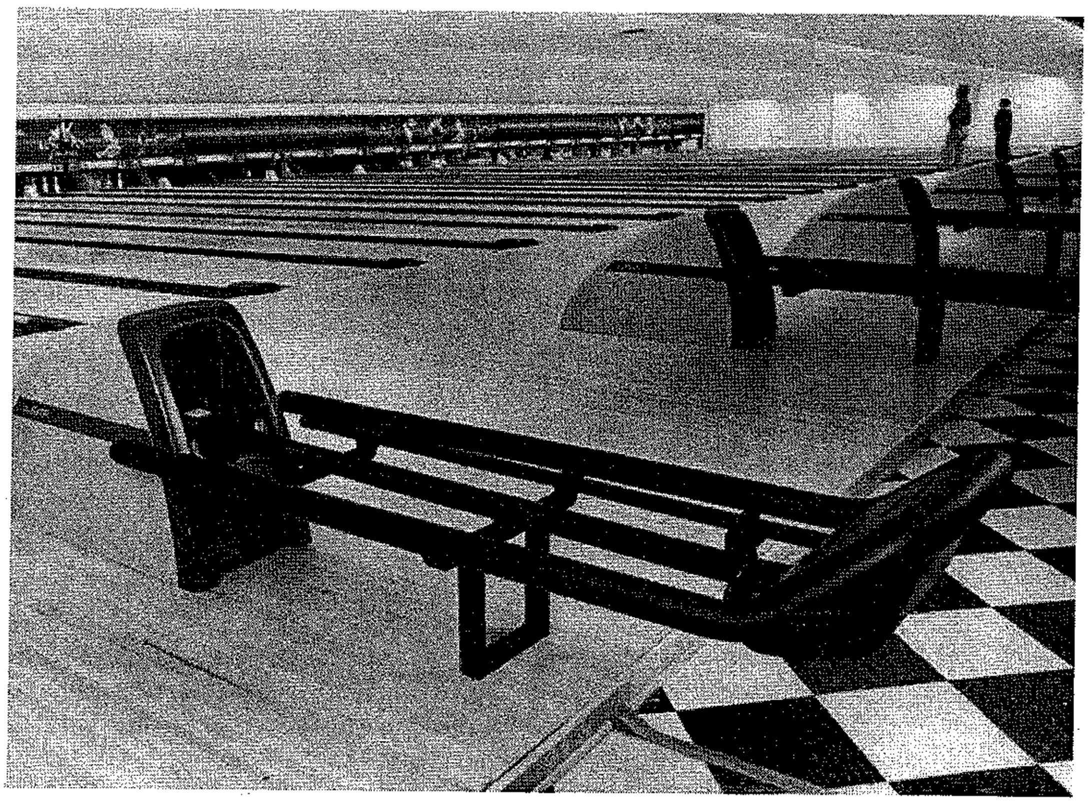
CHAPTER TWO

Development Processes and Organizations



Courtesy of AMF Bowling Worldwide

EXHIBIT 2-1
A ball return, one of AMF Bowling's products.

The Capital Equipment Division of AMF Bowling is the leading manufacturer of bowling equipment, including pin spotters, ball returns, and scoring equipment. An AMF ball return product is shown in Exhibit 2-1. The general manager of the division asked the engineering manager to establish a well-defined product development process and to propose a product development organization that would allow AMF to compete effectively over the next decade. Some of the questions AMF faced were:

- Is there a standard development process that will work for every company?
- What role do experts from different functional areas play in the development process?
- What milestones can be used to divide the overall development process into phases?
- Should the development organization be divided into groups corresponding to projects or to development functions?

This chapter helps to answer these and related questions by presenting a generic development process and showing how this process can be adapted to meet the needs of particular industrial situations. We highlight the activities and contributions of different functions of the company during each phase of the development process. The chapter also explains what constitutes a product development organization and discusses why different types of organizations are appropriate for different settings.

