including Quality Circles and Process Quality Management teams) follow a structured process for decision making, usually for improving quality in a production or service environment. They are effective for operators working on a production line, as well as for management teams working on a complex problem. The team generally follows a pre-defined sequence of steps. The problem statement is clarified and recorded, then information is collected by the team to define and refine the understanding of the problem. Data collection techniques and other skills are taught to team members, as they are needed. Solutions are generated using fishbone diagrams, cause and effect diagrams, and other structured techniques common in quality management. After one or several solutions are selected, they are implemented on an experimental or trial basis, and more data is collected to verify that the problem has indeed been addressed. Successful solutions are permanently implemented.

Although quality teams are used by part-time teams to improve ongoing operations, many of the structured tools and techniques may be applied in a development team environment, particularly in bringing manufacturing information into the team.

6.4.7. High Velocity Environments

Focusing specifically on "high-velocity environments," researchers Eisenhardt and Bourgeois (Eisenhardt 1989) outlined factors which most influence the ability to make fast decisions of high quality:

- Real-time information.
- Examination of multiple alternatives simultaneously.
- A two-tiered advisory system, giving greater weight to those with more experience.
- Obtaining consensus as decisions are made.
- Integration of implementation issues and tactical considerations in the decision process.

The authors argue that these factors are moderated or affected by three “mediating processes” that determine the ability of the manager and group to deal effectively with the above factors:

- Accelerated processing of high cognitive complexity.
- Smooth group processes for expressing and resolving differences.
- Confidence to act in the face of uncertainty.

6.4.8. Practical Considerations

During evolution of a product development project, the team will tend to try different approaches based on members’ suggestions and develop its own decision-making norms and dynamics over time. This can be influenced by leadership from the project manager, particularly in the early functioning of the team. Serving as a good example of situational flexibility and problem structuring is probably better than providing recommendations to the group, since suggestions by the manager may result in abbreviated discussion and premature acceptance. A leader-imposed decision process will likely draw less participation and result in weaker buy-in of resulting decisions. Patience, facilitation, and mediation are important leadership skills. The manager can bring the team's focus back to its mission, vision, beliefs, and developing norms to help provide a basis for the process, and to the firm's business objectives, trends, and evolving information. The project manager should become skillful at clarifying and restating the problem as team discussion proceeds, and at framing the decision criteria according to the project priorities. Because team integration is so important, harmonious relationships among the team remain a high priority, so discussion may have to be interrupted to manage conflicts that become unproductive. A project manager may often benefit by making use of training, both in-house from the human resources function or supplied by external vendors and consultants, to develop his or her own flexibility, confidence, observational skills, and techniques. Often, within an organization, there already exist a set of techniques and norms for group decision making, so the project manager focuses more on situational judgement and leadership to help them work better.

6.4.9. Decision Tools and Decision Support Systems

Another role of the project manager is to help propose appropriate decision tools and support systems. This includes simple analytical techniques, such as decision trees, affinity diagrams, and goal trees, and methods for calculating outcomes and trade-offs, such as equivalent worth calculations and multiple criteria evaluation methods. Group Decision Support Systems (GDSS) are intended to improve group decision making by removing common communications barriers, providing structured decision analysis techniques, and structuring the pattern, timing, and content of the discussion (Shtub et al. 1994).

6.5. Measures of Team Performance

New measures of project performance are needed to reflect the change from traditional functional hierarchies and control-oriented management to flatter cross-functional teams with distributed authority. Traditional performance measures were designed largely to enable control and tightening of workers' reigns. But, teams thrive on just the opposite — on "local" motivation, initiative, analysis, and decision making. Traditional measures presume that a detailed, up-front plan exists, so that actual expenses and progress can be micro-managed to keep the team from going off course. Such measures promote excessive up-front planning and conservatism, given the relative lack of information at that time. They discourage teams from changing plans in a way that might speed projects. They force workers to reach pre-determined checkpoints and adhere to scheduled expenditures, rather than being creative and making advantageous changes.

In product development, planning may not be very detailed until mid-way through the project, due to incremental approach to reducing uncertainties and gathering information. A new performance measurement system is needed to encourage cross-functional cooperation, mutual planning, and commitment among the team. Measures should be designed to gauge progress in the value-delivery process against the team's stated high-level objectives. The purpose of such results measures should be to help the team monitor its own performance and guide internal decision making, in contrast to the traditional measures which serve to give upper management good information to make top-down decisions.

Of course, any measurement system also provides top management a means to intervene if the project team cannot solve problems by itself. But, the team plays the lead role in designing its own process measures, in conjunction with senior management who ensures that the system is consistent with the company’s strategy. In practice, a handful of new measures may be combined with a few traditional ones. Only measures that would actually influence project direction should be used, to avoid too much overhead and preoccupation with numbers. In some companies and projects, development expense is not perceived as an important measure and does not influence team performance, particularly if burn rates are fairly standard or predictable. So, this measure is often dropped in favor of others that measure collective work product and have more meaning to the team as a whole.

Measures traditionally used within functional groups should be avoided, as they may tend to cause team members to revert to functional priorities and loyalties. Negotiation of cross-functional milestones such as pilot builds, clinical trials, and market launch promote important cross-functional discussions; using them as measures of performance keeps that discussion going.

Tom Peters provided the following summary of essential factors in designing measures:

1. Simplicity of presentation
2. Visibility of measurements
3. Collective involvement
4. Undistorted collection of primary information
5. Straightforward measurement of what is important
6. Achievement of an overall feel of urgency and improvement.

A process for creating such measures would include the following stages:

1. Define the kinds of factors used to deliver results, such as time, cost, quality, and product performance.
2. Map the cross-functional process used to deliver results.
3. Identify the critical tasks and capabilities required to complete the process successfully.
4. Design measures that track those tasks and capabilities (Clark and Wheelwright 1995).

New measures may include tracking cycle time and duration of phases within a cycle or major milestones that the team perceives as important. Major milestones are usually identified early, even if detailed up-front planning is not done, and are good indicators of meeting regulatory and market timelines. This data may be folded into a return-map format to illustrate the impact of development time on predicted revenues.

In early development of a product, milestones may be used to measure progress. Other measures may include completion of specifications documents, prototype builds, number of customer evaluations in progress, acquisition of customer feedback from evaluations, completion of various stages of testing, and design review completions. Tasks that require cross-functional participation are particularly motivating to the team as a whole. Design goals and performance of prototypes may serve as a measure, such as number of innovations or improvements, reduction of unwanted aspects of performance, and reductions in size, weight, or cost. Process design goals may be measured in terms of reducing the number of stations and steps or time required, process capability, or reductions in material quantities, cost, and sensitivity to raw materials variations. Measures such as staffing level (in persons, or perhaps in years of experience) may be appropriate as indicators of the resources necessary for the team to do its job.

Measures in later development stages may include product cost, parts number and variety, product quality, critical path time remaining, margins, and revenues.

Care must be given to avoid misuse of performance measures by managers outside of the team, such as by functional managers or top management, in such a way that might provide mixed messages or conflicting motivations. Such behavior can unintentionally undermine the functioning of the team (Clark and Wheelwright 1995).

6.6. Team Rewards

In the team setting, collective rewards are commonly used to enhance performance. Rewards commonly used with project teams include variable monetary incentives such as bonuses based on collective team performance measures, in addition to fixed individual salary rewards based on a performance evaluation process (Chen et al. 1999). The traditional Management by Objectives (MBO) approach typically includes the process of setting goals between and individual and supervisor, using objectives of the organization for the time period of interest. In a similar way, goals collectively generated by teams and other measures of team performance may be used as a basis for rewards. The criteria must be clear and perceived as outcomes that team members can influence (Clark and Wheelwright 1995). Examples might include achievement of project milestones, measures of timeliness of transfer to production and market introduction, quality measures, inventory reduction goals. Collective rewards serve to strengthen mutual commitment to team goals and enhance cooperation.

Firms with multiple projects depend on cross-project cooperation and the sharing of support organizations. Such firms may provide rewards based on performance of aggregate project measures, and company financial performance in addition to project-specific measures. In this way, team members recognize the priority that upper management puts on cross-project support, and are less likely to defend their individual project resources at the expense of others. Gain-sharing plans are often used to provide variable compensation based on overall company performance (Steers 1994).

Intrinsic rewards should be considered in addition to extrinsic rewards such as salary, bonuses, and stock options. These include the ability to select future project assignments, publication in professional journals, receiving a patent, and presenting work at a professional meeting (Chen et al. 1999). Special monetary and symbolic rewards may be given for invention disclosures and other special accomplishments such as cost-saving measures, quality enhancements, and personal efforts beyond normal expectations in support of important goals.

Whatever plan is implemented, it should be understandable and capture the attention of employees. It should be grounded in the visioning process and culture of the firm as a whole, and should enhance communication of the mission, goals, and objectives. A plan that encourages cooperation rather than individual competition will benefit from awards ceremonies that reinforce the stated objectives. Awards should occur promptly and frequently enough to maintain their motivating influence, such as on a quarterly basis.

6.7. Implementing Team Rewards and Performance Appraisals

Team measures and rewards should be a significant part of the overall performance evaluation system, along side traditional individual performance assessment. However, this balance may be difficult to find. Too much focus on the individual may trigger competition and degrade team coherence, but too little may weaken each employee's incentive to improve personal skills and manage interaction styles.

Furthermore, issues may arise within a team that require careful monitoring by the project manager. Particularly during rapid growth, a new product development organization may have poorly defined job definitions and haphazard compensation systems. Periodic adding of employees to a team may result in overlapping responsibilities. In firms transitioning from functional to team structures, many of the new-hires may be generalists, and areas of responsibility may be unclear or undefined at first. Some individuals may integrate into teams better than others, and conflicts may arise as existing team member's areas of responsibility are parsed for sharing with new employees. New members may be brought in to a team with more experience or at higher levels or pay curves, creating resentment among existing team members. Conflicts are exacerbated if team-based incentives are weak or if salaries and promotions are not perceived as equitable. Employees are encouraged to take initiative in defining and negotiating their roles, but they may receive little training or support in how to do this. Without active management leadership during a period of growth or change, these problems can become significant barriers to effective team functioning.

To resolve or prevent such problems, a project manager (particularly in heavyweight or autonomous teams) can focus on several areas:

1. Hire team members who find their work and team collaboration intrinsically rewarding.
2. Help new team members understand or create their roles. Provide them with a wealth of technical and organizational materials to study, and introduce them to key contacts within the organization.
3. Work with existing employees to recognize the need for changing roles and to accept sharing of previous responsibilities with new employees. Provide constant communication about the status of the company, market, and other projects.
4. Work periodically with the team to define their own roles relative to each other, changing those roles as the project evolves and new members join.
5. Invest in team building activities.
6. Provide frequent performance feedback and informal discussion.
7. Help employees identify paths and opportunities for advancement.
8. Make sure that the dimensions used during the interviewing process to evaluate applicant's past behaviors are linked to the performance appraisal

system and to training opportunities. All three systems should be consistent for maximum effectiveness.

9. Work with human resources and management to implement the performance appraisal system within the team so that rewards as perceived as fair, attractive, and linked to relevant performance.
10. Work with upper management and human resources to improve the evaluation/compensation system. For example, a cross-functional task force could be formed to make systems more effective, consistent, and linked with company vision and beliefs statements.

Incentives may include stock options for publicly held companies. For others, variable team-based cash bonuses are used. Individual variable bonuses have not been found effective, especially in team environments (Steers 1994).

Below is one possible incentive system suitable for a projectized firm, developed as an example for this paper (based on the literature and on the author's work experience). Ideally, such a system is defined by a task force containing representatives of all groups in the organization, and would thus be tailored to the specific needs and culture of the firm. This example consists of a variety of team-based and company gain-sharing rewards, paid in quarterly lump-sum bonus (up to 20% annually, average 10%) tied to multiple measures of performance:

- Project goals (set by the team each quarter), 6%

- Overall product development goals (average of projects), 2%
- Measures of timeliness of transfer to production and market introduction, 2%
- Quality measures, 2%
- Customer service measures, 1%
- Inventory and backorder measures, 1%
- Company financial goals, 6%.

Each quarter, every project or functional organization would evaluate completion of last quarter's goals, and set new goals for the upcoming quarter, using participation of all directly involved employees. It is important to make sure that employees understand the program and can see their contribution as relevant. Prompt award of bonuses, after review by a management panel, would reinforce the importance of these goals and the ability of employees to effect their accomplishment. Also given would be fixed cash awards for invention disclosures and patents, and larger awards for contributed suggestions and improvements that produced clear benefits to the organization, as determined by a cross-functional committee based on predefined guidelines.

6.8. Upper Management Support

Project work is strongly affected by upper management actions and policies (as explored in earlier sections). Project managers must work with upper management to:

- Build a company-wide vision and system of beliefs tied to customer satisfaction.
- Set expectations of cross-functional cooperation.
- Build a sense of urgency.
- Define and support the project mission.
- Legitimize the project leader.
- Empower the team with decision-making authority.
- Provide needed resources.
- Reward collective team performance and inter-project cooperation.
- Offer training and job rotation.
- Hold realistic expectations and shoulder risk.

Upper management must do more than merely establish cross-functional teams; they must establish the context and conditions in which cross-functional interaction and rapid development can occur. Even before a team is formed, upper management should set the tone of trust and respect, remove barriers, and establish skills, tools, and methods for cross-functional cooperation. Management should focus on weakening the linkages between team members and functional groups, so that the team can move quickly and independently, while strengthening the motivational structure that supports cross-functional involvement within the team.

Management behavior sets the pattern for inter-departmental cooperation and goal orientation, such as by interaction between functional line managers and vice presidents. Differences in power between functional organizations at the upper management level are often felt at lower levels as a differential in status and as barriers to cross-functional cooperation. Management can further aid in cross-functional integration in several ways:

- Top management should set forth task integration rules. These specify areas in which parties are expected to collaborate.
- Rules may be fortified by sanctions for non-compliance, such as low performance ratings in performance evaluations.
- Establishment of a common enemy may motivate task integration. This may be a competitor or competing technology, or in the case of medical devices, it may be a disease process or condition.
- Management may agree to assume the risk for some errors that the teams may make, holding them harmless for certain negative outcomes, so that their creativity may be uninhibited to innovate (Souder 1987).

Specific problems and solutions for cross-functional relationships will be addressed in a later section.

Senior management initiates projects, providing them with goals and boundaries within which to function. The importance of the product and schedule needs to be articulated, so the team knows why they are being asked to rush development, take risks, and work long hours. Ideally, this includes a clear and urgent team mission tied closely to the mission and objectives of the firm. The visioning process, discussed in the previous chapter, can build a context in which the project's mission has meaning.

Management also needs to ensure that it is perceived as being consistent in its product strategy and support of the project. This requires clear, unmixed signals from management and by showing sustained commitment to the project objectives. A common method to help assure consistency in communication is to have a team sponsor among upper management, which may be a director or vice-president. An important factor is providing money and resources needed to accomplish the team's charter. Not only does this show commitment, but it eliminates excuses and builds a can-do, accountable attitude among the team.

Keeping a team together and on-target requires conscious effort and ongoing commitment by management. To maintain an accelerated schedule, management should keep the project simple, short, and of limited scope (Smith and Reinertsen 1991). Back-and-forth changes in management direction, or mixed messages while management debates the product strategy among itself, can be so demoralizing that any benefits from the improved strategy cannot be accomplished. If management shows consistent commitment to the goals of the project and to the team members, then the team is likely to respond to high management expectations.

Top management's attention or presence in various parts of an organization can send strong signals, although many managers do not seem to recognize this. A survey of CEOs of large companies in the United States showed that they rank product planning and development as the single most important source of future growth and profits, but only 15% indicated "considerable involvement" with it compared to 45% involvement with financial planning (Smith and Reinertsen 1991). Even brief conversations with the development team send a message of management interest and tend to boost morale among the team.

Upper management involvement in a project can have the most beneficial influence if begun early in the project conceptual phase, when project scope is being decided, critical trade-offs are being considered, and most design decisions have yet to be made. Early and sustained attention also helps establish urgency and rallies participation in front-end planning, which can eliminate a top cause of project delay. In practice, most management attention comes as projects near production, when burn rates are high and deadlines loom, but little can be done to influence the outcome (Souder 1987). Furthermore, the wrong kind or timing of upper management attention can be detrimental (as discussed in a previous chapter). Management has empowered the team to make its own decisions; now it has to avoid stepping in, which can suggest lack of trust and punishment for mistakes rather than encourage strategic risk-taking. On the other hand, upper management needs to stay informed about progress and potential bottlenecks, providing resources to bail out the team if needed, or to cut short a project that has proven technically or financially infeasible.

Although the entire team ultimately contributes to its own values and norms, management can provide powerful initial direction in establishing expected behaviors. Performance expectations should be matched by policies, and procedures, including appropriate evaluation and rewards systems. Optimally, there should be coherence among behavior of management, expected team behaviors, and the vision, values, and beliefs of the firm.

No other single decision by upper management has greater impact on successful accelerated development than selection of the project manager (Smith and Reinertsen 1991). Also critical is management endorsement of the selected project manager, followed by active promotion of the person through both formal and informal networks (Souder 1987) (as discussed in an earlier section). If a project manager is inexperienced or weak in certain leadership skills (common among technical project managers lacking marketing or commercial backgrounds), he or she should be given extra support and mentoring from senior managers who possess those skills. Upper management cannot afford to stand back and watch a project manager struggle.

Senior management often designates an executive sponsor to guide each team in gathering information, planning its strategy and tactics, functioning smoothly within the organization, and identifying boundaries of delegated authority and accountability. The sponsor serves as liaison to the rest of the executive staff, addressing management concerns, coordinating communication between project and management, and reporting project status to management. This reduces the burden on other executives and avoids mixed messages (Clark and Wheelwright 1993). Having the project manager report to general management rather than functional middle management helps keep the team visible and free of functional influences. The sponsor may serve as coach and mentor for the project manager and core team, and maintains close, ongoing contact. The sponsor helps the team to identify its limits regarding decision-making power, schedule constraints, resource availability, and issues regarding policies and procedures across the organization. Team performance measures and reward systems (discussed in another section) are often developed by the team itself under the sponsor's direction, and the sponsor ensures consistency with the rest of the organization, reviews progress reports, and awards the incentives.

6.9. Empowerment

Related closely to upper management support of collaborative teams is the concept of empowerment. It is common to hear a manager claim that "here at Corporation X, we empower our people." All too often, such a statement refers to a shallow or incomplete strategy. The goals are noble: increased customer responsiveness, increased pace and quality of innovation, reduced bureaucracy, improved adaptation to change, and promotion of leadership at all levels. But, for empowerment to succeed, it must be a consistent system of strategies, genuinely reflected in the behaviors of managers, and tailored to the specific issues of an organization and its environment. Empowerment cannot be reduced to slogans, fads, or pat techniques. It seems the word "empowerment" is seldom heard at those companies that are most successful at it.

What is meant by empowerment? Typically, it refers to the moving of decision power to lower levels, closer to where the work occurs, or closer to the customer. Often, empowerment refers to giving people control over the conditions that allow their actions to succeed. These are worthy objectives, particularly in situations characterized by rapid change in technologies and markets, emphasis on customer service, or reliance on creative problem solving.

In practice, empowerment often seems a fad, adopted in response to downsizing rather than as a deliberate strategy to improve performance. Employees inherit responsibilities from former superiors or peers eliminated by reorganization. Along with these responsibilities come the expectations of others, often looking for improved performance over the predecessor but without providing adequate training, management support, compensation systems, or resources to assure success much less allow it. Failure is often met with punishment, by either deliberate corrective action, or simply resulting from a system that reinforces the wrong behaviors and discourages the target behaviors.

Even in organizations that are not downsizing, reorganizations may be initiated to fix a dominant problem without attending to the new problems it will create. The result can be decreased productivity and responsiveness, turnover, and perpetual reorganization as management attempts again to fix the consequences of the previous solution.

A few examples of empowerment err in the opposite direction, which could be characterized as overly humanistic as opposed to overly autocratic. Decisions are left to employees and teams, but often with little guidance or structure to make their process efficient and their results relevant to the organization. "We don't give direction... we have *empowered* people here." This may provide benefits such as employee role acceptance and involvement, but decisions often occur slowly, often accompanied by interpersonal and inter-group conflict. Mistakes are tolerated and viewed as valuable experimentation, but in the process, business objectives and deadlines can be de-emphasized or neglected. Considerable delays and expense can be incurred.

This author recently worked in two organizations, each exemplifying one of these errors. At the first, initiative was demanded by managers, yet mistakes or differences of opinion were not tolerated. Bonuses were only granted for heroic individual efforts that resulted in attention-grabbing new product features; these produced resentment among most employees. No team efforts or quality improvements were recognized. In the second, democracy and flexibility were taken to an extreme, resulting in indecision, frequent changes in project direction, and unclear priorities.

Employees can be set up to fail either by an overly permissive management that fails to clarify boundaries and priorities, or by an overly autocratic one that attempts to dictate initiative taking. The result in both cases does not serve the customer or the firm. The solution to these problems does not lie in merely finding the right balance between permissiveness and control. Empowerment requires an environment of shared values, policies consistent with those values, and authentic modeling of those values by all levels of management. It is a system approach to nurturing entrepreneurial collaboration from employees. Peter Block, author of *The Empowered Manager*, names these prerequisites (Block 1986):

1. Entrepreneurial Contract: The basic contract between management and the employee assumes that the most trustworthy source of authority comes from within the person. We act because we choose to do so, not because we are told to. The primary task of supervision is to help people trust their own instincts and take responsibility and ownership for the success of the business. Traditional organizations have a patriarchal contract in which top-down authority and control are unquestioned.
2. Enlightened self-interest: Success is defined in terms of contribution and service to customers and others in the organization. Rewards include meaningful jobs, learning opportunities, creating something worthwhile, growth tied to one's own efforts, and rewards tied to collective accomplishment. Traditional organizations hold a myopic view of self-interest in which success means moving up the ladder, gaining more authority, and earning individual financial rewards.