A Generic Development Process

A process is a sequence of steps that transforms a set of inputs into a set of outputs. Most people are familiar with the idea of physical processes, such as those used to bake a cake or to assemble an automobile. A *product development process* is the sequence of steps or activities which an enterprise employs to conceive, design, and commercialize a product. Many of these steps and activities are intellectual and organizational rather than physical. Some organizations define and follow a precise and detailed development process, while others may not even be able to describe their processes. Furthermore, every organization employs a process at least slightly different from that of every other organization. In fact, the same enterprise may follow different processes for each of several different types of development projects.

A well-defined development process is useful for the following reasons:

- ***Quality assurance:*** A development process specifies the phases a development project will pass through and the checkpoints along the way. When these phases and checkpoints are chosen wisely, following the development process is one way of assuring the quality of the resulting product.
- ***Coordination:*** A clearly articulated development process acts as a master plan which defines the roles of each of the players on the development team. This plan informs the members of the team when their contributions will be needed and with whom they will need to exchange information and materials.
- ***Planning:*** A development process contains natural milestones corresponding to the completion of each phase. The timing of these milestones anchors the schedule of the overall development project.

- ***Management:*** A development process is a benchmark for assessing the performance of an ongoing development effort. By comparing the actual events to the established process, a manager can identify possible problem areas.
- ***Improvement:*** The careful documentation of an organization's development process often helps to identify opportunities for improvement.

The generic product development process consists of six phases, as illustrated in Exhibit 2-2. The process begins with a planning phase, which is the link to advanced research and technology development activities. The output of the planning phase is the project's mission statement, which is the input required to begin the concept development phase and which serves as a guide to the development team. The conclusion of the product development process is the product launch, at which time the product becomes available for purchase in the marketplace.

One way to think about the development process is as the initial creation of a wide set of alternative product concepts and then the subsequent narrowing of alternatives and increasing specification of the product until the product can be reliably and repeatably produced by the production system. Note that most of the phases of development are defined in terms of the state of the product, although the production process and marketing plans, among other tangible outputs, are also evolving as development progresses.

Another way to think about the development process is as an information-processing system. The process begins with inputs such as the corporate objectives and the capabilities of available technologies, product platforms, and production systems. Various activities process the development information, formulating specifications, concepts, and design details. The process concludes when all the information required to support production and sales has been created and communicated.

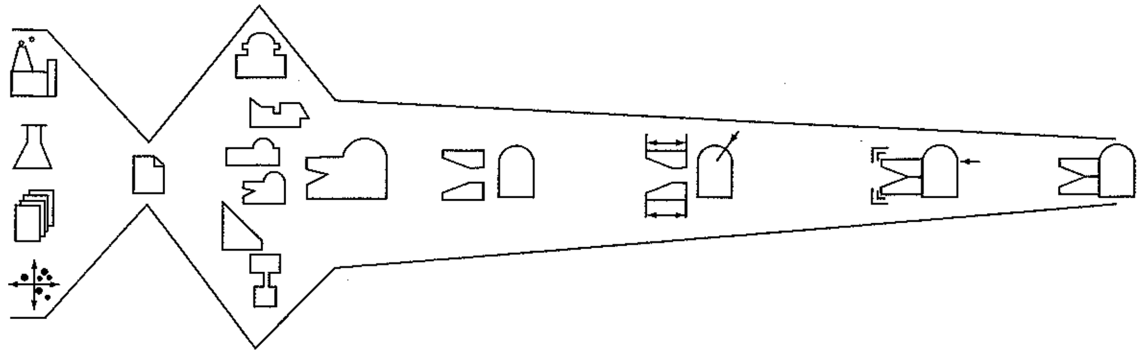
A third way to think about the development process is as a risk management system. In the early phases of product development, various risks are identified and prioritized. As the process progresses, risks are reduced as the key uncertainties are eliminated and the functions of the product are validated. When the process is completed, the team should have substantial confidence that the product will work correctly and be well received by the market.

Exhibit 2-2 also identifies the key activities and responsibilities of the different functions of the organization during each development phase. Because of their continuous involvement in the process, we choose to articulate the roles of marketing, design, and manufacturing. Representatives from other functions, such as research, finance, field service, and sales, also play key roles at particular points in the process.

The six phases of the generic development process are:

0. ***Planning:*** The planning activity is often referred to as "phase zero" since it precedes the project approval and launch of the actual product development process. This phase begins with corporate strategy and includes assessment of technology developments and market objectives. The output of the planning phase is the project mission statement, which specifies the target market for the product, business goals, key assumptions, and constraints. Chapter 3, Product Planning, presents a discussion of this planning process.

1. ***Concept development:*** In the concept development phase, the needs of the target market are identified, alternative product concepts are generated and evaluated, and one



Phase 0: Planning	Phase 1: Concept Development	Phase 2: System-Level Design	Phase 3: Detail Design	Phase 4: Testing and Refinement	Phase 5: Production Ramp-Up
Marketing					
• Articulate market opportunity. • Define market segments.	• Collect customer needs. • Identify lead users. • Identify competitive products.	• Develop plan for product options and extended product family. • Set target sales price point(s).	• Develop marketing plan.	• Develop promotion and launch materials. • Facilitate field testing.	• Place early production with key customers.
Design					
• Consider product platform and architecture. • Assess new technologies.	• Investigate feasibility of product concepts. • Develop industrial design concepts. • Build and test experimental prototypes.	• Generate alternative product architectures. • Define major subsystems and interfaces. • Refine industrial design.	• Define part geometry. • Choose materials. • Assign tolerances. • Complete industrial design control documentation.	• Reliability testing. • Life testing. • Performance testing. • Obtain regulatory approvals. • Implement design changes.	• Evaluate early production output.
Manufacturing					
• Identify production constraints. • Set supply chain strategy.	• Estimate manufacturing cost. • Assess production feasibility.	• Identify suppliers for key components. • Perform make-buy analysis. • Define final assembly scheme. • Set target costs.	• Define piece-part production processes. • Design tooling. • Define quality assurance processes. • Begin procurement of long-lead tooling.	• Facilitate supplier ramp-up. • Refine fabrication and assembly processes. • Train work force. • Refine quality assurance processes.	• Begin operation of entire production system.
Other Functions					
• Research: Demonstrate available technologies. • Finance: Provide planning goals. • General Management: Allocate project resources.	• Finance: Facilitate economic analysis. • Legal: Investigate patent issues.	• Finance: Facilitate make-buy analysis. • Service: Identify service issues.		• Sales: Develop sales plan.	

EXHIBIT 2-2 The generic product development process. Six phases are shown, including the tasks and responsibilities of the key functions of the organization for each phase.

or more concepts are selected for further development and testing. A concept is a description of the form, function, and features of a product and is usually accompanied by a set of specifications, an analysis of competitive products, and an economic justification of the project. This book presents several detailed methods for the concept development phase (Chapters 4–8). We expand this phase into each of its constitutive activities in the next section.

2. ***System-level design:*** The system-level design phase includes the definition of the product architecture and the decomposition of the product into subsystems and components. The final assembly scheme for the production system is usually defined during this phase as well. The output of this phase usually includes a geometric layout of the product, a functional specification of each of the product's subsystems, and a preliminary process flow diagram for the final assembly process. Chapter 9, Product Architecture, discusses some of the important activities of system-level design.

3. ***Detail design:*** The detail design phase includes the complete specification of the geometry, materials, and tolerances of all of the unique parts in the product and the identification of all of the standard parts to be purchased from suppliers. A process plan is established and tooling is designed for each part to be fabricated within the production system. The output of this phase is the *control documentation* for the product—the drawings or computer files describing the geometry of each part and its production tooling, the specifications of the purchased parts, and the process plans for the fabrication and assembly of the product. Two critical issues addressed in the detail design phase are production cost and robust performance. These issues are discussed respectively in Chapter 11, Design for Manufacturing, and Chapter 13, Robust Design.