3. Authentic tactics: Direct and authentic communication is encouraged, including letting people know where they stand, sharing information and control, and taking reasonable risks. This is in contrast to the traditional belief that we must be calculating, controlled, and manipulative to move up the ladder.

4. Autonomy: Freedom to act accordance with our own initiative is encouraged by establishing trust that reasonable risks are safe, and that courage in pursuing quality will be rewarded. Traditional organizations promote dependency and a sense of limits on our ability to contribute.

Some essential elements of empowerment are the granting of decision power to lower levels, closer to where the work takes place, or closer to the customer, and control over the conditions that enable success of those decisions. Empowered teams are usually characterized as democratic or collegial cultures, low in bureaucracy and structure, and high in "generalists" and cross-training. Common values of such environments include:

- Participative leadership and shared responsibility,
- Extensive training and team building,
- Alignment on purposes,
- Emphasis on open and constant communication,
- Synergistic use of the team's creative talents,

- Freedom to define its own processes and procedures,
- A safety net to allow experimentation and mistakes, and
- Rapid response to changing customer needs and environment.

Furthermore, to make empowerment work, a situational leadership approach must be taken. Good examples of empowered teams may have significant differences from one another. There is not "one way" to implement empowered teams. The circular, manager-less organization that works at forward-thinking Semco in Brazil would not fit at traditional General Electric, or perhaps anywhere else. To a large degree, empowerment allows "common sense" of the team to be put to work, in place of top-down procedures and controls. But, common sense varies among cultures, markets, and industries. So each situation may call for different values, strategies, and degrees or types of management direction. The degree of organizational change undertaken as part of empowerment may differ, ranging from modest to revolutionary.

Empowered teams require flexibility, creativity, and interpersonal skill among the team members. A key requirement of management is to provide enough sponsorship and structure for the team so that it can focus and succeed in its mission. This may include:

- Direction as to the team's mission and key business objectives,
- Guidance and information to understand forces in the company and its environment,

- Definition of the limits to discretion and the constraints needed to keep the team cost-effective, and
- Establishment of performance reviews, feedback, and rewards which reinforce target behaviors, emphasizing group achievement, and extinguish undesired behaviors.

These are often not fulfilled by managers attempting to create empowered teams, sometimes reducing the team to a noble failure. Traditional management attitudes can prevent empowerment from working, and include:

- Viewing workers as a cost to be minimized rather than a resource to be developed,
- Maintaining tight control,
- Limiting access to information,
- Viewing jobs as narrow specialty roles,
- Using fear to control employees, and
- Discouraging any activity not demonstrably related to the immediate tasks.

To plant the roots of empowerment deep in an organization, leaders must embody and exhibit the values that they wish others to adopt. Managers must be willing to trust people, to let go of some top-down control, to encourage ownership when such initiative is shown, to delegate decision authority, and to redesign benefits and policies to reward responsibility and risk taking. Managers must avoid the temptation to punish mistakes and micromanage high-risk tasks, responding instead with supportive information, training opportunities, and an attitude of collaboration. This will take time and require shifts in management attitudes.

Employees also may resist a strategy of empowerment. They understandably distrust management's requests for more accountability, having seen pressure and punishment result in the past. There is part of each person that welcomes the safety of a limited, predictable job over the uncertainty and risk that comes with freedom. Managers must patiently and willfully maintain the culture of empowerment in the face of employee ambivalence, and to look to their own behaviors and policies if trust does not increase with time.

6.10. Conflicts

Conflicts typically arise with greater frequency in teams with distributed authority. Rather than something to be avoided, conflict can be a harbinger of creativity and should be channeled into improving the design and teamwork. Ordinary well-established knowledge can often be expressed in familiar terms that everyone can grasp. But, collaboration involves creating new ideas and information, drawing on an unpredictable confluence of two or more individuals’ perceptions and metaphorical representations. Creativity arises when individuals work out a common understanding of a problem in a way that bridges diverse individual perceptions and metaphorical understandings. Creativity thus relies on building relationships that allow for questioning, challenging, and listening to each other. Interpersonal conflict often accompanies this kind of relationship building. Tensions and frictions can trigger crystallization of ideas. Many examples of collaborative relationships throughout history are characterized by conflict (Schrage 1995).

Even in situations requiring simple communication and coordination of activities, some conflict is healthy. The added value of cross-functional participation is that needed information is available at the right time. Information can be elicited during interpersonal conflicts, and subsequent questions and answers can improve shared understanding of project status and objectives.

How conflicts are handled is of great importance (LaFargue 1999). The project manager should lead the team in developing its own process for maintaining acceptance and trust despite disagreements and rising tempers. If conflict results in interpersonal problems or fixed positions, the project manager and other team members can invoke the higher purpose to the interaction, referring to previously established mission statements and behavior norms, to channel friction into creative outcomes. A shared expectation of vigorous, honest, yet respectful discussions toward stated objectives can be powerful in keeping conflicts productive and bringing unproductive conflict into the open. Teamwork benefits from spontaneous participation and self-expression, which cannot happen if people receive the message that they should be different in personality or have different skills than they possess. A norm of embracing diversity rather than of conformity and political correctness seems to help teams collaborate.

Cross-functional involvement brings its own types of problems characteristic to the specific interface, such as marketing-engineering or engineering-production. These will be discussed in the later sections.

6.11. Politics

Another source of conflict is the exercise of political power within organizations. Political power is usually seen as negative, particularly by engineers who tend to respect rational, systematic processes. However, it can be a positive and even necessary element making decisions.

People often confuse the related concepts of *authority, power, and leadership,* crippling their ability to participate in organizational dynamics. *Authority* refers to the legitimate *right* to seek the compliance of others, and is granted by even higher authorities. *Power* refers more broadly to the *ability* to secure compliance, which may arise by several mechanisms. *Leadership* implies that others are inspired to take action voluntarily, going beyond mere compliance. Each of these has its role, and can appear in positive or dysfunctional forms (Steers 1994).

Power is not merely dominance, but the capacity to get things done. Power does not accrue only to those with position authority. Other factors can be influential, such as expertise and credibility, admiration and respect, potential for rewards, and fear of punishment. Such discretion should be encouraged as part of collaborative problem solving and organizational restructuring.

Organizations, alliances, and coalitions within a firm gain power in large part due to their control of resources or other strategic contingencies perceived as critical to the firm. These may include information or key capabilities or competencies. To the degree that these perceptions are aligned with the realities of the environment, politics can serve to improve the effectiveness of an organization.

Politics refers to the process of acquiring, developing, and using power and other resources under conditions of uncertainty and lack of consensus (Block 1986). Political power has constructive uses, such as the ability to intercede on behalf of someone in trouble, lend support to worthy proposals from a less powerful source, speed the advancement of a worthy subordinate, gain access to key executives to address pressing problems, or provide resources to a project when official support is lacking.

Political power can be a mechanism for aligning an organization with the realities and demands of its environment, and with its internal problems. Opportunities and problems rarely receive universal recognition and unanimous agreement on how to respond. Decisions rarely occur rationally, due to limited time and information. Most decisions require speed more than optimization of a solution. In the absence of complete information, reasonable people disagree, and recommendations and initiatives from various groups must be weighed according to their criticality to the company. Many initiatives begin with a mix of support and opposition within the organization from groups that have varying degrees of trust for each other. Politics is inherent in such a process of filtering ideas, building consensus, and testing proposals in practice.

Effective project managers must be able to understand and participate in power dynamics for improving their organizational effectiveness, promoting their projects, solving problems, and protecting their teams. Credibility and influence with superiors and other organizations are key factors in building commitment to a product concept and collaboration across functional and project boundaries. The support of political allies is necessary to survive and thrive during times of great change.

Organizations can develop dysfunctional power dynamics without careful growth management and leadership. This is particularly true when uncertainty and complexity are high, and the survival of the organization is at risk. Political power, which can help an organization respond to its environment, can also serve to obstruct necessary change, sacrificing long-term objectives of the company for short-term interest of a powerful sub-group. This dysfunction can take many forms. Middle and first line managers, caught between the bureaucracy and their workers or customers, may feel powerless, and act out in various ways. Symptoms may include excessively close supervision, controlling behaviors, manipulative application of rules, and narrow territoriality. Upper level managers may compete for position, manipulating vested interests, extending influence beyond their assigned roles, or employing power tactics in unethical ways. Groups that control critical resources or contingencies may seek special advantages. Groups may even work to define what is considered critical within an organization, thereby increasing their political power, making abuses more likely.

Power struggles tend to be reduced if uncertainties and organizational complexities are reduced, and if interdependence is the norm, rather than dependence and competition. The symbolic importance of management actions in building trust, empowerment, and collaboration must not be neglected. A consistent management philosophy of empowerment goes a long way toward minimizing negative politics, at least when market and financial conditions are favorable. Managers can clarify employee job responsibilities and systems for evaluation and reward, and allocate resources based on objective standards and organizational goals. Leaders can promote inter-group cooperation and cross-training, and build norms of open and ethical cooperation.

6.12. Examples from the Author's Work Experience

The author of this paper has participated in a variety of project team structures. During the 1980s, I worked at NASA's Jet Propulsion Laboratory, a huge matrix organization of 9000 people. I served several roles: physicist, developing new materials processing techniques; design engineer, developing systems to perform such techniques; and coordinator between science and engineering organizations. I served on five different projects lasting two to six years each, that used lightweight structures. Some projects began as functional structures, but expanded to lightweight as the need for collaboration increased. Project managers had project responsibility but no direct authority over from 12 to 20 participants, some of who were Ph.D.s with impressive records from other projects, and others from numerous service organizations. A core group consisted of about six members working nearly full time, including a systems engineer. Others consulted part time among several projects. Each project manager and system engineer was aided by one or more liaison/coordinators from the science organization who also served as individual contributors. I was one of those liaisons, coordinating many aspects of the design, testing, and post-flight analysis, as well as designing the electro-acoustic modules for the systems.

Functional expertise at Jet Propulsion Laboratory was quite deep, supported by the long-standing functional group structure. The two main groups participating were a research science organization that performed research under contracts from NASA and industry, and an engineering organization that built hardware for space shuttle and interplanetary missions. The science team was the originator of the project concept, and was essentially the “customer” of the engineering organization, although both were also accountable to NASA contracts for their roles. The objectives of the science team were to develop containerless materials processing technologies that used acoustic standing waves within resonant chambers, called "acoustical levitation," and to use these technologies to study fluid dynamics and glass processing methods in micro-gravity of earth orbit. The engineering organization built and qualified the hardware systems that could perform these experiments aboard the space shuttle, based on science’s functional requirements.

A long-standing tension had existed between the science and engineering organizations. Differences in training, language, motivations, and intrinsic rewards made communication difficult, worsened by the distances between their labs and offices. The project manager was largely a planner and project analyst, participating very little in the day-to-day design meetings. He had little power to influence the members from the science team or other functional organizations that served as specialists on the project.

Several of us from the science organization who were experienced in system engineering took the initiative to serve as liaisons and to “go native” among the engineering team. Armed with no authority, these liaisons used persuasion and personal contributions to bridge the gap between science and engineering, addressing those aspects of implementation (some quite large, at first) that fell through the cracks. Early in the first project, communication between these groups was sporadic and contentious, but persistent efforts to bridge the gap led to better cooperation. The liaison’s efforts and interest in collaboration were seen as an effort by the science organization to take responsibility for the differences, which helped build communication and respect. Eventually, shorter communication channels developed directly between science and engineering staff members to handle various levels of project planning.

Weekly meetings were used at first, then several per week, and finally, daily meetings took place in the lab, everyone gathered around the prototypes and flight systems. Collocation of the core team into a single lab was beneficial in several projects for which this was tried. Nonetheless, occasional but serious disagreements resulted in unilateral decisions by the engineering group that led to degraded performance of the experiment systems on orbit. Last-minute efforts of the liaisons helped minimize the impact of these problems.

Working for medical device manufacturers in the 1990s, I participated in many types of projects. Some were one-time initiatives to fix problems or improve performance, based on proposals that I had initiated. Others were development projects for new diagnostic ultrasound probes, system features, or enhancements, often bundled with upcoming system releases. Small projects used lightweight teams, and larger ones used multi-disciplinary heavyweight structures led by an engineering project manager and guided by a triad of an R&D director, a marketing product manager, and a manufacturing manager.

The largest project was an ambitious new catheter platform and imaging system for performing cardiac revascularization. This concept was based on existing catheters for performing directional coronary atherectomy, incorporating an intravascular ultrasound transducer and imaging computer into a single, innovative design. Physicians and employees felt that the state-of-the-art real-time ultrasound visualization would provide interventional cardiologists with unprecedented guidance of the cutting process. This would allow more complete removal of atheroma from the coronary arteries, leaving a larger passage, reducing the number of patients who suffer repeat blockage, and improving safety by providing a clear visualization of the end-point. Here was a concept that, while expensive to develop and requiring new core competencies, won broad support of physicians, employees, and management.

Components of the system included an image-processing computer console, a motor drive module at the bedside containing the control and pulser / receiver electronics, a small hand-held controller for the physician, and a 60-centimeter catheter with a 1-millimeter transducer in the side of the spinning cutter head. The ultrasound atherectomy project consisted of 14 full-time members in an autonomous team, including mechanical and electrical engineers and technicians, plus part-time support by manufacturing and quality engineers. In addition, six personnel at two contract engineering firms participated by developing software and hardware subsystems. Team members from manufacturing, quality, and reliability participated part-time, traveling 500 miles by corporate airplane one or two days per week. A marketing product manager worked closely with the team and the project manager to guide the requirements definition, and to gather ongoing feedback from dozens of physicians. These end-users were also leaders in their fields and often involved in research using other types of devices, such as angioplasty balloons, intravascular stents, and existing atherectomy devices.

This relatively large project was broken down into three overlapping sub-projects, each led by a senior engineer with supervision authority over his sub-team members. These sub-teams were as large as other entire projects within the company.

The three senior engineers were in turn managed by a project manager, also an engineer, who reported to a director in product development. As one of these senior engineers, I was responsible for the computerized ultrasound console, transducer, transmission line, and cutter head. I was able to work with all of these disciplines on a regular basis, and oversee many aspects of prototyping, animal studies, physician feedback sessions, design, testing, verification and validation, and first clinical use on human patients.

Teams at this firm were very effective for several reasons. First, the firm had recently completed a visioning process, involving all levels of employees, that established a formal definition of the firm's mission, values, and beliefs. This formulation matched the informal structure that existed since the firm's foundation by an interventional cardiologist who invented a new device and technique. Management behaviors, policies, rewards, and employee attitudes were consistent and reinforced each other. A passionate commitment to the patient and user / physician kept the market and technology strategy in step with the marketplace. The small firm remained organized around the vision and beliefs, using a lean management structure with strong, regular collaboration among all levels. Hiring was done carefully, and new hires received extensive orientation and training. Weekly all-hands meetings kept everyone aware of developments, involved, and focused on company goals.

A cross-functional committee was used to select product concepts and direct project activity. The project portfolio was continually reviewed and the product strategy sharpened. This was combined with quarterly planning by each project, working with management sponsors, to set interim goals and measures to be used for evaluation of performance at the end of the quarter. A generous bonus structure provided incentives of 12-25% above base salary, based on collective measures of project and firm performance. Employees knew that collaboration was expected, was productive, and was promptly rewarded. Individual rewards were given only for efforts above and beyond normal duties that created significant quality improvements or cost savings.

Communication within the team was a daily ritual. Each sub-team met almost daily, and the larger team met at least once per week. Everyone had license to participate in every part of the project. Senior engineers were lead technical contributors and sub-project managers, and the overall project manager was a hands-on participant as well. Planning was done in various small and large meetings, using everyone's input and seeking each person's agreement.

The democratic culture that worked well when the firm was small began to cause problems as it grew. Team managers had to become more directive. Directors told the senior engineers to phase out team-wide agreement and implement a more directive process to speed decisions and improve quality by more heavily weighing their greater experience. But, long-standing members of the team sometimes resented losing input into parts of the project, or perceived being passed over when two senior engineers were hired from outside. The concept of "alignment" was used to denote the intent to reach agreement but the need to cut debate and move forward, asking dissenters to support the decision while making practical use of their skepticism. The project manager coordinated schedules from the three sub-team leaders, each of whom led planning sessions among their teams.

These many strengths ultimately could not help the firm when the medical community began to embrace stents in place of atherectomy. A sister company was developing stents, so the firm did not intend to compete with those projects. The loss of sales to stents led to a split among the product planning committee between those that felt the ultrasound-guided device would save the company and those that felt the project was too expensive and too far from commercialization, draining the small firm’s resources. The project manager found herself drawn in many directions at once by increasingly diverging input from physicians and management. The team was directed to investigate several alternative platform concepts, adding more delay. Furthermore, the need to develop electronics for the ultrasound system would distract the firm from its core competencies in disposables, plastics extrusion, and catheter shafts. Some managers felt the dropping sales and pending consolidation with sister companies, previously under a common ownership but operated independently, would reduce need and support for this project.

As these developments were unfolding, the project team reached the milestone of testing the primary design concept in pilot clinicals with human patients, using fully-documented catheters made in a pilot production facility according to formal procedures. Despite success of the clinicals, the product planning committee strengthened its interest in competing concept with radically different user interfaces and performance trade-offs. This strategy was intended to reduce risk of poor market acceptance, but delayed the projected market introduction by over a year. Already five years from a full product launch, due to the need for extensive clinical trials, the project began to be perceived as a drain on capital. A partnership with a well-established intravascular ultrasound console supplier allowed the firm to focus on the atherectomy catheter with a smaller development effort dedicated to the interface electronics between catheter and console. Ultimately, although the technical hurdles were largely overcome, the expected return-on-investment was judged lower than alternative development projects, and risk higher, so the project was cancelled.

7. PROJECT PLANNING AND EXECUTION

This chapter looks at the execution phase of a project, during which the project manager and team implement the concepts described in previous chapters. So far, we have discussed the differences between traditional project management methodology for large projects and more agile approaches for product development. The product development process was introduced, showing ways to improve project selection and achieve a rapid start. We have explored the importance of cross-functional interaction and team management, particularly for innovative product concepts with evolving definitions and technical or market uncertainties. Throughout, the need to adapt these considerations to a particular project and organization was emphasized. Now, we discuss these same issues from the perspective of the implementation phase, adding further detail to the approaches already discussed.

Traditionally, the role of project manager is one of planning, monitoring, and control. In fact, project leaders of lightweight teams are sometimes little more than coordinators and project analysts, updating schedules, budgets, and resource assignments to maintain efficiency and allow oversight by upper management and the sponsor. In contrast, fast-paced product development projects often use small, tightly integrated teams with distributed planning and decision making authority. The project manager is less a monitor and more a participant and catalyst, making sure the team continues to coordinate and address all relevant issues, and working with management to guide the project through the development process, culminating in routine shipments of product.

The goal of this chapter is to explore some of choices and issues that face project managers during the implementation phase, as found in the reviewed literature. These include a streamlined approach to project control that helps maintain team innovation and agility, rapid prototyping, collaborative tools, and ways to manage cross-functional issues.

One should not expect any two organizations to implement the approaches explored in this paper in the same way. The literature shows quite a range of project manager roles, team structures and incentives, scheduling and planning methods, and phase-based structuring of tasks. For example, a small firm that develops and manufactures angioplasty products was discussed in an interview with a senior engineer (Webler 1999). For this firm, speed is of the essence in order to adjust product performance according to market feedback, take advantage of newly available materials, and expand their product line to keep ahead of competition. They plan incremental product releases using small, dedicated teams whose incentives are tied to collective accomplishments. Members from R&D, marketing, quality, manufacturing, regulatory affairs, and clinical research collaborate from the start. The project manager, product engineers, and marketing personnel work closely with customers to evaluate user requirements, but only a relatively sketchy functional requirements document may be written. Scheduling of projects is relatively fluid, based around a brief product development manual, with plans worked out along the way around interim milestones mapped out by the team. Changes in the firm's product strategy sometimes influence the feature and performance goals well into the implementation phase. However, as a medical device developer, formal procedures and controls are required, increasing as the project matures. FDA mandated design controls require a device history file be kept, beginning in the concept phase. Clinical trials may be required using devices built according to tightly controlled procedures. Designs are first used by selected physicians to guide refinements before a widespread product launch.

Near the other extreme of the product development spectrum, a large microprocessor developer such as Intel needs large teams to deal with the mounting complexity of its products and shorter design cycles and market lifetimes. Heavyweight team members are mostly microelectronics design engineers and some process engineers, who design to a well-defined product concept and detailed specification frozen early in the project. The project manager focuses mostly on technical issues and resource needs. A detailed work breakdown structure is developed down to the level of individual contributors and tasks, using a detailed template based on a history of numerous similar projects, and filled in using bottom-up estimates by those who will do the work. Weekly reports of status and work hours from each individual are reviewed by project leaders and entered into a large scheduling engine and resource usage tracking system that automatically rolls up the data. Effort-based progress is tracked and compared to an extensive historical database that enables improved estimates of completion dates. This relatively detailed system and costly overhead structure is justified by the large, geographically dispersed workforce (Nobley 1999).

A worldwide network of sixteen research sites with 4000 professionals presents a similar problem to Merck & Co., who, like Intel, emphasize detailed planning. However, the diverse product line and reliance on specialists in medicine and medical technology requires a balance between cross-functional interaction and functional group expertise, leading to a flexible lightweight structure. Developing a new drug may take five to ten years. A strategy of empowerment promotes initiative and creativity among the experts performing fundamental research. Researchers have some freedom to pursue personally chosen investigations, with more discretion granted to those who have shown good judgement and results. Merck's CEO, Dr. Roy Vagelos, characterized their philosophy as hiring the best people and providing them with excellent training and personal growth opportunities. As a project matures, a highly-structured process is followed for development, clinical evaluation, and regulatory approval. A staff of eight coordinators reports to a senior vice president of planning and support 400 research projects (data as of 1993). These coordinators oversee the development of detailed project plans using advanced software, and serve as liaisons among research, marketing, manufacturing, and other functional groups. Project teams form their own objectives, and regular status reports and meetings are used to monitor progress against a critical path timeline. Regular program reviews help address critical activities that are late, coordinate preparation of regulatory filings, and provide ongoing synchronization of research with market needs (Dinsmore 1993).

Valid generalizations are particularly hard to make about the implementation phase of projects, as these examples demonstrate. There are significant differences among projects, firms, and industries. This paper attempts to illuminate the range of options, rather than recommend a single, universal approach. In particular, this paper focuses on approaches relevant to competitive markets who rely on cross-functional collaboration in creating innovative solutions. This provides the greatest contrast with the other extreme — traditional project management methodology used on large systems engineering projects. Product development projects that combine both the need for speed and necessity of control, such as the Intel and Merck examples above, must create an effective hybrid between these two extremes that is suitable to their industries and organizations.

7.1. Project Control

Control of project activities and monitoring of progress is a basic responsibility of project management. In accelerated projects using concurrent methods, top-down control is more problematic due to the faster pace, overlapping of tasks, and decreased up-front planning. Speed is generally a higher priority than development expense. Traditional methods were designed to track progress against a relatively fixed, pre-determined plan and to monitor expenses closely. In product development, such methods can slow progress and restrict the team from pursuing creative solutions. In addition, such systems have high overhead costs that may not be justified. Consequently, control is accomplished by quite different means.

7.1.1. Recommendations for Rapid Product Development

7.1.1.1. Delay Detailed Planning

Fundamental to the CE approach is a reduction of front-end planning and an ongoing refinement of the plan with input from the entire team. Change in the project plan is allowed and even encouraged as a means to shorten development. Everything needs to be fast: communication among the decision-makers, approval processes, meetings, and generation of reports and other documentation.

7.1.1.2. Empower the Team

The focus in rapid product development is to empower the team rather than to control it. The philosophy of control in the CE approach is similar to that of the quality movement: to build-in planning and control rather than to impose it by non-participants. The emphasis shifts away from the traditional view of controlling work toward empowering and enabling team success. Control is more subtle and distributed in the CE approach, with only the essential constraints made formal (Smith and Reinertsen 1991). Decision-making is moved down to the lowest level practical, usually to those people performing an activity. This is the only way to make rapid development possible. The project manager is more interactive and participatory rather than the traditional role of asking for updates and giving direction.

7.1.1.3. Form Interim Goals

Rather than measure progress rigidly against a detailed, up-front plan, the development team continually develops interim goals as it works to accomplish its major milestones.

The project manager's early duties are to help the team identify key questions to be answered and to set priorities among them. Opportunities to shorten the critical path are the project manager's focus. Areas of risk in the project and their impacts must be identified and removed from the critical path, often by pursuing simultaneous alternatives and retaining flexibility until unknowns are answered. Intermediate, achievable deadlines must be established to motivate action in the face of complexity and uncertainty. Long lead-time items and vendors must be identified.

These interim goals and major milestones are used as measures of project progress and as a basis for incentive bonuses. Senior management manages the team to its contract, and conducts streamlined formal reviews tied to major events. Truly autonomous teams are even less accountable to external management aside from aggregate resource limits; the project manager is, in essence, CEO of the effort.

7.1.1.4. Capture the Product Development Process in a Brief Document

A firm’s product development process is often provided as a manual, guiding projects through the necessary phases. It should be kept simple and flexible according the specific needs of a project and firm. The philosophy is to equip the team to make good decisions and give them access to past learning, not to restrict their options. The document may contain a flowchart of the process, a description of the purpose, definition of design reviews and deliverables, and a list of the signatures needed to authorize progress. A more detailed manual may provide more control and reduce technical risk slightly, but may discourage creativity and initiative. Furthermore, long, detailed procedure documents tend to suffer from low awareness and low compliance.

7.1.1.5. Adapt the Procedure to the Project

Firms tend to apply the same standardized procedures designed for their largest projects to the smaller ones. This can restricted teams from pursuing creative approaches that might speed development and explore creative design solutions. Consequently, larger companies sometimes do not compete as well in new product development. A better approach is to adapt procedures flexibly to a given project, based on its size, strategy, and other factors such as regulations specific to the particular product. Small projects should require far fewer controls and procedures, particularly if a dedicated team of modest size is used. Specific requirements may be negotiated among management, production, documentation control, marketing, and regulatory affairs. This process of adaptation should be begun at an early stage, forcing rethinking of the project schedule and leading to removal of roadblocks before they are encountered. The degree of control is low to start and increase as the project proceeds through its development cycle. The total investment, burn rate, and number of resources typically increase with time, and the number of design details and documents mushrooms (Smith and Reinertsen 1991).

In highly regulated environments, such as medical device development, the approach is further structured to include conformance to design controls. Documentation systems must be well developed and controlled, beginning with lab notebooks during feasibility evaluation which also serve to document inventions. Document control increases as the project proceeds through design development, verification, validation, assembly procedures and inspections, clinical trials, and regulatory submissions.

7.1.1.6. Streamline Control Systems

Control systems in development projects can be streamlined because the focus is on shortening the schedule using empowered teams, rather than on controlling costs using a top-down approach. Teams are typically much smaller in product development projects, requiring less management and supervision. Rapid development depends on motivated people who provide much of the direction, control, and tracking of their own activities. The combined effect of rewards for collective team performance, shared quarters, and frequent, open communication leads to a peer pressure to make good trade-offs about schedules and expenses as they collectively steer the project. Development projects are often harder to predict due to overlapping activities and less up-front information and planning, and the team responds to changes in real time of their own initiative, so monitoring against a defined plan is not very practical.

Traditional tracking of progress is designed to flag tasks that are behind, triggering management involvement, but does nothing to encourage or handle early completion. In fast-paced development projects, management involvement is more continuous, in a process of refining decisions and making mid-course corrections. Upper management and the project manager are involved in an ongoing reshaping of the product concept and refinement of the project plan. Often, the schedule is the primary constraint, so project scope and feature set may be reduced to maintain speed.

Written reports to management are typically less formal and briefer than in a traditionally managed project. Management prefers to receive information verbally and frequently, and may visit the team regularly to show support and interest.

Accelerated projects de-emphasize corporate control over expense burn rate, but accentuate a sense of schedule urgency. The cost control methods of traditional projects are often absent in development projects. Project costs are often well understood based on previous similar projects, and there is little benefit to tracking actual expenditures against projected budgets. In fact, spending more to gain a measure of acceleration is often pursued (Smith and Reinertsen 1991).

Controls on small procurements and expenses are typically relaxed, and authorizations for larger ones are streamlined so that approvals occur more quickly. Authorizations for large expenses are anticipated, just as are other long lead-time items in the project. Controls and structure are increased as the project proceeds.

7.1.2. Design Controls

In traditional, large projects, configuration management is typically very formal from an early stage and controlled by design reviews. This is understandable for technically complex projects that involve many subsystems, participants in many geographic locations, and funding oversight by a sponsor, such as NASA and Congress. A functional requirements baseline may be established in the conceptual phase, containing technical data about functional characteristics, demonstration tests, interface and integration characteristics, and design constraints imposed by operational, environmental, and other considerations. Approval is subject to a preliminary design review. Performance specifications are contained in a design requirements baseline, subject to review at a critical design review. As the system is built, a product configuration baseline contains information on acceptance testing, supporting literature, operation and maintenance manuals, and parts lists (Shtub et al. 1994).

In contrast, configuration management in fast-paced product development is much less formal and extensive. A collocated team, often with a dozen or fewer people, can move much more quickly when systems are kept to a minimum. This is not to say that systems have no place; some may be well integrated with design automation such as CAD and CIM, providing enhanced efficiency, particularly for derivative products for which drawings and test data already exist.

Requirements for design control and document change control systems may be extensive for some projects and industries but minimal for others. For example, the medical device industry is subject to FDA requirements on design controls, recently revised to better harmonize with ISO 9000 series quality systems, in addition to control of manuals, labeling, instructions for use, and promotional materials. This mandate has been met eagerly by a few medical device industry executives who feel that strong design controls enhance the bottom line, as well as improving product quality and safety, and meeting regulatory requirements (LaBudde 1998). Such systems, whose development may have come in response to regulatory requirements, are then available to enhance development productivity and time to market. However, these requirements are not welcome to new or small firms without established systems or multiple projects across which to amortize the expense.

Design control systems can provide enhanced communication within the team and with field personnel, traceability of requirements and design elements, and capture of change history. Designing and developing a complex product such as a medical device is an iterative, creative process involving many people. Rapidly changing design inputs, device architectures, and component designs can affect verification and validation plans. Changes to designs and documents, information from design reviews, and corrective-action observations must all be communicated among members of the development team, as well as with marketing, research, testing, manufacturing, and regulatory and quality systems. Keeping team members up-to-date with changes can be especially challenging when teams are geographically dispersed, involve outside suppliers, or are composed of employees from several merged companies.

Communication is enhanced by using systems that allow multi-user access across a network to documents, and which alert team members to changes.

Traceability is the establishment and maintenance of associations among elements of design and project management documents. Traceability adds value during the design and manufacturing process because it contributes to controlling and understanding user needs and product changes. It enables mapping of user requirements to design specifications, permits change-impact analyses throughout the product life cycle, aids in verification and validation testing, makes efficient use of existing test data when developing derivative products that reuse design elements, and contributes to speedy preparation of high-quality regulatory submissions.

Benefits of such systems include products that more effectively and thoroughly satisfy user needs, with fewer defects, recalls, and service calls. Thus, there are expenses and risks associated with ignoring or delaying investment in design control systems (McCay 1998).

On the other hand, elaborate systems impose significant costs in terms of initial development and the adoption of many new processes, methods, and tools. Manufacturers must consider the return on investment for such systems that contribute to design control compliance, and evaluate what aspects of the design control solution result in the biggest return on investment. These factors will vary among companies based on their marketplace, company culture, regulatory environment, technological advances, and previous investments in control systems.

Furthermore, systems should be applied flexibly to different projects, and adapted as the project proceeds. For example, document change control applied in the design phase places an undue overhead burden on the dynamic, creative process. By holding regular meetings, perhaps daily, and working together on prototypes, the team keeps each other abreast of changes in the design phase without resorting to rigid systems. Opinions vary as to when drawings should come under formal control. The best systems allow flexibility to apply different levels of control for different parts at various times, according to the need for stability versus the ability to make further changes. For example, a drawing for a long lead-time supplier may fall under revision-level control long before other machine drawings. If all drawings are controlled too early, the project will find itself bogged down in engineering change procedures. Having computerized control of drawings generated by CAD, for instance, makes purchasing's job safer, but waiting for part numbers may slow building of prototypes and pilot units (Smith and Reinertsen 1991). Typically, formal document change control procedures begin before pilot production phase. During production ramp-up, engineering change control procedures should be uniformly in effect.

This highlights one important benefit of early manufacturing involvement. By being involved in the design phase, before formal drawing control is imposed, there is much more likelihood that designs will be modified to accommodate issues of manufacturability and manufacturing cost. Manufacturing involvement will be discussed further in a later section.

7.1.3. Design Reviews

Formal reviews are a traditional method for monitoring progress, and one of management's primary responsibilities. Often, they are called design reviews, particularly when focused on the technical aspects. But, formal reviews generally have two functions. The first is to monitor primarily technical aspects, such as performance, cost, and manufacturability. The second is to evaluate business implications, including resource and budget needs, alignment with product goals, and authorization for continued development. Traditional reviews often combine these functions in one or several days of intensive meetings at critical decision points. As we shall see, these have several shortcomings — they are too infrequent to be effective in guiding the project, and too comprehensive to go into sufficient depth. Often, reviews bring projects to a halt while preparing and conducting them and responding afterwards to recommendations and action items. In projects that employ concurrent engineering approaches, the approach to design reviews must be modified to address these shortcomings.

In the traditional, sequential approach, upper management holds infrequent, large design reviews marking the end of each phase. The project as a whole moves on to the next phase when all the requirements of the preceding phase are met, at which time responsibility for the project often passes from one functional group to another. The project sponsor is often present to evaluate status and determine readiness to proceed. Upper management and the sponsor must give authorization to begin the next phase, or the group goes back to address inadequacies. A bottleneck near the end of a phase can slow or stop the entire project.

Such reviews are intensive and comprehensive, covering an entire project phase, limiting the degree of detail that can be explored. To compound this, the parties are relatively uninformed about technical details before the review. Traditional projects rarely use integrated teams or have ongoing upper management involvement, so little interaction will have occurred between reviews. The combination of this wide gulf of understanding, a large body of work to be reviewed, and vested interests can cause such meetings to be long, tense, and unproductive. Poor decisions and oversights often can result because people get tired of thinking and discussing (Meltzer 1994).

Traditionally, a successfully completed review calls for a long list of signatures to be obtained before work can proceed. In some cases, the people doing the development are more concerned with getting signatures than in hearing useful feedback or critique of their work. Because of the adversarial nature of traditional reviews, teams often focus more on selling their work than on objective evaluation and selection of alternatives. They may become excessively optimistic or engage, perhaps subconsciously, in biasing the presentations in their favor.

In the concurrent engineering approach, the concept of design reviews remains important, but their implementation and the dynamics among the participants is markedly different. Informal communication and monitoring of the project is emphasized, and formal reviews are shorter, more frequent, and more focused. Phases are overlapping or concurrent, which de-emphasizes the tollgate function of reviews. Teams are cross-functional and enjoy frequent upper management interaction, so the parties are generally very well informed and up-to-date. Both management and the team are constantly prepared to make fast decisions, because the competition and market opportunities may change at any time without waiting for the design review schedule.

The team is empowered to make most decisions internally, and takes the lead in monitoring its own progress and reviewing its own work. Progress becomes the subject of frequent informal meetings and discussions, and monitoring status becomes the responsibility of everyone (Hull et al. 1996). Meetings include regular team meetings, sub-group meetings for various tasks and subsystems, and purpose-oriented meetings called by the team. This last category includes various mini-reviews that might draw participation from various functional groups and other development teams with relevant experience or expertise. Mini-reviews may address concept alternatives, subsystems designs, drawings, procedures, or test results, repeated for successively more-detailed designs. Such in-process reviews are the engineering equivalent of in-process quality inspections in manufacturing (Smith and Reinertsen 1991). In-process reviews and regular progress reports during team meetings take a proactive and positive tone, rather than one of top-down review and management by fear.

The project manager, with upper management guidance, is responsible to see that the project remains within the desired scope, although this may change somewhat after the initial mission is given to the team. Preferably, a project scope is more likely to be reduced that expanded, in order to maintain schedule, and the atmosphere of urgency leads to some degree of scope self-control.

Reviews involving management are relatively informal and held more frequently than in the traditional phase-based approach. Because business and market environments may change dynamically, reviews often focus more on the market fit and product strategy than on review of technical details. Most products fail because of market issues, such as emerging customer needs or competing products (Reinertsen 1992). By holding frequent reviews covering smaller portions of the project, feedback can be gained more quickly and corrections made earlier. Reviews can be shorter and more streamlined, and the list of participants tailored to the subsystem or issue under review. While this approach may require more management time, it is rewarded by efficient use of time, better development of team members' skills, higher levels of motivation, more innovative and higher quality designs, better market fit, and higher financial returns due to earlier market launch.

The tone of management reviews is more collaborative and supportive than in traditional phase-based projects, aimed at accelerating progress rather than controlling or halting it. The focus of reviews is to weed out technical inadequacies, keep the project on target toward its commercial objectives, and control the start of critical tasks such as pilot production or clinical trials. Reviews are intended to motivate the team to do complete, defensible, well-documented work and to commit to aggressive yet workable timelines. To keep a review moving quickly, firms try to limit the number of participants and to distribute review materials in advance of the meeting to allow preparation. People from other development teams that have relevant experience are included in the review, as well as newcomers that may bring a fresh perspective.

Formal design reviews may differ in importance and approach from firm to firm. They are less likely to be important in smaller firms, flatter organizational structures, autonomous teams, faster-moving markets, and less-regulated environments. In some projects, a phase may be authorized to begin when a comparatively small list of managers feels that enough information exists to begin the earliest part of the next phase. Typically, the team is already authorized to begin laying the groundwork for successive phases without awaiting signatures. This may include making drawings before the specifications are approved, soliciting bids from vendors based on preliminary drawings, or beginning breadboards and early prototypes before the concept has been selected.

Larger firms that rely on functional structures will often rely more heavily on formal design reviews. However, they may find ways to modify the traditional process, motivated by the need to speed development and improve market acceptance while retaining upper management control. One example is a “tollgate process” adopted by General Electric in the late 1980s (Clark and Wheelwright 1993). GE traditionally had undertaken very large projects, such as jet engines, turbine generators, and plastics, and much of their work relied on strong functional groups with deep expertise. Newer projects tended to be smaller and relied less on functional expertise, while issues of time-to-market and fit with market strategy were increasingly important. Management wanted a consistent process that could be applied across an increasingly diverse set of business, to smaller projects as well as large, breakthrough as well as derivative. Their objective was to improve management intervention to manage risk and maximize resource utilization against major market opportunities.

GE's solution was a "tollgate process" consisting of frequent reviews attended by senior management, each focusing on smaller chunks of the project to make sure that projects could not get very far off track. These reviews began early, during conceptual development, and maintaining high involvement throughout. Projects for which this process was used lasted two to four years, with phases that overlapped somewhat to increase the cross-functional interaction. In addition to the integrative function of the business-oriented tollgate reviews, program managers were assigned to coordinate across functions through a team of representatives (i.e., a "lightweight" structure).

General Electric's tollgate process kept management actively involved, increasing business orientation in an otherwise technology-driven culture, and giving them a chance to terminate or redirect projects at frequent intervals. It is an interesting compromise between the formal, infrequent phase reviews of traditional project management and the more frequent, informal reviews of a heavyweight team. The tollgate process consisted of ten management reviews:

1. Customer/Consumer Needs: Quantification and articulation of the nature of the customer needs. Generation of product line management/marketing concurrence on desired product specifications.
2. Concept Review: Conceptualization of product design alternatives in response to definition of customer needs. Authorization to develop product prototypes.
3. Feasibility Review: Presentation of product design approaches.
4. Preliminary Design Review: Agreement on product design and manufacturing approach. Authorization to make pilot equipment.
5. Final Design Review: Final product design. Final equipment design.
6. Critical Producibility Review: Verification that in-plan production on prototype equipment replicates the final process (on small scale) as it pertains to product, process, and equipment.
7. Market/Field Test Review: Review of results of market and field tests conducted with products made on prototype equipment.
8. Manufacturability Feasibility Review: Final equipment review in production mode.
9. Market Readiness Review: Verification that all marketing steps have been completed prior to product introduction.
10. Market Introduction and Follow-Up: Determination of what changes (if any) need to be made in product, process, etc..

7.2. Structuring the Project

7.2.1. Traditional Project Planning Methods

The traditional method of structuring project work centers on generation of a detailed work breakdown structure (WBS). The WBS is a blueprint for execution that defines objectives, deliverables, and specifications for each task, plus schedule, budget, resources, and personnel assignments. This process of disagreggation and integration involves considerable up-front planning to reach the necessary level of detail.

Once tasks are defined in the WBS, scheduling can be accomplished by creating network diagrams of the tasks or task groups, indicating precedence relationships. The best known network techniques are PERT (program evaluation and review technique) and CPM (critical path method). The major difference between the two is that CPM assumes that activity durations are deterministic, while PERT treats them as random variables, characterizing them as optimistic, pessimistic, and most likely values (Shtub et al. 1994). Use of computer programs allows extremely large and complex project networks to be constructed with finely detailed modeling of tasks and their probable durations. Large projects traditionally develop a hierarchy of charts, beginning with the major milestones or phases, and working down to the detailed level (Heisler 1994).

Traditional projects often rely heavily on the WBS for generation of resource loading, schedules, and budgets, which typically are needed at a very early stage for the project proposal. Even before the project begins, a detailed WBS, schedule, and bottom-up budget must be prepared. This is essential if firms are bidding for a contract from a single sponsor, or if subcontract bids are to be solicited for portions of the project. Controlling costs and efficiency are typically the priorities of large projects, so every effort is made to rearrange personnel assignments and task orders o smooth the overall resource requirements, a process known as resource leveling. This allows efficient use of a stable pool of resources. Often, overall duration of the project is of secondary concern.

The most widely used method for displaying and tracking progress is the Gantt chart, which enumerates activities along the vertical axis and their start and stop dates on the horizontal axis. This view emphasizes the scheduling of tasks but usually does not explicitly show task precedence relationships (Shtub et al. 1994). Network and schedule diagrams draw attention in various ways to the critical path of activities that determines the minimum overall duration, and aid in minimizing the critical path by adjusting personnel assignments. Tracking of development expense is often a major focus, and start dates of tasks may be delayed deliberately for the sole purpose of reducing development expense burn rate.

7.2.2. Accelerated Product Development Projects

In accelerated projects, less up-front task planning is typically done, due to the need for a fast start and the relative lack of complete information. Much of the information needed to guide the project is marketing in nature, and is generally regarded as soft and uncertain. This can be frustrating to engineers who often expect more precise direction from marketing (Smith and Reinertsen 1991). Project managers may find the early, relatively undefined portion of a project to be most challenging in terms of planning and structuring the work, particularly if the team is newly formed. This is the time to map out major objectives and work backwards, identifying the critical questions that must be answered quickly in order to make further decisions. Often, some initial prototypes or experiments can be identified, and the team can set out in a few different directions to gather information and identify more questions.