4. ***Testing and refinement:*** The testing and refinement phase involves the construction and evaluation of multiple preproduction versions of the product. Early *(alpha)* prototypes are usually built with *production-intent* parts—parts with the same geometry and material properties as intended for the production version of the product but not necessarily fabricated with the actual processes to be used in production. Alpha prototypes are tested to determine whether the product will work as designed and whether the product satisfies the key customer needs. Later *(beta)* prototypes are usually built with parts supplied by the intended production processes but may not be assembled using the intended final assembly process. Beta prototypes are extensively evaluated internally and are also typically tested by customers in their own use environment. The goal for the beta prototypes is usually to answer questions about performance and reliability in order to identify necessary engineering changes for the final product. Chapter 12, Prototyping, presents a thorough discussion of the nature and use of prototypes.

5. ***Production ramp-up:*** In the production ramp-up phase, the product is made using the intended production system. The purpose of the ramp-up is to train the work force and to work out any remaining problems in the production processes. Products produced during production ramp-up are sometimes supplied to preferred customers and are carefully evaluated to identify any remaining flaws. The transition from production ramp-up to ongoing production is usually gradual. At some point in this transition, the product is *launched* and becomes available for widespread distribution.

Concept Development: The Front-End Process

Because the concept development phase of the development process demands perhaps more coordination among functions than any other, many of the integrative development methods presented in this book are concentrated here. In this section we expand the concept development phase into what we call the *front-end process.* The front-end process generally contains many interrelated activities, ordered roughly as shown in Exhibit 2-3.

Rarely does the entire process proceed in purely sequential fashion, completing each activity before beginning the next. In practice, the front-end activities may be overlapped in time and iteration is often necessary. The dashed arrows in Exhibit 2-3 reflect the uncertain nature of progress in product development. At almost any stage, new information may become available or results learned which can cause the team to step back to repeat an earlier activity before proceeding. This repetition of nominally complete activities is known as development *iteration.*

The concept development process includes the following activities:

- ***Identifying customer needs:*** The goal of this activity is to understand customers' needs and to effectively communicate them to the development team. The output of this step is a set of carefully constructed customer need statements, organized in a hierarchical list, with importance weightings for many or all of the needs. A method for this activity is presented in Chapter 4, Identifying Customer Needs.
- ***Establishing target specifications:*** Specifications provide a precise description of what a product has to do. They are the translation of the customer needs into technical terms. Targets for the specifications are set early in the process and represent the hopes of the development team. Later these specifications are refined to be consistent with the constraints imposed by the team's choice of a product concept. The output of this stage is a list of target specifications. Each specification consists of a metric, and marginal and ideal values for that metric. A method for the specification activity is given in Chapter 5, Product Specifications.
- ***Concept generation:*** The goal of concept generation is to thoroughly explore the space of product concepts that may address the customer needs. Concept generation includes a mix of external search, creative problem solving within the team, and systematic exploration of the various solution fragments the team generates. The result of this

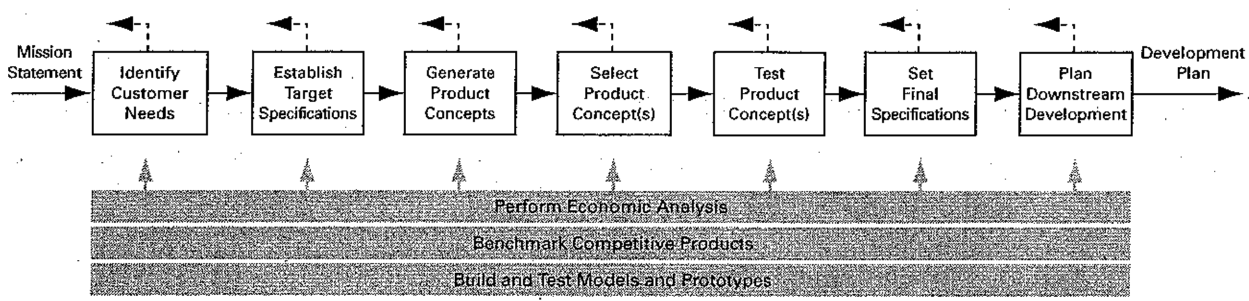


EXHIBIT 2-3 The many front-end activities comprising the concept development phase.

activity is usually a set of 10 to 20 concepts, each typically represented by a sketch and brief descriptive text. Chapter 6, Concept Generation, describes this activity in detail.