The following quote (Smith and Reinertsen 1991) from a monograph by engineering professor Billy Vaughn Koen, of the University of Texas, defines the engineering method in a way that is particularly relevant to the start of a project:

> “The engineering method [is defined] as the use of engineering heuristics to cause the best change in a poorly understood situation within the available resources. This definition is not meant to imply that the engineer just uses heuristics from time to time to aid his work, as might be said of the mathematician. Instead my thesis is that the *engineering strategy for causing desirable change in an unknown situation within the available resources* and the *use of heuristics* [Koen's emphases] is an absolute identity. In other words, everything the engineer does in his role as engineer is under the control of a heuristic. Engineering has no hint of the absolute, the deterministic, the guaranteed, the true. Instead, it fairly reeks of the uncertain, the provisional and the doubtful. The engineer instinctively recognizes this and calls his ad hoc method ‘doing the best you can with what you've got,’ ‘finding a seat-of-the-pants solution,’ or just ‘muddling through.’”

In the early days of a project, when information is limited and the design process is fairly chaotic, planning and control take on a different meaning. The perspective of the project manager is two-fold: defining the broad strategic objectives and major milestones, while planning only the immediate tasks necessary shape the project direction. Initial planning is kept to a minimum, focusing on a few critical questions and long lead-time items. Only as the project end points become better defined is a more detailed plan possible. Detail is developed in a rolling fashion, recognizing the effects of uncertainty and the inherent inaccuracy of longer-range estimates.

Tools such as a WBS, PERT/CPM networks, and Gantt charts are still used, but the philosophy differs and the limitations of these tools become more apparent. An accelerated development project plan is much more fluid than for a traditional project, and opportunities to change the plan are constantly explored. The goal is not to plan everything up front, but to answer the most pressing questions first, loosen dependence on high-risk tasks, adjust to new information, and shorten overall development. So, network diagrams and Gantt charts typically reflect a higher-level, simpler breakdown of the work, and the level of detail diminishes for tasks further in the future. Planning responsibility is more distributed, and team members may be responsible for generation of plans and schedules for the tasks they conduct. The project manager integrates these data into an overall plan and schedule.

PERT and CPM models have many limitations, even when used with traditional projects, such as difficulty in accurately estimating durations, variances and costs; the questionable validity of using beta distributions to represent durations and of applying the central limit theorem; and heavy focus on the critical path. The models are highly sensitive to the activity time estimates and precedence constraint definitions. Delays may cause the critical path to shift among various branches, rendering previous priority setting invalid. Such networks may be highly inaccurate for other than short-term calculations, particularly for fast-paced development projects that change content over time. The network formalism tends to limit the flexibility that is the hallmark of an integrated team. As the project progresses, the ordering of tasks may change considerably, invalidating older versions of the model unless complex contingency planning was done up-front. Management responses once errors in the estimates is discovered can themselves be costly; underestimates can result in reallocation of resources and delays, while overestimates can lead to unproductive management activity in attempts to shorten the schedule or accommodate the predicted delay.

If critical path models are to be used, a better approach would be to focus on critical activities, the ones with greatest duration uncertainty that lie near the critical path, and to isolate these so that overall schedule is minimally impacted by delays. Given the highly parallel nature of concurrent engineering projects, nearly any uncertain task may end up on the critical path. Thus, the focus should be on managing risk and contingency planning, rather than on calculating durations and managing the critical path.

In the concurrent engineering approach to product development, projects are analyzed in terms of phases, as they are in traditional sequential project management. However, phases overlap significantly and may be executed largely in parallel, rather than being sequential. The workflow is more continuous. Typically, tasks are scheduled according to the few critical interdependencies among them, rather than according to a strict ordering of their parent phases and detailed precedence constraints. Precedence relationships are thought of as softer, resembling flows of information rather than yes/no prerequisites. Consequently, network diagrams have less relevance since the precedence relationships are not always well defined. The emphasis on time favors use of Gantt charts.

In the traditional approach, tasks are reordered, delayed, and lengthened in order to limit and smooth development expense and resource requirements. In contrast, accelerated development projects usually work as quickly as they can with the assigned team, reordering tasks to speed resolution of uncertainty and accomplishment of key milestones, with much less regard for expense burn rate.

Scheduling and monitoring progress for small projects is sometimes accomplished with simple tools, such as a spreadsheet and checklist. However, if advanced scheduling software and systems are used, the firm should commit to gathering relevant information and learning from experience. Eventually, this will help refine plans and predictions by using this database in combination with bottom-up planning from those doing the work. Project management software is discussed later in this chapter.

One pitfall of detailed schedules and sophisticated software for generating charts and reports is that it distracts from face-to-face discussions. Charts give the illusion of certainty but do little to assure it. Regular interactions among team members keep progress occurring and status updates flowing. In a highly-interactive team setting, Gantt charts serve as a focus for discussion and a record of the commitments of individuals doing the work. Smith and Reinertsen, in writing about schedules such as PERT or CPM and Gantt charts in their book *Developing Products in Half the Time*, recommend against using software to keep plans updated due to the workload involved. Instead, they recommend using a CAD system to draw the overall Gantt chart, posting it on the wall, and marking them with colored markets or pins (Smith and Reinertsen 1991). However, there can be no denying the benefit of newer scheduling tools and software, assuming that they are used sparingly to fill real needs rather than as an end in themselves.

7.2.3. Project Activities in Each Phase

Traditional project management teachings provide a generic breakdown of project phases, very much like the phases described in systems engineering methodology but with a more managerial, cross-functional purpose. Older versions in particular betray the defense and aerospace genealogy, referring to construction, delivery, and operations of the “system.” Recent versions have been made more general, but still treat the project as a separate activity rather than an integral part of a product portfolio and business strategy. In contrast, firms that engage in product development tend to describe project phases in terms of a customized set of steps that is specific to the technology, firm, and industry. The start of the project is more clearly linked to market research, and the later stages reflect ongoing production and the need for successive product cycles. An example breakdown for a product development project, stated in generic terms, is given below:

1. Concept Development: A preferred conceptual design and advantageous architecture are worked out to achieve the desired level of performance for the target market.
2. Product Planning: Largely in parallel with concept development, early models are built and technical possibilities explored and tested to prove the concept, while financial and market planning proceed. Customer needs, preferences, and feedback are explored.
3. Product/Process Engineering: Here, implementation of the concept and architecture are accomplished. Products and processes are laid out in concept, captured in a working model (physical prototype or computer model), and subjected to tests that simulate product use. Changes are made to close performance gaps, and the design-build-test-analyze cycle repeats as needed. Medical device prototypes may be tested in animal or lab models that mimic human use. Engineering release signifies that all requirements have been met.
4. Pilot Production: During pilot production, many units of the product are produced and the manufacturing process is tested. Commercial tooling and equipment is in place, and parts suppliers are ready for volume production. Systems made on the production line are available for testing. Many factors come together for the first time: design, tooling and equipment, parts,

assembly procedures and sequences, and production personnel (supervisors, operators, technicians).

5. Production Ramp-Up: After the process is refined and debugged, a low but sustained level of high-yield production begins. Confidence is gained in production methods and supplier chains. Products begin to ship. Production works to achieve target levels of volume, cost, and quality (Clark and Wheelwright 1993).

Each industry or firm may have its own more particular breakdown of phases. For example, a firm that develops therapeutic medical devices might define its product development process in terms of the following steps, showing the importance of regulatory submissions, clinical studies, and related reviews:

1. Feasibility / Research.
2. Define user needs and design inputs.
3. Concept development and concept review.
4. Design development and design review.
5. Design verification and clinical readiness review.
6. Clinical study, if mandated by regulatory agencies.
7. Transfer to manufacturing, process and design validation.
8. Regulatory filing review

9. Physician preference testing

10. Design changes or line extensions

Within each phase, characteristic issues that each functional group must address are usually outlined in a product development procedure document or manual. In development projects using integrated teams and concurrent techniques, these issues tend to be somewhat less confined to a given phase due to upstream and downstream collaboration. For example, quality engineers might become involved in the in the design phase rather than waiting for the production phase. Manufacturing processes might be developed in parallel with design, often influencing the design. Field service might become involved at the prototype phase to provide serviceability advice.

Nonetheless, the breakdown by phases is a convenient way to outline activities and make checklists of deliverables, so that future project teams can inherit experience from those who have come before. The product development process is embodied in these documents, and learning from project experiences is captured and folded into revised documents. Learning may come from successes that cut development time, or problems identified in post-project audits. Documents may include flowcharts of the development process and tables of responsibilities for each functional member or group for each project phase. With each revision, the process is made more effective. The temptation to make the documents longer and more comprehensive should be avoided, since thick procedures are rarely used. A heavyweight or autonomous team needs only top-level guidance and checklists to stimulate their creative efforts at problem solving and proactive problem avoidance.

One example of such a tabulation is given in Table 4. This was taken from a study of a project to develop a new infant heart monitor by Medical Electronics Incorporated (Clark and Wheelwright 1993). MEI faced difficulties in achieving cross-functional integration, given the traditional functional organization used at the time. The authors of the study proposed this ideas summarized in this table as the basis for improving cross-functional integration. The table defines critical milestones along the development path from initial concept to full commercial operation, for three main functions: engineering, marketing, and manufacturing. One aspect featured is that product and process design begin simultaneously, but process testing and validation take longer due to longer lead times for tooling and equipment development. This is indicated by the two-stage detailed design and development phase.

Table 4. Functional Activities Map to Aid Cross-Functional Integration (after Clark and Wheelwright 1993).

Phase of Development	Engineering	Marketing	Manufacturing
1. Concept Development	Propose new technologies; develop product ideas; build models; conduct simulations	Provide market-based input; propose and investigate product concepts	Propose and investigate product concepts
2. Product Planning	Choose components and interact with suppliers; build early system prototypes; define product architecture	Define target customer's parameters; develop estimates of sales and margins; conduct early interaction with customers	Develop cost estimates; define process architecture; conduct process simulation; validate suppliers
3. Design Stage I – Detailed Design, Design Verification, and Process Development	Do detailed design of product and interact with process; build full-scale prototypes; conduct prototype testing	Conduct customer tests of prototypes; participate in prototyping evaluation	Do detailed design of process; design and develop tooling and equipment; participate in building full-scale prototypes
4. Design Stage II – Process Verification and Product Refinement	Refine details of product design; participate in building second-stage prototypes	Conduct second-stage consumer tests; evaluate prototypes; plan market rollout; establish distribution plan	Test and try out tooling and equipment; build second-stage prototypes; install equipment and bring up new procedures
5. Commercial Preparation	Evaluate and test pilot units; solve problems	Prepare for market rollout; train sales force and field service personnel; prepare order entry / process system	Build pilot units in commercial process; refine process based on pilot experience; train personnel and verify supply chain
6. Market Introduction	Evaluate field experience with product	Fill distribution channels; sell and promote; interact with key customers	Ramp up plant to volume targets; meet targets for quality, yield, and cost

The process shown in this table includes early and continuous activity by all functions (although only three are listed in this example), in contrast to a sequential “throw it over the wall” process. For example, input from the customer and from production are gathered during concept development. Also, prototypes are built early in development so that customers can evaluate them and interact with engineering and marketing before the design proceeds very far. In this way, designers have at least one feedback loop based on customer experiences during the design phase (Clark and Wheelwright 1993). All functions participate in design and testing.

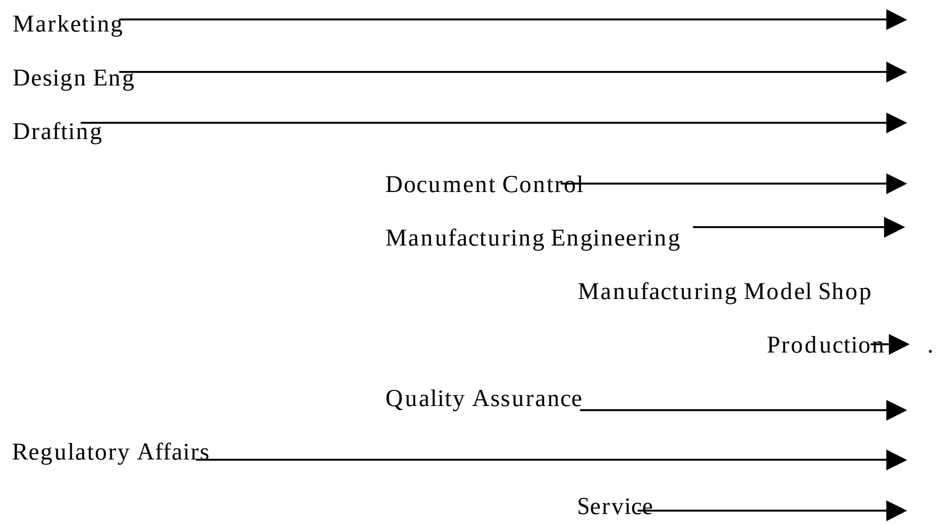
This table is a summary of only the high-level tasks for the three major functions, placing these tasks in the most relevant phase. Other functions are involved as well, as the firms internal product development procedure would indicate, no doubt. Among those functions not shown is quality assurance and reliability, which would participate in the translation of user needs into specifications in the product planning stage, evaluation of failure modes and hazards in the design phase, development of verification and validation test plans to be used beginning in the design stage, and so on. Furthermore, firms will likely break down the process to a finer level of detail, showing the specific phases that are required for the particular product technology, market, and management structure.

An example of a more detailed breakdown is given in Table 5 (split on two pages). This shows the product development process for a manufacturer of diagnostic medical devices (which have a lesser level of concern regarding safety and efficacy compared to therapeutic devices, and correspondingly fewer regulatory hurdles). Activities appropriate to each phase are indicated; but this should not be interpreted as advising the team to wait until that phase to begin planning and coordinating across functions. Creative solutions to speed development often result in tasks being moved earlier in the cycle, and occasionally, later.

For example, consider the process acquiring tooling, dies, and fixtures, which may be long lead-time items on the critical path. Injection-molded plastics, investment castings, forgings, and stampings can complicate efforts to shorten schedules. Tooling can be lengthy and expensive to produce, making rework even more problematic if tooled part do not perform as expected. One strategy to deal with this is to begin initial production partial tooling. This may cause initial part or assembly costs to be high, but this can be reduced by phasing in tooling. Another strategy is to commit to tooling that may not be perfected yet, which may provide a head start if rework is not needed, or can be followed by improved tooling. A third approach is to use so-called soft-tooling, which refers to quickly-fabricated tools that are made from relatively soft material and easily modified. A subsequent, more durable set of tooling is made after going to production.

The following table is relatively brief compared to what might be itemized in a firm's product development manual. The aim of such a manual is to provide guidance for the team in meeting requirements of the organization; if creativity and innovation is required, the procedure should be kept brief and flexible, perhaps 20 or 30 pages, so that it does not fall into disuse. Higher degrees of regulation and lower needs for innovation will tend to increase the size and detail of such a procedure. One obvious example is the high level of regulation in government defense or civil system development contracts.

Table 5. New product development phases and associated activities (after Rosenau and others). Continued on next page.

Phase:	**Feasibility**	**Optimization-Engineering Model**	**Design-Engineering Prototype**	**Pre-Production**	**Production**
Maximum Time (Months):	1 - 24	6	4	4	3
Key Goals:	Concept Proven	Functional model; System-level Design Frozen	Complete working unit; Pre-Production Release	Production Release	Product Shipping
Functional Specification:	Simple, First Draft	First Tighten; then Complete	Compliance verified		
Outside Activities:	Simulations or Animal Studies	⇑ Preliminary Clinicals	⇑ Full Clinicals	⇑ Product Announced	⇑ First Ship
Documentation:	Sketches	Sketches	Formal Drawings	Red-line Drawing Control (informal)	ECN Control (formal)
Departments Involved:	 Marketing Design Eng Drafting Document Control Manufacturing Engineering Manufacturing Model Shop Production Quality Assurance Regulatory Affairs Service				

Phase:	**Feasibility**	**Optimization Engineering Model**	**Design Engineering Prototype**	**Pre-Production**	**Production**
Key Decisions:	Continue to invest or drop exploration	Select most attractive combination of product attributes for initial market intro.	Whether production is justified; Confidence in regulatory strategy	Prod. methods, tooling design, vendor selections	Production Rates, inventory levels
Key Outputs:	Simulation or model demo of new concept	Approved Spec, critical path schedule for Design	Complete Docs for production, breadboard system, critical path schedule for pre-production	Production and testing of prototypes, final docs, production schedule	Products Shipping
Some Typical Activities:	Technology-critical experiments and analysis Process-critical bench & pilot trials Exploratory market research	Technical trade-off studies, algorithm development, critical code and board layouts Crude production cost estimates Market research and test marketing, Musts and Wants clearly defined, Market segments and competition understood	Boards laid out, production prototypes built, tested all critical functions Production cost estimates and schedule complete Product's promotion developed Discounted cash flow analysis Labeling ready for FDA	Complete designs, parts lists, scale up, formulas, QA plan, service requirements, test specs, vendor qualifications Product name selected, advertising planned, sales and distribution plans complete Final regulatory compliance Order long-lead tooling	Ramp-up production Final service and training manuals Final sales support materials, advertising, promotion
Schedule, cost, risk trade-offs:	Parallel concepts? Size of effort depends on strategic importance Acquire technology?	Scope versus schedule Parallel designs or models? Authorize long-lead items prior to design phase?	Authorize long-lead items for pre-production?	Authorize long-lead tooling for production?	

7.2.4. Technology Transfer

One reason for breaking work up into phases, particularly in traditional projects, is to denote transfers between organizations responsible for those phases. At these transfer points, information must pass between groups and decisions must be made.

Many types of technology transfer have been studied in the literature. Entities involved in technology transfers include outside organizations such as laboratories, universities, suppliers, other companies, and even customers. Reasons may include purchase of technology, licensing, and research grants. For the purposes of this paper, we will focus on the more common problem of internal phase transfers within a single project, which involves groups such as central research and development, divisional research and development, divisional engineering, manufacturing, and marketing.

Organizational and project structures have a tremendous impact on the frequency and quality of communication that constitutes technology transfers. One reason that autonomous or heavyweight teams work well is that inefficiencies and discontinuities in the transfer process are largely avoided. Furthermore, teams that use early simultaneous involvement benefit from the synergies that arise during collaboration, a benefit that the traditional concept of technology transfer ignores.

To evaluate the effectiveness of internal technology transfer, Souder analyzed 256 projects in his database. First, he looked at technology transfer within projects in terms of a generic technology transfer process, shown in Table 6. Specific phases are defined, noting the typical problems and conflicts that arise in each. Roles of each participant may change from phase to phase, whether as listener / observer, consultant, decision-maker, or performer. Note that this generic model represents a relatively traditional organizational structure and phase-based approach, with clear boundaries between functions and well-defined contributor roles. Souder had developed this model beginning in 1976, so it is not surprising that it reflects a traditional approach. Nonetheless, this is a reasonable basis for a model, because it is conceptually clear and represents the most problematic case to study.

Table 6. Souder's Core model for phase transfer process (Souder 1987).

Inventor:	Major Decision Role				Consultant			
Designer:				Listener	Major Role		Consultant	
Engineer:			Listener			Major Role		
Marketer:			Consultant		Minor Role		Major Role	
Manufacturer:			Listener		Consultant		Major Role	
	Personal Selling ⇓	R&D Decision ⇓	Major Decision ⇓	Major Decision ⇓		Major Decision ⇓		
Phases:	Concept Generation	Concept Development	Concept Elaboration	Product Definition	Product Engineering	Pilot Start-up	Manufacturing	Marketing
Funding:	Shoestring funding	Pilot R&D funding	R&D funding	Organizational funding				
Typical problems, barriers, and conflicts	Disagreements over the technical means and the priority of the idea.	Inability to agree on the product specifications.	Problems of trust, e.g., R&D may be reluctant to hand off the idea to the next party	Conflicts over different perceptions of the product.	Conflicts over cost-performance design trade-offs.	Problems of facilities available.	Problems of capital allocations and scheduling.	Problems of commitment, e.g., lack of sense of ownership of the new product.

7.2.4.1. Stage-Dominant Model

The SD model is characterized by specialized functional groups that are separated from each other. Participants describe their activities in terms of finite responsibilities and limited authorities. They describe their work in terms of owning only their narrow responsibilities rather than of the overall project. Institutionalized transfer points denote hand-offs between parties with formal change of responsibility, at which point emotional commitment ends. No one party has overall responsibility for the multiphase effort. Communication is by written status reports between executive managers.

7.2.4.2. Process-Dominant Model

The PD model is also characterized by specialized functions. However, there are no apparent discrete transfer points. Rather, a gradual transition of technologies and responsibilities occurs, with personnel transitioning to other projects. Participants describe their work in terms of finite periods of interactions, instead of distinct hand-offs or continual interactions. Awareness is limited to immediately adjacent functions, with which they work in ad hoc fashion until both are satisfied that sufficient know-how has been transferred. Transfer occurs in the manner of a short-term miniature task force involving two or more persons from adjacent linear phases for a finite time. Communication is largely verbal between liaisons.

7.2.4.3. Task-Dominant Model

The TD model uses a team model and has no identifiable hand-off points. Personnel are functional specialists, but not as rigidly designated as such. They discuss their work in terms of the end product, the overall schedule, and their contribution to the whole. Responsibilities are not restricted to specific phases. Communication channels are frequently crisscrossing and overlapping, using all types of media. A dynamic overlapping of roles and team spirit is common, characterized by active outreach and partnership, resulting in a flexible responsiveness that enables it to deal with change.

The characteristics of these three models are summarized in Table 7.

Table 7. Significant Characteristics of stage-dominant, process-dominant, and task-dominant models of technology transfer (from Souder 1987).

X = This item characterizes this model

Significant Characteristics	*Phase Transfer Models* *SD*	 *PD*	 *TD*
1. Personal Interactions			
Infrequent, Short Duration	X		
Periodic, Short Duration		X	
Frequent, Continuous			X
2. Division of Tasks			
Well-Defined	X		
Flexible Boundaries		X	
Overlapping			X
3. Information Flows			
Limited to Need-to-Know	X		
Only at the Technology Transfer Points		X	
Free Flow, All and Anything			X
4. Communication Media			
Written Only	X		
Primarily Verbal		X	
All-Channel, All-Media			X
5. Coordination Mechanisms			
Clearly Defined, One Person	X		
Spread among Several Persons		X	
Diffused among Team Members			X
6. Cost Control Center			
Department Cost Center	X		
Two-Department Center		X	
Project Cost Center			X

7.2.4.4. Relative Effectiveness

The effectiveness of each of these three models in terms of phase transfer success was evaluated under conditions of easy or difficult technologies (in meeting project technical targets), and easy or difficult market environments (in meeting customer expectations and commercial objectives). All three types of projects were about equally successful when technology goals were easy (about 80%). But, when technology was difficult, only the TD model maintained its effectiveness. The PD model dropped to 56% and the SD to 33%. This matches our expectation that team structures should be more effective with challenging technologies. Results as a function of market difficulty are analogous to those for technology difficulty. The TD model has a slight edge over the other two under easy market environments, but this advantage increases under difficult markets to a doubling of effectiveness scores.

The success of project outcomes was analyzed in terms of whether the technology was "accessible" or well understood at the start of the project. Again, the effectiveness of PD and SD models dropped off significantly when the technology was relatively inaccessible. The same was true when analyzed in terms of other variables such as the amount of organizational competency with a technology, and the degree to which the project was well defined. The reason for the robust performance of the task-dominant model in all cases appears to be the use of cross-functional teams with open communication flows, overlapping roles, and ownership of the entire project.

Souder examined the conditions under which the SD and PD models might be more effective than the team-oriented TD model. He found that the task-dominant model was impaired when used under the following conditions: low environmental uncertainty, stable market dynamics, routine technologies, rigidly defined task objectives, hierarchical R&D organizations, and heavy emphasis on paperwork flows. Under these conditions, team personnel became bored with the simplicity of the technologies and built products more elaborate than the customer wanted. Management attempts to restrict the team resulted in conflicts that delays. Team members found the emphasis on formal paperwork emotionally debilitating. Few such problems resulted when the SD model was used under similar conditions.

Such cases of a mismatch between the model used and the environmental conditions were not common in the database. Apparently, managers were able to select appropriate structures under most circumstances. Even if the TD model were effective under all circumstances, it would not be cost effective to use it when simpler methods would suffice. As we have noted, team structures have their costs and drawbacks, including reduced functional group communication and reduced management control. Each of the three models has its appropriate uses, as indicated in Table 8 from Souder (Souder 1987).

Table 8. Conditions for using the three phase models (from Souder 1987).

	Use the following model:		
Under the following condition	**Stage-Dominant (SD) Model**	**Phase-Dominant (PD) Model**	**Task-Dominant (TD) Model**
Environmental Uncertainty is	Low	Medium	High
Market Dynamics are	Stable	Variable	Constantly Changing
Technology is	Routine	Specialized	Poorly Understood
Innovation is	Incremental	Continuous	Radical
Task Objectives are	Rigid	Flexible	Fluid
Jobs are	Well-defined	Ill-defined	Undefined
Responsibilities are	Rigid	Open	Undefined
Communication is	Vertical	Horizontal	Multi-directional
Organizational structure is	Centralized	Decentralized	Matrix
Major Goal is	Minimum costs	Implementation	Idea Generation
Emphasis is on	Cost control	Activity control	Creativity
Source of funds is	Corporate	Division	Project
Source of Decisions is	Top Management	Group	Project
Familiarity with Technology is	High	Moderate	Low
Familiarity with Consumer is	High	Moderate	Low
Accessibility of Technology is	High	Moderate	Low
New Product Management Method is	Top-down structures	Project management methods or new product structures	Teams and taskforces

7.3. Requirements definition

In earlier sections of the paper, we looked at the process of identifying product concepts, and claimed that quickly committing to a well-chosen project was the easiest way to speed time-to-market. In a similar way, the requirements definition phase of a development project is critical to implementing that concept quickly and successfully in terms of market acceptance. This stage should be seen as a critical step in translating the product concept into a commercial success, demanding high-level attention from all participants. This is especially important if there is a high level of uncertainty such as a new technology or a new market segment, or particularly if both are present (Smith and Reinertsen 1991).

7.3.1. Common Problems

A poor execution of the requirements and specifications development can delay the start of design, derail functional group cooperation, stretch out development, unduly increase product cost, and damage market acceptance of the resulting product. The care that went into product planning and concept selection can be wasted.

Unfortunately, requirements and specifications documents are often churned out as if a procedural necessity that must be disposed of before the real work begins. Many firms seem to get this stage over with quickly to bypass the expected controversy and cross-functional conflict. It is understandably difficult to map out unknown territory and to put customer needs, priorities, and tradeoffs into words and numbers, especially given the many required inputs and agreements from various disciplines. Resulting documents may be inadequately specific, ambiguous, or even self-contradictory.

In other cases, requirements documents are not generated at all. Engineering and marketing may think they agree on requirements, only to find that perceptions differ as design progresses. Often, a requirements document may be viewed as “just paperwork,” as opposed to “getting something done.” Possibly, some parties prefer not to be pinned down, thinking they may wish to change their minds later. If fundamental questions about customer expectations and architecture are not resolved early, they will become embodied in designs, triggering delays, added expenses, and even greater conflicts later between functional groups.

Organizational dynamics can play a factor in poor specifications development. For example, marketing is strongly allied with sales and tends to focus on product features and comparisons to competitors. Marketers are more likely to want short development schedules and to be skeptical of development times estimated by engineering. Engineering tend to prefer to implement new technology, particularly developed in-house, and to improve measured performance. Engineers may perceive marketing indecision as the cause of most delays. Manufacturing prefers stability and efficiency and may resist the learning curve that comes with new technologies and processes.

7.3.2. Cross-Functional Participation

One way to deal with these problems is to have the functions collaborate in developing product specifications. All too often, marketing develops a functional requirements document, and engineering develops a specification document, each with its own jargon and vision of the product. A better approach is to involve all parties in developing the documents, preferably one single document, so that differences are worked out and agreed-upon solutions are recorded. Users and customers should be involved in appropriate ways, including meetings with the “thought leaders” in the market and handling of mock-ups and prototypes. Specifications then will reflect the cross-functional shared understanding of customer needs and preferences and product benefits (Smith and Reinertsen 1991).

7.3.3. Level of Detail

The degree of detail needed in product requirements and specification documents differs among various types of projects, ranging from a sketchy skeleton (Peters 1994) to a detailed, comprehensive product specification (Sahni 1992). Questions about the length and level of detail of these documents are valid subjects for debate, and firms differ in their approaches, just as project planning differs in its up-front detail. A small team developing incremental improvements may possess a very good understanding of customer needs and technical means to achieve them without needing much marketing input or a detailed requirements document. With frequent cross-functional interaction, there is less need for pre-defined checklists and agreements. On the other hand, a large project developing a complex system must rely on long, detailed specifications documents, hammered out among business partners in advance and based on technical standards.

A requirements document should address the market for the product, who the users are, their skill level, the quantity to be sold, demand for consumables, frequency of use, accessories, and clean up procedures. An important trap to avoid is unwritten assumptions. The user interface should receive particular attention, because marketers, customers, and engineers often perceive it differently. Often, these turn out to be seen differently by different individuals or departments. Adequate detail can be important to ensure that misunderstandings are resolved early (Meltzer 1994).

Documents need to be checked for consistency, lack of ambiguity, and completeness. They should also be scrutinized and compared with competitors' offerings and plans and the state of the art. It can be challenging to iterate the documents and gain alignment among all parties, but the interaction necessary to do so is a primary benefit of producing requirements documents.

7.3.4. Voice of the Customer

Product requirements should be linked to a rational process of gathering customer information and setting target features, performance, and benefits to the customer. Passionate focus on the customer is the central theme in creating distinctive products with long market lives, large market share, and premium prices. To maintain development speed, this process should not become a bottleneck. Design activities are likely to begin and occur in parallel with requirements definition activities. In fact, prototypes are a primary way of sharpening customer insight needed for the requirements. Compared to the linear, traditional approach, project managers should be willing to proceed with the barest skeleton of a requirements definition (Reinertsen 1992). As the project progresses, customer information may become much more detailed, and both the requirements and design specifications will evolve.

Advocates of customer focus suggest continual interaction between the development team and customers to keep the product concept in line with the market. Engineers might discuss advanced technologies with expert customers and thought leaders, and focus on basic needs and features with the less experienced users. Often, engineers do not want to take the time, or do not enjoy being second-guessed by customers. Having a prototype evaluated by a panel of customers can be a humbling experience. However, engineers should learn to crave this feedback, using any opportunity to get it, such as trade shows, customer visits, and visits by customers to the plant. They should ask customers to be critical, to say what they hate, what is wrong, or what is not as good as the competition (Meltzer 1994).

Engineers should also learn how to be sensitive to the customer’s feelings and to concerns of sales people who often bring the two parties together. For example, engineers often explain how their product should be used, rather than listening to how it is perceived and used in practice. Engineers must learn not to lecture or show off to customers. Engineers often make the mistake of speaking about upcoming product innovations, causing customers to delay orders or at least triggering this fear among sales people. The sales person can often provide guidance in the interaction, and the engineer should respect their suggestions and preferences. The sales person works hard to develop relationships with customers and to present the product line to them. One way to help customers express themselves freely is to make the questions impersonal; for example, an engineer might say, "another customer told me that this feature was helpful. Do you think he was just being nice?" Or, he might ask, "another customer told me he would be willing to pay an extra $500 for this feature. Do you think that is really worth it?" This reduces the customer's tendency to avoid offending, and helps the engineer get past any defensiveness (Meltzer 1994).

Conventional wisdom is that specifications should be frozen early; this may be a response to the problems of creeping elegance, unclear product definition, or inconsistent management direction. In practice, market conditions and customer information change, so specs must change from poor initial guesses to a more refined, informed set. Compromises may have to be made regarding features and performance to balance time-to-market considerations. As a result, specifications often finalize gradually. Allowing change in specifications should not be taken as permission to avoid requirements definition, differences of opinion, or interdepartmental conflict. Rather, changes should arise from a deliberate choice to limit initial definition in favor of early prototyping and a concerted effort to bring in new information and deepen understanding of the customer and technology.

Specifications should focus on customer benefits that the product will, rather than features or design options. As the project moves into the design phase, the development team should have the widest possible flexibility and range of choices to optimize trade-offs among speed, cost, performance, and expense.

7.3.5. Quality Function Deployment

The quality function deployment (QFD) process may be used to assure early consideration of trade-offs among customer requirements and systematic linkages with design specifications. This is an excellent tool to keep focus on the customer perceptions, on competitors product benefits, on the relationship of specs to underlying customer requirements. Many misunderstandings about user requirements and poor tradeoff decisions can be avoided by carrying the QFD process forward beyond the requirements definition into the design process. It can serve to carry the voice of the customer all the way to the manufacturing line, guiding any changes under consideration. Reported benefits include reduced costs and time to market, and increased reliability (Clark and Wheelwright 1995). When used well, QFD can result products with brilliantly chosen and well implemented features that capture the loyalty of customers.

An additional benefit of the QFD process is that it helps bring functional members together and promotes interaction, rather than merely shuttling specifications drafts back and forth that are easily ignored, misunderstood, or approved without adequate review. Creating a specifications document is too multifaceted and fragile a process to perform sequentially. Collective participation in writing them promotes discussion of many factors, including relevant customer needs, the degree of technical innovation, the scope of changes made to existing designs and processes, the price range, competitor’s products, and the intended advantages or positioning of the new product. This allows everyone on the team to start evaluating concepts, technologies, potential problems, and needed resources. The product requirements will then better embody the customers’ point of view.

One drawback of the QFD process is that participants may become mired in the mechanical procedure and detail, and lose sight of the objective. Users often complain that the process is carried beyond the point of revealing useful insight (Smith and Reinertsen 1991). This may be minimized by keeping the focus on building a mutual understanding of the product and the critical linkages that are needed to make important trade-off decisions.

Another limitation is that QFD is not a customer research method, but a decision framework based on customer inputs. QFD is most powerful when combined with top-notch market research using techniques such as choice modeling. Lack of good market research techniques may be one cause for lack of QFD adoption in product development outside of a few applications such as the auto industry.

7.3.6. Practical Suggestions

Often, an off-site workshop is an appropriate place to bring the necessary focus and collaboration in generating the key requirements. Another purpose of the event is to begin to build understanding and support for the concept and design among the participants (Smith and Reinertsen 1991). As with many types of collaborative meetings, a facilitator should be chosen that is perceived as having a neutral position regarding the outcome. Otherwise, participation may decrease.

Many specifications documents contain excess detail about aspects that are easily described and understood, to the neglect of some of the most important aspects of the product (Smith and Reinertsen 1991). Frequently, boilerplate verbiage is inherited from previous products, producing the appearance of an evolving document, but with little meaningful content. Writers should force themselves to focus on the most crucial elements of the product. They should focus on areas that are new to the present concept and, hence, less likely to take care of themselves, and on areas for which specifications have failed in the past. Only after the crucial and new aspects of performance are specified should checklists of relatively obvious or secondary requirements be added.

During the early days of a fast-paced project, it may be hard to get a team started on writing a specification. Little is known at the outset, and information is arriving rapidly. It is best to start early and use the incomplete specification as a focus of discussion and as a “living document.” This will prevent the perceptions of different groups from diverging, and promote convergence. Fortunately, short product cycles have the advantage of limiting the window for specification changes, so the document is likely to remain relevant.

For situations in which QFD may be perceived as excessively structured, lengthy, or formal, author Robert Meltzer suggests another way to evaluate trade-offs between engineering and marketing. Functional groups can define rating scales for various features representing their perceptions to aid in communication and negotiation with other functional groups. Marketing can rank requirements in terms of a "scale of desirability," intended to communicate the expected impact on sales. Rankings might range from "beyond customer expectations, will knock their socks off," represented by rank five, to "we have this feature now, and it must be at least as good" represented by rank one.

Similarly, Engineering can reciprocate by providing a "scale of engineering difficulty" to help marketing understand lead-times and the degree of technical and schedule risk associated with various desired features. Meltzer's version starts at rank one, representing "prior art," then continues up through rank five, for "no one has done this before, but the technology is now available," up to ten, representing "cannot engineer past the physics." The point is not that difficulty in itself is to be avoided, but that the costs and risks must be weighed against benefits to sales and market strategy.

Meltzer, whose expertise is in the medical device field, suggests that a matrix of engineering difficulty versus marketing desirability be charted, placing numbers representing requirements into the appropriate box of the matrix. Using this visualization, marketing and engineering are able to discuss features and trade-offs with a better-shared understanding, leading to faster agreement and better prioritization. For example, features in the quadrant of high desirability and low difficulty will easily be agreed upon. Those with high difficulty and low desirability should be readily dropped. Care should be exercised regarding those of high difficulty and high desirability, as too many such features will increase schedule risk and strain engineering resources (Meltzer 1994).

Another tactic recommended by Meltzer is to write the operator's manual at an early stage. The manual defines the product in non-engineering terms, and can serve to focus both engineering and marketing groups on the customer experience. Writing the manual can bring up assumptions for discussion and force evaluation of details at the beginning of the development process.

7.4. Challenges in Cross-Functional Integration

This section addresses a few of the many barriers to achieving cross-functional integration in project work, adding a few comments to those contained in earlier sections. Despite advice by many authors to employ cross-functional teams, many organizations find a balance between functional and project structures serves their interests best. These “balanced” teams are somewhere on the continuum between lightweight and heavyweight structures. Many consist primarily of engineering disciplines, such as the Intel example, often including manufacturing engineering. Others integrate stronger participation by marketing to help projects track evolving customer perceptions and competition. Organizational and team structure does have a considerable impact on cross-functional integration. However, we must also recognize that the formal organization chart is not a complete representation of a far more complex set of informal relationships and dynamics (Smith and Reinertsen 1991). Interpersonal networks of alliances and departmental agendas can alter the functioning of an otherwise well-designed organization. Similarly, employee role definitions do not assure that individuals will function as envisioned. Personal and functional alliances or differences in opinion on strategic or tactical matters may create factions within the team and the wider supporting organization. This section explores some cross-functional roles, common problems and approaches to resolving them.

As discussed earlier, even dedicated team structures often have problems coordinating with other teams and support groups within a firm. The team must be deliberate about how they are perceived, selling the project team and its capabilities to marketing, production, and management (LaFargue 1999). Functional and lightweight structures may find it difficult to gather early input and coordination among the variety of issues, including cost, quality, human factors, safety, regulations, assembly and testing, shipping, delivery, and repair. Fostering collaboration at the working level is more difficult still, requiring formation of ongoing relationships.

7.4.1. Issues at the Marketing-Engineering Interface

Problems in the engineering-marketing interface can be particularly troublesome, because issues can arise in the early stages of a project and continue throughout. Marketing and engineering often jointly establish the product-market segments that a firm intends to pursue, which is perhaps the most critical management decision for a technology company (Riggs 1983). Differences in product conception and target market can cause ongoing debates among upper management (or new product committees or structures, if used), marketing, engineering, and project management. Such debates often delay projects and can change their direction, often several times, wasting huge blocks of time. Nonetheless, some ongoing debates are necessary if a firm is to avoid rushing the wrong product to market.

In the author's work experience, teams were often directed by an engineering manager working with a product manager from marketing, each with similar authority and neither in charge of the other. Decision making between engineering and marketing was particularly troublesome, such as when technical solutions did not seem to optimally match customer needs, resulting in confusion about product configuration. Many approaches were used to steer teams and iterate product concepts. These included marketing conjoint analysis, prototype tests by key customers in simulations and animal studies, guidance from new product committees comprised of managers from across the organization, and discussions among the team, product planning committee, and customer advisory committee. In lower-risk projects, some stalemates were broken by compromises between the engineering project leader and marketing product manager. Market response was mixed and often led to design iterations.

Apparently, conflicts between marketing and engineering are common. Souder studied 289 projects in terms of R&D-marketing interaction quality. Over half of projects studied exhibit some disharmony, and the degree of disharmony was correlated with the eventual success of projects. Such conditions of disharmony were extremely difficult to overcome once they began, so prevention or early intervention is important.

Persistent misperceptions between functional groups were common. For example, marketing often wished that R&D would be more flexible and responsive, seeing them as impractical. R&D often held the position that marketing wants everything too quickly and is too willing to accept imperfect designs. Souder characterized the 289 projects into three syndromes:

- Harmony: Rich and frequent interaction with no significant or persistent problems.
- Mild Disharmony: This was characterized by a lack of interaction (which was common in type I and II organizations). People did not attend meetings and did not see the value in informing each other and asking questions. Documents were not routed to the right people. Projects arrived late or did not perform as planned.

  Also characteristic of this syndrome is a lack of communication. A deliberate separation was maintained due to negative feelings. Each perceived the other as stealing credit, and top management accolades often created jealousies. New products did not match market needs or missed necessary features.

Another form of mild disharmony arose from complacency, often resulting from past successes. This lack of friction led to a failure to question each other's methods and provoke change. High regard led to a blind faith and hesitancy to intrude. As a result, important information was often overlooked.

- Severe Disharmony: Distrust often resulted from past failures or perceived failures. In some cases, a lack of guiding principles from top management contributed. Personality conflicts became institutionalized in some cases, allowed to continue by top management. Dynamics often centered on the relative dominance of one of the departments. Reward systems only supported interaction within functions. Such projects yielded products that often failed to perform or were not cost effective.

Eight guidelines arose from data and from suggestions by members of the firms involved:

1. Break large projects into smaller ones of nine or less to reduce interface problems.
2. Take a proactive stance toward interface problems.
3. Eliminate mild problems before they become bigger ones. Severe disharmonies were extremely difficult to eliminate.

4. Make open communication an explicit responsibility of everyone. For example, use an open door policy, quarterly meetings, exchanges of personnel, evaluations based in part on this interaction. These took time to spread and overcome accumulated skepticism.
5. Promote and maintain dyadic relationships. Pairs can be assigned to work with another of complementary skills across the interface. Such Dyads became kernels of a wider circle of interrelationships.
6. Use task forces and product committees. These contain top level managers at first, shifting the membership to functional members as the project progresses to foster interaction and harmony.
7. Involve both parties early.
8. Clarify the decision authorities. Establish a policy that issues can only be brought to upper management bilaterally, to force negotiations.

An example of role clarification is as follows:

Marketing: Identification of potential customers; Conducting research to determine customer needs; Definition of demand and price-volume relationships; Analysis of market trends; Analysis of competitive products; Determination of price strategies; Forecasting market trends.

R&D: Technology forecasting; Choice of technical means to develop product; Development; Scheduling within time allowed; Allocation of resources.

Joint roles and responsibilities: These depend on the situation. Some technical functions require marketing knowledge, or vice versa. Some markets have customers that are much more technically sophisticated than others (Souder 1987).

7.4.2. Issues at the Engineering-Manufacturing Interface

Early manufacturing involvement provides three main advantages. First is to overlap two major tasks — product and process development — that were traditionally done in sequence. Second, working on product and process simultaneously results in superior design trade-offs that avoid the substantial downstream delays that result from poor upstream decisions. Product concepts are often based as much on process capability as anything else, particularly for certain types of products such as disposable medical devices and other process-intensive or low-margin products. By the time designs are being committed to paper, most of the basic choices that influence manufacturing cost and methods have been made. Early decisions have a limiting effect on later ones (Smith and Reinertsen 1991). The only way to make significant improvements in cost and quality is to make them earlier in the conceptual and design phases. Third, many problems can be avoided entirely if a process expert can steer the design team away from problematic processes or unproven capabilities (Clark and Wheelwright 1993).

Design decisions are also usually process decisions, and both have significant product cost implications. For example, consider an early engineering decision regarding materials and primary manufacturing processes. These in turn can influence requirements for materials strengths and properties still to be selected in later stages, such as plating, assembly, bonding, curing, coating, and sterilization processes. Without process expertise, engineers might design themselves into a corner. The best design decisions also take into consideration subsequent impacts, including JIT work flow, part handling and holding methods, contamination control, and inspections (Smith and Reinertsen 1991).

Unfortunately, process engineers are typically occupied solving problems out on the production floor when design engineers are making these important decisions. By the time process engineers see designs, controlled CAD drawings are already done, greatly decreasing the likelihood of modifications. However, if process engineers are part of product development teams from the beginning, then these problems may be worked out more easily on a chalkboard or sketchpad before the first CAD drawing is started. Design iterations are made, in most cases, before the drawing is made or controlled. Downstream, fewer iterations and drawing changes are needed, greatly speeding the process while resulting in higher quality designs. Manufacturing capabilities will be better leveraged because designs are chosen that make use of the organization’s skills, equipment, and experience.

There are several problems that can keep this from occurring. A process engineer is often busy cleaning up details of the last project while the next one is beginning. Designers are thus left to make decisions on their own, unaware that they may be committing to a problematic process downstream. One solution may be to free process engineers of other duties as a new project begins.

Another source of difficulty is that process engineers, once assigned to a development team, may lose touch with the details of production problems, becoming less effective at anticipating and preventing them. The environment of a design team and that of a process engineer in production have different paces, motivations, and priorities. If a process engineer moves full-time to a design facility, they may begin to make some of the same mistakes the designers do. For the same reason, it is not sufficient to have design engineers with process experience, although such cross training is valuable to both designers and process engineers. So, the best solution may be for the process engineer to spend a significant amount of time in both environments, yet with a degree of freedom from production problem solving.

Designers should also spend time on the production floor periodically to observe and analyze how their product might be manufactured. They can tour the factory, participate in production lines, and interview technicians and managers about critical process steps and bottlenecks. This can also establish contacts for keeping communication flowing upstream; it is unlikely that such visits alone with give the designer enough familiarity with production methods and problems. These steps will help improve producibility of future products as well as the present project. One advantage of having designers visit production is that their pace of work is much less rushed, allowing time for cross training and investigation. Production personnel are often on too tight a schedule to visit engineering offices, and their reward structure discourages taking the time (Smith and Reinertsen 1991). A “pull” system works better, in which the design engineers are responsible for obtaining manufacturing input.

Firms can do many things to encourage cross-functional teamwork and to institutionalize parallel product-process development. One common approach is to codify guidelines for designers to use that avoid production problems and make best use of manufacturing capabilities. Designing for manufacturability will be discussed briefly in a later section.

Manufacturing processes need the same kind of attention during development that the product design itself does. Process capability studies can be conducted to gives design engineers a measure of what can be done efficiently, maintaining high quality levels and yields. Efficiency involves issues such as availability of machinery, workability of tools and fixtures, orientation of parts, and workflow. Before a product engineer employs a new or modified process, it can be evaluated with manufacturing participation in an early process feasibility study, and later in a process validation. This may use prototype tools, early molds, and hand-made parts — whatever is necessary to give an early opportunity to evaluate production methods for the new product.

Pilot production runs come too late to identify these issues, but are nonetheless important in debugging processes and as a learning experience for product engineers, closing the loop on their design choices and expectations. Primarily, it is an opportunity for the development team to reduce down-time and minimize scrap or rework that may result at the switch-over to production — issues of top-most concern to production management.

Occasionally, creative approaches may be used to plan for production. Consider a new product that will require greater precision in manufacturing a particular component than is currently needed for present products. The firm may buy higher-precision machines or develop tools, and phase these into production lines for present products. This way, the capability to build to higher precision could be developed over time, before the capability would be needed. In essence, the present products would cost a bit more because of the extra measures needed. But, parts that failed to meet the new targets would still be usable for present product, avoiding losses due to scrap. Another approach is to assume that problems will be encountered, and to allow time in the schedule to ramp up the production capability, mistakes and all. Yet another is to anticipate delays from production changeover by building up a “safety stock” inventory ahead of time. Such creative approaches may be hard to sell to plant managers who have specific measures for productivity, cost, inventory, and scrap. Support from top management and some policy changes may be necessary.

7.4.3. Vendors and Contractors

Increasingly, firms are purchasing more critical high-technology components and subsystems, making reliance on external expertise during development more important. Manufacturers prefer to have more than one sole source for a component, avoiding the trap of having only one vendor capable of making a part or supplying exclusive technical expertise. Having multiple suppliers submit prices on a component tends to drive the cost down and minimize disruptions (Clark and Wheelwright 1995). Nevertheless, in many cases, having larger contracts with a single vendor allows negotiation of better terms and specifications and a closer, more trusting working relationship (Clark and Wheelwright 1993). Strong vendor relationships can extend a firm’s product development capabilities without requiring them to gain expertise in all incorporated technologies. Both firms may benefit from joint creative efforts. This argues for early involvement of procurement and quality engineers in a project, as well as for long-range consideration of purchasing objectives in strategic planning.

In addition to strong vendor relationships, firms are increasingly using outside firms and contract employees to carry out a variety of functions that used to be fulfilled internally. Several factors contribute to this trend toward outsourcing, including organizational downsizing, fast-paced competition, and the increasing depth and breadth of technologies in products, firms are turning to contract engineering firms and consultants (Conn 1998). Smaller start-ups that need to conserve cash or firms extending their product concepts beyond their core competencies are particularly likely to turn to outsiders. Often, a business may prefer to handle development in house, but lacks available staff or specific expertise. Firms may turn to service providers, at first merely to speed development of a subsystem or to get help with a technical problem, but often find the relationship expanding. This may lead to acquisition of additional technical expertise, new inventions, and improved product concepts. Some companies may not want to invest in space or equipment, particularly for an unproven product. Outsourcing gives them the capability to test a product or explore a new business direction before making long-term capital commitments.

Providers offer many services, such as help with product concepts, feasibility studies, regulatory issues, patent applications, and manufacturing services. Contract service providers may take part in only a portion of a project or design, or build entire products. Some providers specialize in a particular function; others offer everything from concept development to delivery of the finished product.

Outsourcing is probably not a good idea when the function is a core competency, when staff and equipment are available, and when time is not an issue. Components that must be closely integrated with the rest of an instrument being produced can be challenging situations for outsourcing. Regulatory issues can become problems later in development; for example, a provider to a medical device manufacturer must have the necessary ISO standards and GMPs in place.

Issues of confidentiality and intellectual property rights should be defined up front as part of the contract. Both companies should have a clear understanding of the working relationship, schedule, contact persons, amount and location of participation, methods of communication, and duration. It is best to spell out as much of the business arrangement as possible in advance (Conn 1998). Nonetheless, the day-to-day sharing of information and problem solving must be based on trust, just as it is with internal team members.

Vendors and contractors pose special problems in cross-functional integration and collaboration. Their representatives may participate as team members, at least to a degree, working closely with product engineers as well as manufacturing engineers. They do not necessarily share the same motivations and behavioral norms, requiring some special sensitivity and treatment.

Procurement engineers may work with a team on a regular basis to help with these external relationships. In the investigative phase, purchasing can help establish price, performance, timeliness, quality, and reliability objectives and trade-offs. Later, purchasing can inform the team about various suppliers' abilities to meet those objectives. After alternative conceptual solutions are developed, purchasing can determine economic and schedule implications for the materials, components, and subassemblies needed by each option. Identification of standard items available from multiple suppliers can also be provided during the design phase, and trade-offs among performance, reliability, and cost can be aided. Once a manufacturing plan is established, procurement should challenge any uneconomical or unwise requirements. During production, purchasing can pursue cost reductions from suppliers, and help evaluate proposed engineering changes.

Firms sometimes acquire technology or developed products from other sources in an effort to speed development. This can help the firm make up for lost time or missing capabilities. But, it should be recognized that this may not provide a head start compared to other firms who may have been working on similar products for as long or longer than the source from which it was acquired. Also, acquisition means that some profits will have to be shared and some ongoing dependence is implied. Such strategies may work well if the two parties have complementary capabilities in development, sales, marketing, or distribution that provide advantage over competitors (Rosenau 1990). However, technology transfer from an external source is likely to be even more troublesome than internal transfer, with different company cultures and various conflicts that can arise when the originators must turn over control.

7.5. Risk Management

Throughout this paper, reference has been made to the different approach to risk in fast-paced product development projects. Development projects are risky — perhaps only 20 percent of the result in successful products or processes (Riggs 1983). Accelerating schedules and using state-of-the-art technologies may further increase chances of failure. Project managers need to balance all types of risk, work concurrently on them, and manage them according to their impact on the business objectives of the business. Starting with limited information, managers must use a strategy of risk reduction over time and risk containment (Laufer 1997).

We have distinguished between technical risk and market risk. Technical risk is the probability of failing to meet the performance targets of the product specification. Sometimes, product cost targets are also grouped with technical risk, particularly if technological innovations to reduce cost are being attempted. Market risk is the probability of not meeting the needs of the market, assuming that the specification has been satisfied. Schedule risk can be considered part of market risk, because the impact of delays manifests as loss of sales, market share, and penetration. For the most part, risks associated with new products are more commercial than technical (Riggs 1983). High product costs or low margins may result in a decision not to commercialize a product.

Proactive approaches to risk management are required. A reactive response to problems combined with a “success-oriented” schedule invariably will result in numerous surprises and delays. Project managers and core team members must identify high-risk areas early in the project, keep them visible and under discussion, and minimize and balance their impact. Proactive risk management means reducing risks you can control, while planning for what you cannot. A wisely implemented concurrent engineering approach can make dramatic improvements in development time without significantly increasing technical risk, while possibly reducing market risk.

When schedules are shortened, the most obvious casualty will be performance or quality. Using partial information and assumptions to perform tasks in parallel will certainly increase technical risk. This can be compensated for by anticipation and management of risks, by use of cross-functional teams, and by designing with attention to all phases of the product life cycle, such as manufacturability, reliability, and maintainability. Use of early mockups and prototypes, handled by cross-functional members and customers, can help bring problems to the surface. As a result, technical risk may not be increased at all.

Minimizing market risk depends on customer deep knowledge and ongoing customer feedback during development, and on development speed to avoid being caught by changing market conditions. Commercial failures usually result from having inadequate market research, from having specifications that fail to define what the customer needs or desires, or from the earlier introduction of competing products. For this reason, development teams often include marketing expertise and customer representatives, and approaches such as market research, quality function deployment, and customer interaction and prototype evaluations. These help get the specifications right and refine them over the course of the project, which can dramatically improve market acceptance. Market research also evaluates competing products under development, helping avoid loss of sales to unanticipated competition. Market research requires analytical skills and techniques that the sales organization may not possess, given that their emphasis is on moving the present product line. Techniques include focus groups, competitive analyses, and an ongoing refinement and verification of industry intelligence. Typically, market studies precede development, and market tests follow it; but in fast-paced development, these need to be woven together throughout the project (Smith and Reinertsen 1991).

Traditionally, more emphasis placed on technical risk. Historically, project managers are more accustomed to dealing with it, and project management teachings offer well-developed techniques for assessing and avoiding technical risk (Smith and Reinertsen 1991). One is the close monitoring of development cost and technical progress. Another is investing in more time to get technical issues refined and resolved. But, there are drawbacks to these which, in fast-paced innovative projects, become too costly. An inappropriate level of monitoring can suppress team initiative and willingness to experiment. An empowered team works best when freedom to fail is an established value, so that creativity, experimentation, and honest communication can occur. Participants must feel open and unguarded about potential problems, to that they are not discouraged from discussing them. Excessive formality of design reviews or detail of planning will create excessive delays, more costly than the risks they are intended to avoid. The longer development lasts, the more market risk.

Too much emphasis on avoiding technical risk will yield longer development times due to over-management, but the completion dates will have smaller variance. In the few cases for which a predictable release date is more important than an early one, this may not be a problem. On the other extreme, too little emphasis on monitoring and control may yield shorter probable development times, but with larger variance due to possible unanticipated problems, that is, a higher likelihood of large schedule slips. The key is to balance these two, as appropriate to the marketplace. For example, computer products benefit from fastest time-to-market, while sporting goods are seasonal. Medical devices is a more complicated case to manage, requiring coordination of clinical schedules, regulatory approval delays, and medical conference trade show dates, with a strong pressure to reach market quickly.

One method to manage technical risk is to limit the amount of risk in any single task or project. An incremental innovation approach brings products to market sooner and more often, gathering info on smaller refinements and folding in running cost reductions. Technical challenges in each project are more manageable. Careful selection of product architecture can open opportunities to respond to market changes and user feedback in successive projects.

One of the most important ways of limiting technical risk is to separate invention from development. Feasibility studies and investigations should fall earlier in the development funnel, before a project team is launched and before incurring all the requisite expense and organizational effort. Selection of a product concept for development means that sufficient confidence exists in the technical approach, and that backup approaches exist for those that might be risky.

Backup positions should be maintained for both technical and market risks in development projects. If identified early, the best people can be put to work on high-risk tasks and their backups. Strategic initiatives might be pursued as backups such as partnerships to gain the needed technology or market presence.

7.6. Architecture

Product architecture can have long-reaching implications for a project and those that come after it. The step of committing to an architecture can be a difficult one. We tend to prefer to avoid decisions that limit our options, especially knowing that, if we choose poorly, there may be almost no chance of recovery. Usually this design choice is approached as a way to achieve performance goals or reduce costs. But, architecture can be seen as a tool for achieving rapid product development. The process of selecting an architecture requires some reflection and time, rather than rushing through it in order to begin the detailed design activities, the "real work."

A small team of high-level generalists is often more effective at architecture development for a new system project than a larger team of specialists. Generalists tend to focus on the basic design of the system, its architecture and basic specifications and logic. This team can be supplemented by a small number of specialists that are able to work within the established framework to implement the design (Smith and Reinertsen 1991). Technical specialists may overly influence the architecture according to the preconceptions and standard practices of their discipline, rather than thinking of customer benefits and product development implications of architectural options.

Upper management does not always give system design the attention it deserves. At this early stage of the project, the burn rate is too small to draw much management attention. If the system architecture is not done properly, it can prevent timely completion and market introduction. Often, these decisions are left to specialists, who are too far from customer and relevant business concerns to recognize these priorities (Smith and Reinertsen 1991).

The early part of a design process is the most highly leveraged period. During the first 10 percent of a design, decisions are made that determine roughly 90 percent of product cost and performance. Thus, the project manager must discuss technical details at length with relevant specialists to jointly evaluate the design options. Key questions and decisions during this period should be:

1. To what degree should functionality be modularized?
2. In which modules should functionality be placed?
3. How much reserve performance should be put in each module?
4. What type of interfaces should be used between modules?
5. How much technical risk should be taken in each module?

Each question has implications for speeding development and allowing for future changes. For example, modularity in a design may allow field upgrades or smaller incremental releases, and may enable sampling of customer response before committing to further developments.

7.6.1. Modularity

Modularity has several advantages. Most obviously, it affects the product configuration. For example, it can make a table-top unit smaller by putting the power supply elsewhere. But it also affects project management. Modularity allows a design project to be divided into separate tasks, which may then be run in parallel. It also reduces risk. For example, a problem may affect only one small module, so redesign will cause less delay and cost. If a technology used is changing quickly, it may soon allow higher performance or lower cost. Modularity allows smaller redesign efforts, with fewer changes to documentation. Changes can be implemented by field upgrades, and modules can be temporarily swapped out to allow sampling customer acceptance. On the level of product strategy, modularity allows easy design and manufacture of product variations. A modular line of products may enable a firm to address more market niches.

Modularity is not without its disadvantages. It can add to product cost if the modules are housed separately, and for additional parts and engineering of the required interface (both electrical and mechanical). Modularity can reduce performance if the interface is not adequately specified. In medical devices, separate modules can be combined more flexibly by physicians for off-label uses (combinations of products not specifically FDA approved), which offers the advantage of greater flexibility, but presents possible safety risks (Smith and Reinertsen 1991).

7.6.2. Functional Allocation

Choosing which modules should contain various functions requires rethinking the way they are used. For example, HP’s first low-cost plotter moved paper in one axis, pen in the other, allowing faster performance with lower costs. HP’s inkjet design relocated the print heads into the ink cartridge itself, reducing size and improving ease of use. Putting heads into the cartridge to form "pens" raised the cost of supplies, but users were willing to make this tradeoff. However, moving functionality between modules or locations can lengthen a product cycle (Smith and Reinertsen 1991).

7.6.3. Performance Targets

An over-ambitious or unnecessarily high performance goal will add to product costs. On the other hand, time might be saved a strategy of over-specification. For example, by designing a power supply in parallel with the modules it supplies, giving it more than enough capacity rather than waiting for a power budget to specify the power supply's components.

7.6.4. Interfaces

Interfaces should be as stable as possible to avoid redesigns. Designers should specify the interface early to allow for concurrent development of modules sharing the interface. Also, sticking with a design avoids the loss of morale that can occur when work has to be discarded following a change, which eventually leads the designer to slow his pace. To help keep interfaces stable, they should be sufficiently robust to tolerate expected loads and conditions. A bit of excess capacity can prevent the need to change it later on (Smith and Reinertsen 1991).

Using standard interfaces allows designers and suppliers to understand a design more quickly. Standard interfaces have long been debugged and characterized, and their strengths and weaknesses are well understood. Standards also aid in communication among design team, which is especially useful if designers are in different locations.

7.6.5. Technical Risk

No one module should contain too much technical risk, or its team may become bogged down and its schedule may become the critical path. Teams should quickly identify at least one technically feasible solution for each module, then leave designers to find improved solutions, if possible. Also, there is a compounding effect if too many modules each have significant risk. The overall risk becomes too high (being the product of individual risks). A better balance is to concentrate a reasonable amount of risk in a few modules, which simplifies communication and management, and optimizes aggregate risk. The best resources can be assigned to the most critical modules. Proven technology should be used in as many modules as possible, so that development can focus on the new and risky technologies.

7.6.6. Contingency plans

Contingency plans are recommended for high risk subsystems, in particular. This may call for lowering performance targets, or using less cost-efficient technologies. Modeling of trade-offs can be used to make these business decisions based on predicted economic outcomes. Usually, such models point to staying on schedule and using the less cost-effective technology, compared to a delay to reduce costs. Future incremental upgrades are always possible.

7.6.7. General issues

When developing system-level specifications, it is better to specify the desired functionality rather than the technology to be used to achieve it. This minimizes constraints on the designers and may allow for some creative optimized solutions. On the other hand, creep in features or technological sophistication must be monitored, otherwise systems margins may be overrun, triggering massive redesigns. This can devastate a development schedule. Early constraints may be formulated, such as "keep all circuitry on one printed circuit board," which appropriately constrains the technical scope without dictating a technical approach. Putting a cap on product cost can be tempting, but this is less effective because it is too hard to predict and involves too many assumptions. A better approach is to limit aspects that are easy to agree on, like weight, size, and so on (Smith and Reinertsen 1991).

7.7. DFM Tools

Implementation of cross-functional integration should be supported by whatever tools and methods that may be available and cost-effective. The discipline of Design for Manufacturability (DFM, here meant to include producibility and assembly) deserves special mention, as it represents the embodiment of downstream information from production and quality assurance that can be used at the start of product design. Designers are provided with methodologies that result in more manufacturable designs, including general principles and standards plus other information specific to the technology or company. DFM tools present designers with a variety of guidance, including design rules; design principles for efficient part handling, assembly, and reduction of part count; a portfolio of capable processes mastered by the firm; guidelines for selecting materials and tolerance values; libraries of qualified parts and vendors; and other structured approaches and information that bring the value of accumulated production experience to the center of the design process. Use of DFM techniques and tools is essential for speeding time-to-market, lowering costs, and improving quality. This is particularly true for process-intensive and low margin products. Implementation of DFM tools should begin in the concept phase, during which most of a product's cost is determined.

DFM approaches must be evaluated in a comprehensive view of the product development process. Some DFM goals add to development time, such as lead-time for combined parts, qualification of lower-cost parts and simplified modules, and development of new tooling. In fast-paced development programs, cost and efficiency of production may be deliberately compromised for the sake of speed. If long lead times to lower costs are likely to delay product releases, then other approaches may be sought. Because earlier product launch is often rewarded with premium pricing, a firm may allow its initial costs to be higher rather than delay market release. After release, cost reductions may be folded into successive product revisions, or completed as a running change in production as they are available. The product plan may deliberately make use of short, successive releases to accomplish these cost reductions and other goals such as incremental feature or performance enhancements. Modularity of architecture and reusability of parts may be important to this strategy. Together, these approaches may also allow more product varieties to be produced cost effectively. In this way, DFM structured methods are not a panacea, but have an important role to play, and affect strategic decisions about the project plan and architecture (Clark and Wheelwright 1993).

In fast-paced development projects, cross-functional team often include one or more manufacturing members, usually by the prototype phase if not before. One reason is to get a quick start evaluating trade-offs between manufacturability and other aspects of performance or features. Trade-off discussions may center on a list of possible product features, with members of different functional groups trying to communicate their perceptions to the team. Robert Meltzer suggests that manufacturing develop a “scale of manufacturing difficulty” to help in such trade-off discussions with engineering and marketing (Meltzer 1994). This scale ranges from a ranking of one, representing “we can meet specifications with present personnel and facilities,” through rank five, for “we can meet specifications by developing the needed process internally, for which feasibility has been demonstrated, but scale-up and improvements in yield and quality are needed,” to the highest rank of seven, representing “a presently unknown process or technique is needed.” In this way, participants can better understand the positions taken by other functional groups, speeding discussions and improving trade-off decisions.

7.8. Prototyping

Prototyping has been discussed throughout this paper as an important activity in fast-paced product development, particularly if uncertainty exists about the technologies used and product fit to market. At this point, it is appropriate to summarize and put this information in perspective, and to examine how prototyping strategies might vary according to the type of project.

Prototypes are an essential medium for information sharing, interaction, integration, and collaboration. Those firms that consistently employ rapid prototyping find their products reaching market faster (Clark and Wheelwright 1993; Peters 1994). "Effective prototyping may be the most valuable 'core competence' an innovative organization can hope to have," according to Michael Schrage, Research Associate, MIT Sloan School Center for Coordination Science. "Strong prototyping cultures produce strong products." But, the idea that developers can arrive at new products by playing with prototypes is anathema to managers educated to believe that predictability and control are essential. Schrage distinguishes between "spec-driven organizations" and "prototype-driven organizations." Organizations of the former type focus on analysis and design, the latter on experimentation (Schrage 1993).

Faster prototypes mean more iterations of the design-build-test-analyze cycle, more learning, and more optimization. Sony design executive Nobuyuki Idea claims the average time between product concept and rough working prototype is one week (Peters 1994). A primary goal of pilot production groups is to provide rapid prototyping services to development teams. If possible, prototypes for evaluating different aspects of design may be done in parallel.

Prototyping is traditionally done by engineering as part of a system or module design-build-test cycle, and later by manufacturing to work out processes and procedures. Marketing may build mock-ups to evaluate industrial design and customer perspective.

Prototyping takes on greater importance in fast-paced concurrent engineering. Prototypes are created in earlier and more frequently in a strategy to speed development and focus the cross-functional team on anticipating and solving problems. This process of periodic prototyping is seen as a high-leverage activity that is central to the development process (Clark and Wheelwright 1993). The team takes current thinking about a product, builds a prototype that embodies key aspects, and it is tested to determine whether assumptions are correct and further refinements are needed.

Prototypes may be of several forms. They may be representations such as CAD and solid models; simulations such as FEA, heat transfer, circuit simulation; physical geometric mock-ups such as foam, cardboard, stereolithography, or laser sintering; engineering models or breadboards that demonstrate functionality; and pre-production prototypes that resemble production units including the method of manufacture.

The use of incremental product cycles greatly enhances the ability to make prototypes; larger technological leaps or numerous changes can delay the point at which prototypes can be built. Partial solutions can be tested before they become embodied into detailed designs. Prototyping capability can be leveraged across multiple projects, sharing common support systems such as pilot production facilities and staff, to shorten development cycles across the organization (Clark and Wheelwright 1993). Several reasons for rapid prototyping can be listed:

- Proof of concept: technical approaches or combinations of features can be tried to verify the product concept at an early stage.
- Cross-functional collaboration: Early use of prototypes provides a focus that aids cross-functional discussion, bringing marketing, manufacturing, suppliers, and customers into the loop early. Concepts that might be discussed within engineering can be made accessible to others by embodying them in prototypes. Collaboration is enhanced because all functional members can handle and observe the prototype in their own ways. The prototype becomes the centerpiece for building a common understanding among the participants. Development of prototypes can focus attention on the manufacturing process at an early stage.
- Customer feedback: Customer feedback is tremendously improved in frequency and quality when a prototype is available to handle and test at the plant, the customer site, or a trade show. Concepts can be evaluated before the project proceeds very far. Prototypes offer a learning process that is particularly important for radical innovations beyond what the customer can ask for or envision, limiting traditional research methods. The result is

unprecedented levels of customer acceptance and reduced market uncertainty.

- Early insights: Fast experiments allow quick decisions to be made and alternative concepts to be eliminated early on, allowing the team to focus on a single concept. This early collaboration and iteration can begin in the requirements definition phase, resulting in specifications that better reflect the cross-functional shared understanding that usually does not develop until late in the project.
- Early changes: Prototypes made to sketches allow the team to learn and iterate before drawings are put under control systems. Even if early CAD drawings are used, they typically have a level of detail appropriate to prototypes and are often quick to produce. Changes can be made before formal control is imposed, resulting in better quality and fewer ECNs.
- Design optimization: The design-build-test cycle is critical to development and quality improvement. This may involve virtual or physical prototypes. Problems can be identified without waiting for system integration or regulatory acceptance testing. Changes can be made to close performance gaps, and the cycle repeats. Faster learning can result in higher quality, faster completion, or both.

- Project management: Managers should remain involved in guiding prototype development and evaluating results to keep projects on target and to help determine priorities and schedules.

To realize these benefits, a firm needs the capacity to develop prototypes quickly. This may involve a model shop staffed with creative machinists or a pilot production facility. Fast response from vendors and suppliers is also critical. This capability can be shared across multiple projects and generations of product. Prototyping costs should be reasonably inexpensive. Use of simulation can greatly reduce prototype costs and increase frequency (discussed in a later section). Often, higher-cost fabrication methods such as hand machining, or soft tooling may be needed to speed prototype development. This attention to prototyping capability pays dividends in acquired knowledge, which product development capability and shortens cycles with each project. Projects with greater uncertainties in technology or market fit will achieve higher payoffs from prototyping efforts.

The approach to prototyping differs depending on the kind of project. For one, the project objectives should determine which functional group should have primary control of and input to the prototypes. This presents a challenge to management to best match the details of the design-build-test cycles with the requirements of each development project (Clark and Wheelwright 1993).

- Breakthrough technologies call for an approach that focuses on evaluating performance and iterating specifications. Prototypes are developed in rapid response to the needs of engineering, rather than a more cross-functional team approach that might constrain technical innovation. Control of prototypes remains with engineering until fairly late in the project when manufacturability remain becomes important. Engineering interacts with customers who evaluate early versions.

- Platform system development focuses on the product architecture and behavior of the system. Many factors must be integrated, such as physical dimensions, ergonomics, software, sensors, aesthetics, ease of use, safety, and reliability. A schedule of periodic prototyping is recommended to evaluate system level performance on an ongoing basis. Prototyping remains a cross-functional team activity to focus on balance and integration, and allow evaluation of interactions and tradeoffs. If prototypes are only in the hands of engineering, the technical focus may skew the architecture and hurt customer acceptance. Specifications may be broadly defined early, but remain flexible and may be refined in derivative versions of the product.
- Incremental product refinement projects often focus on product cost or reliability. The basic architecture is unchanged, but manufacturability improvements are most important. Prototyping relies on early involvement and input from manufacturing, as well as quality and reliability. Control over prototypes passes to manufacturing relatively early in order to give these issues priority. Specifications are frozen early, and the focus is on

representativeness and replication. A team focus would be overkill and complicate the process.

Pitfalls in the prototyping process arise from several factors. Team members may not be equipped or inclined to deal with customers. This may require use of team representatives who possess necessary people skills, and suggests development activities for team members. Another problem is that differences between prototypes and final products must be minimized or addressed so that customer feedback is relevant. Lastly, the process of building prototypes is fast-paced and sometimes lacks adequate documentation to understand key decisions and reproduce designs (Frame 1994).

7.9. Computer Augmented Design Tools

Computer based concurrent engineering tools should be an important part of any firm’s strategy to improve speed, responsiveness, and efficiency. Concurrent engineering involves the co-design of the product by all disciplines and parallel performance of tasks, often by groups in different locations. Thus, the need for access to a common database and for tools to aid in collaboration is becoming critically important. Time-to-market can be further shortened by automation tools that increase efficiency, and these tools are becoming less expensive every day.

Many authors recommend the use of computer based tools such as CAD to accelerate and improve the design process. It certainly seems reasonable to assume that a well-defined and efficient product development process could be accelerated by tools for communication and automation. However, mixed results have been reported to date, possibly because tools have not been well matched to organizational needs, or because underlying problems in the product development process had not been addressed. Technological fixes can be appealing and may divert attention from the more difficult process of developing organization-wide improvements. Applying automation to the wrong process will just speed up the mistakes, while giving the illusion of progress (Smith and Reinertsen 1991). Another problem is that the tools themselves may not be designed with a true picture of human interaction or of how tools facilitate work in concurrent engineering. The design process is not well understood and therefore hard to automate. Differences in individual perception can make standard representations of data and models less useful than intended. Particularly in early design stages, team members interact and seek and share information in unpredictable ways that are not accommodated successfully by most CE tools (King and Majchrzak 1996). The market for CE products is still rather young, with some industries showing much higher adoption than others. Standards and user interfaces are still evolving. Furthermore, use of a common database can slow progress if it is seen as a rigid control system with forced compliance. It should be seen as a liberating tool that enables access to desired data and makes changes easier and faster (Smith and Reinertsen 1991).

At present, the use of specific tools should not be recommended in a blanket fashion. Implementation of such systems can be expensive and time consuming, and results can be poor if application is piece-meal or compliance and follow-through is weak. Instead, tools should be selected as part of a firm’s broader strategy for product development process and communications infrastructure development. Careful attention should first be given to a firm’s existing product development process to eliminate waste and bottlenecks while building a coherent enterprise-wide strategy. Review of best practices from related firms and industries may help identify the aspects of product development that can be made more effective. Specific prototyping and modeling needs vary depending on the technologies and products being developed. Computer-based tools should be selected and applied to accelerate critical design functions that a firm has committed to doing frequently and well.

Computer based tools, when applied in support of workable NPD processes, can help to compress schedules, reduce costs, and improve product quality, and thus require the attention of project management in product development. However, the study of such tools goes well beyond the topic project management, belonging more to the topics of information technology or business process redesign, and to specific technical disciplines. Consequently, coverage in this paper will be brief, focusing on a few examples and concepts relevant to project managers. Rather than discuss the alphabet soup of technologies and product names, our focus will be on the methods by which benefits can be realized, and on deciding when and how to implement such tools.

First, let us speculate about some ways in which computer augmentation might improve competitiveness, based on the principles outlined in this paper. Our overall objective is to bring higher quality products to market more quickly and at lower costs. Five general areas for computer augmentation are outlined below, along with some objectives that might be sought in each area:

1. Improving design tools:
    - Reduce design time
    - Increase use of inherited designs and experience
    - Increase early cross-functional involvement in design steps
    - Accelerate design-build-test-analyze cycle by using the most efficient means, such as simulations instead of prototypes
    - Improve speed and quality of simulations
    - Improve speed and quality of prototype fabrication
    - Improve customer requirements focus and product quality
2. Capturing information and ideas:
    - Improve documentation speed, completeness, and quality
    - Capture discussion sessions
    - Capture product design information for future reuse
    - Efficiently archive more data from simulations and tests
    - Harness lessons from past projects

3. Communicating information and ideas among various parties,
    - Increase the frequency of interaction across functional and organizational boundaries
    - Increase the speed and amount of shared data
    - Increase richness and choice of media, such as audio, video, whiteboards, and solid models for sharing information and ideas
4. Coordinating actions among teams, across functions, and in the wider design chain:
    - Publish project plans and schedules
    - Allow interaction with and updating of plans and schedules
    - Track task status, negotiations, and commitments
5. Enabling collaboration, often over long distances:
    - Provide shared spaces, such as video and computer screens, in which participants can dwell together and creatively generate new ideas and information
    - Enable interactions between people and various models, representations, sketches, and other representations, allowing them to view, modify, handle, and move virtual them.

In the above list, as in earlier sections, the concept of collaboration is highlighted. One reason for breaking this out separately is that the process of collaboration is poorly understood; consequently, tools intended to aid in collaboration among remotely located participants are often ineffective. Tools for communication and coordination are often referred to as "collaboration tools," but these are not enough to engender a synergistic, creative mutual participation. Communication is the act of conveying *existing* information or ideas; but, collaboration is the collective creation of *new* ideas, of co-creation in a collective entrepreneurship. Collaboration cannot be deconstructed as the mere conveyance of individually generated ideas and coordination of individual actions.

As essential element of collaboration is the generation of a shared understanding, such as when theorists pour over a chalkboard or musicians perform together or artists working the media with their hands. A shared space is always present, which may have physical, visual, auditory, tactile, or conceptual / metaphorical elements. Individuals spontaneously participate together within this space in a variety of ways, arguing, questioning, challenging, and building relationships. These activities help bridge differences in perception and establish shared visual and spatial metaphors that aid in understanding.

The challenge of collaboration across functional and organizational boundaries is even more difficult due to the different languages, perceptual frameworks, and motivations of various groups. At least artists or musicians or theorists benefit from a rich shared background and context. But, cross-functional collaboration is a relatively new human process, requiring more time and greater richness of interaction for commonality to arise. Most tools for communication focus on verbal thinking, which is too automatic and does not capture the underlying metaphorical understanding. Here is one reason for the importance of face-to-face team interaction, particularly around mock-ups and prototypes. Tools for long-distance collaboration must fulfill these functions in other ways.

Not all projects, or phases within a project, require collaboration. Design tasks that are routine or are variations of a well-established process may not benefit much from collaborative interaction. However, innovative product development means solving new problems, or solving old ones in new ways. Projects for which new combinations of customer needs must be addressed, or changing technologies are to be employed, or cost reductions are required, often can benefit from collaboration.

With these concepts in mind, one can look at various tools to get a sense of their potential to improve aspects of the development process. Some tools are true collaboration aids that directly support cross-functional interaction spanning diverse locations. Others provide communication and coordination within projects. Still others serve to share information across multiple projects, link functional groups separated by project boundaries, and warehouse information for later use, capturing lessons and building a knowledge base. Commonly reported uses include managing product information and making it available for review and update; providing change and versioning control; linking design automation, simulation, and analysis tools using interoperable data formats; providing design standards, DFM design rules, and component libraries; linking requirements to underlying customer information and design decisions; integrating supply chain partners; providing decision support services and expert systems; and updating and tracking project plans, tasks, decisions, rationale. A mature information system would enable various types of communications between individuals and workstations, managing how data is acquired and shared within the task, project, program, and enterprise, and allowing query and online reporting capabilities (Carter and Baker 1991).

Consider the use of CAD drawings beginning early in a design phase, which is recommended by many authors. This cannot be said to help all projects with which it has been tried; in fact, some research suggests CAD may actually slow the process (Peters 1994). For example, management might decide that placing a CAD workstation in process engineering would help involve process engineers in early design decisions. But, it would be unlikely to be used for several reasons. The process engineer is likely to be too busy with troubleshooting on the production floor to take initiative to look at drawings, much less to be trained on the CAD system. Early engineering drawings may not be final enough to elicit a meaningful reaction from the process engineer. And, by the time drawings are in CAD form, it may be too late for a reaction to make a difference (Smith and Reinertsen 1991). Clearly, changes in management processes are needed before CAD is likely to make a positive impact in this case. If the process engineer is compelled to use the workstation, productivity is likely to drop.

Tools need to have a strategic benefit, and one that users can recognize, before they are adopted. For example, the benefits of early CAD use would be unimportant in a situation where prototyping is relatively quick and inexpensive, analysis of prototypes is subjective or qualitative (such as aesthetic judgements), and participants are local and can meet easily. However, if some decision-makers are located many time zones away, the CAD models may be worthwhile to allow visualization and discussion of concepts before prototypes are even built. Designs that have expensive prototyping costs, or those that are difficult to test and analyze for failures, are strong candidates for early CAD usage, because the drawings provide input for simulations such as finite element analysis (FEA) or mold-flow analysis. CAD models can serve as input to an expert system that evaluates manufacturability and manufacturing costs.

As modeling tools become more important, so does CAD. An obvious example is development of aircraft; CAD drawings provide data for FEA simulation and analysis of loads and stresses, fluid dynamics simulations, and others that would be prohibitively expensive and time-consuming to perform experimentally. Computer models of designs may go through several iterations until the desired performance is achieved, without ever incurring the expense and delay of tooling, fabrication, assembly, and test. Furthermore, if the new product is a variation of existing products, inherits some common parts, or uses an existing library of components or design rules, then the use of CAD from day one is clearly appropriate.

The above example also shows how tools may develop first for industries that require them, and later are adapted to other applications for which good return-on-investment is not so obvious. This is currently the case for software products categorized under the name “computer assisted engineering” (CAE). CAE provides an integrated set of tools for the activities of design, simulation, analysis, iteration, and optimization. For example, a prototype may be drawn into CAD format, and solid models may be viewed and manipulated in real time across the internet to allow styling decisions to be made. The model may be imported into FEA and other simulation packages to analyze loads, failure modes, vibration, fatigue, and other aspects of performance. Results may be used to change the design, at first to narrow down concepts and weed out performance problems, then to optimize the design in preparation for physical prototype fabrication. Results of physical prototype tests further refine the models and help build design rules for future projects.

CAE is sometimes implemented as part of an integrated system referred to as design chain engineering (DCE). In DCE, interconnection is established between a manufacturer and its suppliers. Many elements must come together: standardized and documented design methods and processes, product data management (PDM) system, configuration and revision control, network system management, CAD and CAE applications, remote 2-D and 3-D visualization tools, web browsers, and security. The investment in people, tools, and processes can be significant.

The CAE approach has many advantages, especially as part of a DCE network. First, simulated testing can avoid the need for as many prototype cycles, reducing the count from three, for example, to as few as one, thereby eliminating several tooling and testing cycles and associated costs (see figure 4). More activities can be done in parallel because physical prototypes are not needed. Poor aspects of a design can be eliminated early in the process before they become embedded. Technical risk is reduced as design performance and predictability can be proven much earlier. Failures in physical prototypes or products can be analyzed and redesigned more quickly. More fine-tuning of designs may be done, improving quality of the final product, with benefits including greater market acceptance, reduced rework, waste, and returns. Products may be released closer to the market demand, thereby reducing market risk. Geographically dispersed developers, consultants, and suppliers can be interconnected, and collaboration is enhanced by visualization tools that allow manipulation and modification in real-time. For example, these tools may enable early collaboration such as among a toolmaker, design engineer, and industrial designer.

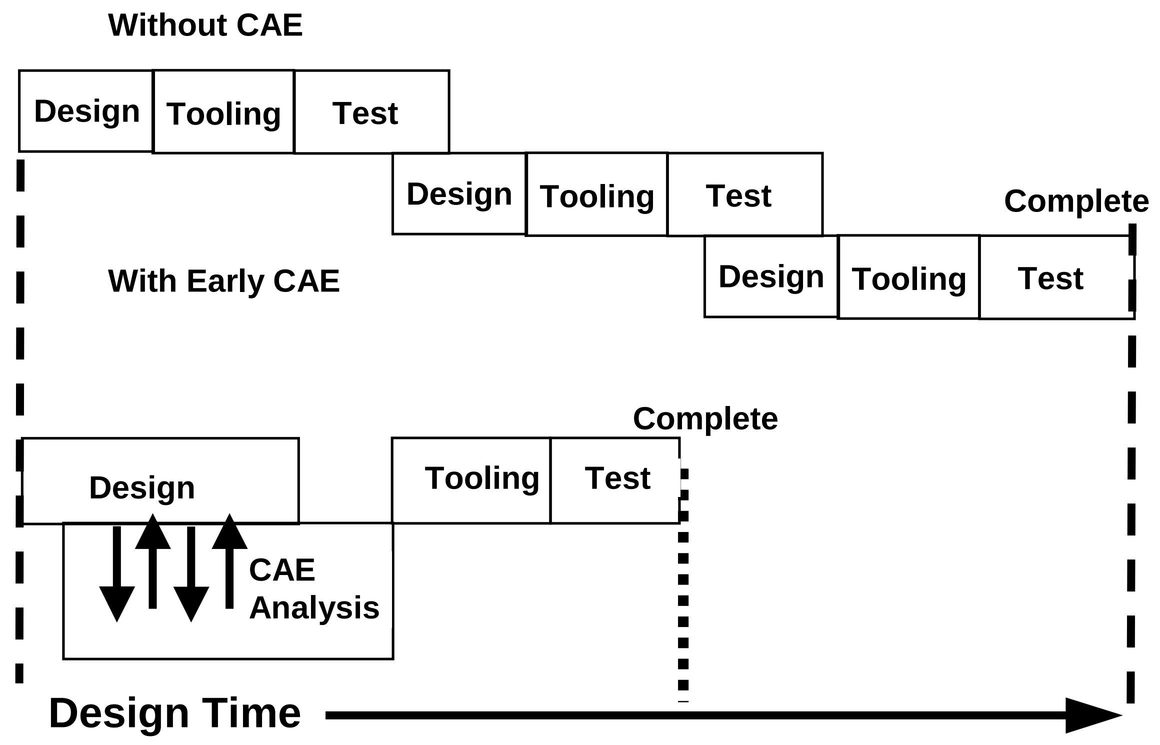


Figure 5. Use of CAE may lengthen the initial design and delay the first prototype, but reduce the number of prototype cycles needed, resulting in earlier completion.

CAE has enjoyed wide adoption in aerospace, for which the long prototype cycles and high prototype cost, combined with the need for high quality, make the investment decision easy. Prototype test costs may be up to 500 times that of simulation costs. CAE is also becoming widespread in the automobile and other industries (Neill et al. 1999).

Design activities using CAE typically center around three participants: the product engineer who is responsible for the overall concept, schedule, and vendor management; a designer who generates documentation and is responsible for manufacturability; and a CAE analyst who is skilled at evaluation and optimization of designs. At present, most CAE tools are designed for a specialist who works with them daily, and the learning curve is long. This sometimes produces a bottleneck or reduces utilization of CAE by designers and engineers. Some CAE vendors are moving in the direction of adding simplified CAE tools for use by the designers themselves. Most designers lack the competencies that are required for developing FEA and other models. For this reason, features such as wizards are provided to help designers set up and analyze the simulations. A core group of CAE specialists would maintain and monitor use of these tools by designers early in the design phase, and provide higher-quality analyses to them later on. Just as engineers have adopted DFA tools to improve manufacturability before a design reaches the production group, so too can designers adopt simplified CEA tools in the early stages of product design.

The key with simulation tools is to focus only on what the model needs in order to satisfy the evaluation. A more complex model can take longer to build, and unneeded features can hide programming mistakes. General-purpose models may be used for products with a high degree of commonality, allowing a basic model to be adapted to product variations (Smith and Reinertsen 1991).

7.10. Project Management Software

Project management software is a crucial, basic tool, providing the ability to make and iterate plans and schedules, test “what-if” changes, evaluate critical paths, predict and monitor costs and timelines, capture progress, and generate reports (Shtub et al. 1994). Preferably, this information should be available on a network to team members and open to modification by authorized members. Ideally, documentation from the project should be hyper-linked, stored, searchable, and served in a seamless manner across the entire supply chain. In most firms, the tool should allow for sharing of resources with other projects according to changing priorities. Data collected may also aid in planning and monitoring the project portfolio and product development strategy.

How important is project management software? For small firms and projects, managers might each use their own methods, possibly as simple as a spreadsheet and checklist. For them, speed is of the essence, and the learning curve of complex products provides a reasonable disincentive. However, this may continue to serve as a barrier to adoption later on when the benefits become more relevant. As product development capability and strategy become important, a standardized tool is of great benefit to allow cross-project coordination of resources and facilities, and to build a database of project management experience that can help plan and schedule future projects. In the latter situation, commitment to standard databases and tools yields significant benefits to program managers, directors, and top management, even if the initial learning curve is uncomfortable for the project managers and team members. Ideally, products are selected that have appropriate features and interfaces, and that are perceived by the users as important to the strategy of the project and firm, so that adoption and compliance will go smoothly. As a project reaches the pilot production stage, reliance on business information systems jumps dramatically. Ideally, information should be shared and consolidated across the enterprise from the beginning, including partners and suppliers in other locations.

Project management software products span several market segments, from stand-alone software packages, to more elaborate modules within enterprise resource planning (ERP) systems, to customized systems. These products change quickly enough that coverage in this paper would not be appropriate. However, a few examples will be cited to point out trends, such as improved flexibility to accommodate less-predictable types of projects, web-based publishing to enhance coordination, integration across the enterprise-wide system, and cross-project tools to allow management of the project portfolio and product development strategy.

Software for project management typically has most of the following basic capabilities:

- Work Breakdown Structure (WBS) – elements of work to accomplish goals
- Organizational Breakdown Structure (OBS) – people available and reporting
- Schedule views: CPM network, PERT with probabilities, Gantt bar charts, resource planning
- Cost breakdown structure (CBS)
- Project monitoring and control: actual versus planned time, cost, resources, deviations
- Output for reports and presentations
- Easy to use and informative Graphical User Interface
- Compatibility with office suite or groupware
- Client / server capability

For a given project and organization, some key features and requirements should be evaluated, including:

- Maximum number of tasks, projects, resources, resource costs, calendars
- Specific capabilities depending on the project: non-linear distribution of resources, leveling, equipment availability, duration probabilities (usually

Monte Carlo), direct versus indirect costs, types of precedence relationships, modeling of delays, reporting

- Data file formats (database, native)
- Platform requirements; cost; completeness of documentation; vendor support

In addition to these basics, some packages may offer tools for economic evaluation and decision making. High-end packages may include purpose-specific reporting and analysis features for multiple-project evaluation and strategic planning.

As of 1995, there were over 125 project management packages. One popular low-end title is Microsoft Project. The latest version extends its capabilities beyond a simple desktop application by providing a degree of compatibility with web publishing, group email, and database file formats. High-end packages such as several from Primavera provide more integration capabilities and emphasize program management and strategic planning. Often, firms have their own customized reporting and tracking software and use a standardized scheduling engine to make cross-project resource sharing and monitoring by upper management much easier.

Some of these systems may be integrated with an enterprise resource planning (ERP) network. For example, SAP provides a Project Management module for their ERP product, SAP R/3. It appears to be aimed at larger companies running relatively conventional projects. It may require customization to be appropriate for new product development, and the learning curve for the programming tools needed to customize the application may be prohibitive for a small organization. This module would only be appropriate if the firm used the SAP ERP system across the enterprise.

7.10.1. Stand-Alone Application Package Example

Microsoft Project is one of the most commonly used application software products, and serves as a good example of present products. Some newer features of Microsoft Project 98 appear to provide some of the flexibility needed by development projects, improved ease of use, linkages across multiple projects, and some crude interoperability and web-based publishing capabilities.

- "Project Map" helps new users get started
- Multiple views allow highlighting of key info and status in display and mouse-based modifications
- Split tasks to simulate interruptions
- Resource availability can vary over time via "contouring"
- Resources for multiple projects can be sharing from a resource pool
- Link inter-project dependencies
- Best and worst case timelines with probabilities
- Fixed cost accruals in addition to variable costs
- Project documents can contain hypertext links to other documents
- Export and publish web-based reports and charts

- Share data with Microsoft Office, Outlook schedule and contact software, and Microsoft Team Manager
- Save projects in database file format (.mpd), compatible with ODBC-compliant databases such as Oracle Server 7.3, Microsoft SQL Server, or Microsoft Access 97 databases, allowing ad-hoc queries across multiple projects
- Team interaction by MAPI-compliant mailer (Microsoft Exchange or Lotus Notes) or a Web server; track receipt and acceptance of assignments; collect status info; send reminders

These recent enhancements show the general trend towards interoperability with office suites, groupware, and enterprise-wide information systems. In particular, automated communication among the project group and offsite partners is now expected for all but the smallest projects.

Microsoft Project 98 does not integrate transparently, but requires file format conversions and web publishing of views and reports. This falls short of true integration in which the borders between applications would be transparent to the user. Furthermore, team communications is only via email assignments and status reports, rather than direct input to project plans via the network. Microsoft Project 98 seems better oriented to a top-down management style rather than a collaborative style. Perhaps, this is a reflection of Microsoft's own management culture. As Mike Rose, CIO of HP, said, Microsoft's IT philosophy is that of a "dictatorship" whereas HP's is a "community."

7.10.2. Managing the Project Portfolio

Primavera differentiates themselves from Microsoft Project 98 by a focus on integration and on tools for strategic planning of multiple projects. Primavera offers a spectrum of products, from small stand-alone project management applications to integrated suites designed to interface with popular enterprise-wide solutions via programming interfaces. Primavera's project management modules have been available for some time, including Primavera Project Planner (P3), which is similar to Microsoft Project 98.

Of greater interest are the more recent, ambitious packages, collectively termed the Primavera Concentric Management Solution. This is an integrated set of tools to manage everything from small projects to large programs, and to bridge these tools to enterprise-wide information technology. A small-project management tool is included, as is a larger, multi-project planning package. Additional modules address specific need such contract management, Monte Carlo schedule and budget risk evaluation, database management, programming of the modules, and interface between with ERP systems of Oracle, PeopleSoft, and SAP.

Going beyond what other vendors dub "enterprise project management," Primavera claims to better focus on projects as assets or investments, emphasizing return on investment. They outline six approaches used by their system to achieve this focus:

- Role-based Tools and Perspectives — Different levels, as well as types, of users get the specific information they need to do their jobs. For example, executives need a summary view of their project portfolio, detailing how projects are performing against budgets and time lines, and identifying items not yet completed. The CFO can view projects according to cost accounting structures, with appropriate hooks into the corporate ERP or accounting system. A resource manager can look at the project resource hierarchies to ensure that individuals are assigned to tasks according to their unique skills. A project manager can analyze the project according to the WBS and experiment with different scenarios. Front-line workers can use web-based timesheets and to-do lists to receive and update their assignments.
- Hierarchical Project Management — This allows all of a firm's projects to be planned, analyzed, and controlled within a single framework, or project hierarchy. It provides for both top-down and bottom-up planning, and for comparing the two perspectives, to ensure that plans are in line with project objectives.
- Optimization of Limited, Shared Resources — This recognizes that people's time, not capital, is often the critical resource. Assigning the right person to a task and making the most of the people in the project, regardless of where

they are geographically located, are essential. The “Project Portfolio Management” system helps make trade-off decisions with regards to who should be working on which project, and allows planning of assignments based on role, long before availability of individuals is known. Thus, for example, a human resources executive can analyze upcoming projects to anticipate staffing requirements and begin appropriate training or recruiting. A functional manager should be able to instantly identify when key resources will free up for work on other projects.

- Real-time Communication — A key attribute of Project Portfolio Management software is the ability to provide top executives with timely feedback about projects and project portfolios. It also provides project and line-of-business managers with insight into the strategic vision for the business, as set forth by the senior executives or strategic planners. Workers can be quickly informed about changes in priority so they can focus on the most important tasks.
- Visible Project Performance — Project Portfolio Management software emphasizes project performance measurement that is forward-looking, not just a backward-looking metric. It helps companies identify what happened and why, so that they can identify problems and trends in time to correct them, and to spot opportunities for getting to market first. It raises both the

visibility and accountability for projects within an organization, increasing the likelihood of success.

- Integration — Project Portfolio Management software integrates with accounting and other enterprise information systems. Both pre-configured and custom-built interfaces may be used. Other departments will be able to see the immediate consequences of changes, including the financial impact of schedule changes.

Some of these benefits could be derived from most any project management package if APIs are exploited to make it interoperable with an enterprise-wide, strategy-based IT solution. But, Primavera appears to have built critical enterprise-oriented perspectives into the structure and interface of their software, plus built-in compatibility with several popular ERP vendors. The attention to enterprise strategy, ROI, cross-functional involvement, and IT integration is impressive.

Primavera applies the phrase “project portfolio” — basically, a program of related projects — to their new offering, Primavera Prospective. Primavera’s newest offering appears to tackle some often overlooked factors in project success — visibility among upper management, universal access to information via a personal choice of tools, and flexible and automated reporting tools tailored to different roles in the enterprise. Rather than settle for the traditional project manager’s tactical perspective of accomplishing tasks, it emphasizes the strategic role of a portfolio of projects in the context of the strategic vision and resources of the enterprise as a whole. This product offers the approaches listed above in a more integrated enterprise-wide solution, appropriate to new customers who are in a position to implement from scratch. A web browser is the primary interface. One new module is called ESP, an executive information system that provides real-time high-level information about projects and project portfolios. The objective is to support long-range planning and decision-making by measuring the "health" and performance of projects and detecting trends. Another new module helps integrate cross-project assignments and timecard information.

7.11. Post-Project Audit

To enhance product development projects, organizations must capture lessons about tasks and capabilities that cut across disciplines, functions, and departments. This can be neglected in the rush to move on to the next project, especially because there are no traditional ways to capture this learning.

Learning about the behavior of the product development system is different from individual learning and information sharing. Many elements come together and interact in complex patterns, and problems often occur at the boundaries where no one is charged with capturing and teaching competency. Problems are broad-based and poorly defined. The objective is to avoid past mistakes and make proactive changes to improve project selection and definition, shape project management, and develop the organizational structure for improved success in future projects. These issues span more than any individual’s contribution or accountability.

In organizations where the dominant structure is functional, there may not be a single source for learning from past projects. Functions often manage learning in their areas of responsibility, and inherit some information from earlier projects. But, they may not focus on team / project level which can be so important in fast-paced product development (Clark and Wheelwright 1993).

To help identify what went wrong and right, a systematic mechanism is needed that can gradually and persistently gather lessons for organizational learning. Clark and Wheelwright recommend a project audit that consists of a systematic review by each cross-functional team (Clark and Wheelwright 1993). This is not a post mortem to evaluate past divergences from procedures or place blame, but a cooperative review to learn from experience. An audit consists of a review of the project, interviews of participants at all levels, and gathering of data about execution and performance. There are five crucial themes:

1. View learning as team process
2. Create model of development process
3. Gather and analyze data regarding specific problems.
4. Search for patterns in results
5. Pursue and eliminate root causes

It may be difficult not to gloss over the steps or rush to next project. The importance of learning to a firm's competitive capabilities should be the raised as a more important, if not urgent, concern. Also, it should not be allowed to become a witch-hunt to place blame, but should be limited to identifying opportunities for the future. Areas to look at include:

- Pre-project activities and decision-making
- Project structure, setting, and background
- Team staffing, skills, management, values, and rewards
- Working-level linkages between functions and groups
- Prototyping and test cycles (strategy, speed, quality)
- Senior management participation and reviews

The focus should be on identifying specific recommendations to enhance cross-functional cooperation and assistance, including:

- Improving procedures or streamlining
- New or better tools and methods (such as joint engineering-marketing QFD)
- Changing the process (sequence of activities and phases)
- Structure of the organization and locus of responsibility
- Principles such as values and decision making.

If audits are done quickly and in a cooperative spirit, people will be more likely to contribute. If captured lessons are consistently translated into implementation of better procedures, systems, and philosophies, then post-project audits may become an important and valued tradition and component of the product development process.

8. SUMMARY AND CONCLUSIONS

Project management is no longer one body of knowledge. Traditional project management arose in large system development efforts with huge resources and ambitious technical objectives. Today, project management methods are applied to many types of efforts, including product development projects of all types. Leaders of such projects must exercise situational judgement in selecting management approaches and applying them to unique circumstances. Fortunately, the literature provides a wide range of examples from which to draw.

Product development is ultimately intended to provide a stream of revenue from ongoing sales of products, often consisting of successive generations of products or product families. The objectives are commercial ones, and the setting in which projects occur are dominated by business and organizational strategy. Thus, project management must take on organizational strategic goals along side technical, cost, and schedule goals typical of traditional project management practices. In a sense, project managers must become general managers, involved in product strategy, architecture, market research, resource allocation, and so on.

This paper has focused on product development projects facing fast technological change and market competition. The challenges of rapid technological change, market fragmentation, and intense global competition force managers to change the way projects are run, compared to traditional projects. Product lifetimes are shorter, customers are increasingly demanding and sophisticated, and product quality must be improving. More product variations must be developed with fewer resources and shorter schedules. Firms must carefully plan their product releases to meet these growing challenges. Project managers must make time-to-market, product strategy, product distinctiveness and quality their highest concerns.

This requires new thinking about tradeoffs among development cost, product cost, feature sets, performance, and product strategy. It also requires project managers to broaden their roles within the business. This new thinking can be framed as contrasts or opposites. For example, planning must begin very early, but details must be postponed until the appropriate stage, using a short plan-act-evaluate cycle for feedback and correction. Managers must focus on both short- and long-term horizons simultaneously. Project leaders need to use both an inward orientation to manage the team, and an outward orientation to monitor developments that will change project direction. They need to use both formal and informal procedures to control progress and quality while engendering team collaboration. They need to employ both high-touch communication by hands-on participation and “management by walking around,” and high-tech communication using computer-based productivity, communication, and collaboration tools (Laufer 1997).

Project managers can have a great impact on revenues in many ways. Time to market can be reduced by quickly bringing the right resources to the project, fostering early collaboration with suppliers, assuring thorough prototype testing and requirements definition, and so on. Project managers can also control manufacturing costs by making manufacturability and process development part of the early design phase. Changes late in the project lead to repetition of engineering effort (often with compromises to manufacturing cost and quality), waste of materials, and delays in schedule. This can be avoided by early prototyping, a comprehensive requirements definition process, and early attention to manufacturing and quality issues.

Compared to traditional plan-coordinate-control style of project management, the competencies and skills required of a project manager have expanded. This includes product strategy, technical knowledge, business bottom-line orientation, market and customer understanding, and team leadership by persuasion and collaboration. The traditional roles of delegation by top-down authority, monitoring, control, and up-front planning and structuring of the project by work breakdown structure, have fallen into lesser roles. Project managers now are initiators, entrepreneurs, and participants rather than mere coordinators and planners. The job is at once more difficult and more enriching thanks to these changes. Project managers must orchestrate the following:

- Product strategy
- In depth knowledge of technologies
- Intimate understanding of changing customer needs
- Understanding of emerging markets and competition

- Understanding of how to transform technologies into want-satisfying products
- Climate in which creative ideas can flourish
- Teamwork and collaboration of many specialists
- Systematic decision making and risk taking

Project managers need to use a variety of approaches to achieve the above conditions:

- Flexible organizations that emphasize open communication, movement of personnel across department boundaries, and individual initiatives within team settings
- Modification of traditional project management methods to focus on time-to-market and work with preliminary, changing information
- A strategy of incremental innovation and overlapping activities
- Willingness to accept calculated risks
- Participative decision making techniques
- Patience with group dynamics, uncertainty, and experimentation
- Maintaining close contacts and trusting relationships with customers leading to free exchange of ideas and testing of prototypes

- Continual involvement with new technologies, trade societies, and professional activities, keeping the firm in the mainstream of information flows, interpersonal influence, and new ideas
- Intercepting new trends, building power, and influencing the organization.

Finally, some important principles for managing new product development projects are listed below (Clark and Wheelwright 1993; Laufer 1997; Souder 1987).

1. The product development process is an important core capability and company asset. This process should be carefully developed, guided by new product development committees or structures with ongoing top management participation. Continuous improvement of the process includes systematic organizational learning from past projects with an emphasis on cross-functional linkages.
2. Management must take a systematic and careful approach to the selection of projects. Every proposed idea, from any source, should be viewed as a precious commodity. Firms should develop and maintain processes for idea generation, evaluation, and documentation, involving the submitter in each step. The evaluation and decision processes should involve the entire organization, using established criteria that relate to the organization's goals and purposes.
3. Product mapping should employ a strategy of incremental innovation so that smaller, faster projects can more rapidly build technical knowledge, market

share, customer feedback, and revenues. Follow-on projects build on that success with derivatives, improvements, and cost reductions. Product architectures must be chosen that enhance this strategy and allow for product variations.

4. Top management has many roles in product development: design organizational structures that support the process; lead the development of an organizational vision and mission; reinforce belief systems and norms within the organization; and establish clear project missions and contracts with project teams. Universal participation should be used in creating the above to improve the quality and acceptance of the results.

5. Managers must carefully select the most cost-effective team structure for each project, balancing the needs and influences of functional groups and project teams. Heavyweight or autonomous team structures with dynamic interaction and cross-functional collaboration are most effective for uncertain technologies and markets and for challenging technology transfers. Mutual accountability replaces traditional functional allegiances. Teams should be kept small, breaking down large projects into smaller teams where needed. The memberships and roles may change during the life of the project. For routine projects in which technology and markets are well understood, teams add little value compared to traditional functional groups, and can be costly, disruptive, and limit the deepening of functional group expertise.

6. Project managers should have backgrounds that support the most important needs of a project. For example, managers with good commercial backgrounds will be most successful leading projects that have uncertain markets and demand organization-wide commitment. If the market is well understood but the technical is not, a technical background is most important. Greater uncertainties suggest stronger team structures and authority of the project manager compared to functional groups. Upper management support and endorsement of the project manager must be highly visible and ongoing.

7. Overlapping of phases and tasks is increasingly employed to speed development. This approach works synergistically with the cross-functional team approach, which ensures early consideration of all aspects of the design and product life cycle.

8. Managers should start planning early, yet postpone detailed planning due to initial lack of information. Key questions, long lead items, and high-risk technical and customer issues must be addressed early to define the pacing problems and bound risks. Plans and schedules should evolve in a strategy of rolling reduction of risk and uncertainty. Decisions must be timely rather than high in certainty, and plans must include contingencies. Plans should anticipate changes that may be needed to accommodate new customer or market information. Core team members participate in overall project planning and schedule their own work.

9. Planning uses a multi-phase breakdown, similar to traditional project planning, but tasks must be managed to occur in parallel as much as possible. This means breaking the tyranny of sequential phases and comprehensive phase reviews. Use more-frequent, less-formal reviews and numerous small in-process design reviews conducted by the team members themselves.
10. Proactive risk anticipation and management is the responsibility of project managers and team members alike. This includes structuring tasks so that no single critical task has too much risk. High-risk tasks are loosely coupled to minimize mutual impact. Redundancy may be used to manage risks; this may reduce efficiency but more than compensates by speeding development and providing contingencies. Prototypes, both physical and computer models, and other experimental reality-checks provide frequent feedback from customers and tests of technical assumptions.
11. Project managers must constantly scan the environment and market, keep aware of business objectives and resources, and both isolate the team from disruptions while connecting it to needed information. Core team members also monitor developments in their specializations.
12. Managers should not try to control innovative or uncertain development projects with traditional progress-monitoring and activity-control techniques, but should focus on shortening time-to-market using empowered teams and relaxed control systems. Traditional approaches emphasize bureaucracies, hierarchies, narrowly

defined jobs, conformance to established rules, centralized decision-making, top-down communication, and economic efficiency. Responsibility should replace authority, and communication must be multidirectional and collaborative. Procedures are kept simple and are flexibly applied. Automation is used to support and enhance, not to control and restrict.

13. Motivation comes from intrinsic achievement and from collective measurements and team rewards. Everyone shares awareness of the goals of the organization, including innovation, acquiring new markets, and fulfilling customer needs.

14. Disharmony between groups must be eliminated early before it becomes difficult to repair. This applies most notably to the engineering-marketing interface. Lack of understanding, appreciation, or communication, and distrust must not be allowed to continue. Make open communications an explicit responsibility of every person, and get everyone involved early in the project and throughout. Participants must come to have deep appreciation and respect for each other's work.

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