- ***Concept selection:*** Concept selection is the activity in which various product concepts are analyzed and sequentially eliminated to identify the most promising concept(s). The process usually requires several iterations and may initiate additional concept generation and refinement. A method for this activity is described in Chapter 7, Concept Selection.
- ***Concept testing:*** One or more concepts are then tested to verify that the customer needs have been met, assess the market potential of the product, and identify any shortcomings which must be remedied during further development. If the customer response is poor, the development project may be terminated or some earlier activities may be repeated as necessary. Chapter 8, Concept Testing, explains a method for this activity.
- ***Setting final specifications:*** The target specifications set earlier in the process are revisited after a concept has been selected and tested. At this point, the team must commit to specific values of the metrics reflecting the constraints inherent in the product concept, limitations identified through technical modeling, and trade-offs between cost and performance. Chapter 5, Product Specifications, explains the details of this activity.
- ***Project planning:*** In this final activity of concept development, the team creates a detailed development schedule, devises a strategy to minimize development time, and identifies the resources required to complete the project. The major results of the front-end activities can be usefully captured in a *contract book* which contains the mission statement, the customer needs, the details of the selected concept, the product specifications, the economic analysis of the product, the development schedule, the project staffing, and the budget. The contract book serves to document the agreement (contract) between the team and the senior management of the enterprise. A project planning method is presented in Chapter 16, Managing Projects.
- ***Economic analysis:*** The team, often with the support of a financial analyst, builds an economic model for the new product. This model is used to justify continuation of the overall development program and to resolve specific trade-offs among, for example, development costs and manufacturing costs. Economic analysis is shown as one of the ongoing activities in the concept development phase. An early economic analysis will almost always be performed before the project even begins, and this analysis is updated as more information becomes available. A method for this activity is presented in Chapter 15, Product Development Economics.
- ***Benchmarking of competitive products:*** An understanding of competitive products is critical to successful positioning of a new product and can provide a rich source of ideas for the product and production process design. Competitive *benchmarking* is performed in support of many of the front-end activities. Various aspects of competitive benchmarking are presented in Chapters 4–8.
- ***Modeling and prototyping:*** Every stage of the concept development process involves various forms of models and prototypes. These may include, among others: early "proof-of-concept" models, which help the development team to demonstrate feasibility; "form-only" models, which can be shown to customers to evaluate ergonomics and

style; spreadsheet models of technical trade-offs; and experimental test models, which can be used to set design parameters for robust performance. Methods for modeling, prototyping, and testing are discussed throughout the book, including in Chapters 4–6, 8, 10, 12, and 13.

Adapting the Generic Product Development Process

The development process described by Exhibits 2-2 and 2-3 is generic, and particular processes will differ in accordance with a firm's unique context. The generic process is most like the process used in a *market-pull* situation: a firm begins product development with a market opportunity and then uses whatever available technologies are required to satisfy the market need (i.e., the market "pulls" the development decisions). In addition to the market-pull process outlined in Exhibits 2-2 and 2-3, several variants are common and correspond to the following: *technology-push* products, *platform* products, *process-intensive* products, *customized* products, *high-risk* products, *quick-build* products, and *complex systems.* Each of these situations is described below. The characteristics of these situations and the resulting deviations from the generic process are summarized in Exhibit 2-4.

Technology-Push Products

In developing technology-push products, the firm begins with a new proprietary technology and looks for an appropriate market in which to apply this technology (that is, the technology "pushes" development). Gore-Tex, an expanded Teflon sheet manufactured by W. L. Gore Associates, is a striking example of technology push. The company has developed dozens of products incorporating Gore-Tex, including artificial veins for vascular surgery, insulation for high-performance electric cables, fabric for outerwear, dental floss, and liners for bagpipe bags.

Many successful technology-push products involve basic materials or basic process technologies. This may be because basic materials and processes are deployed in thousands of applications, and there is therefore a high likelihood that new and unusual characteristics of materials and processes can be matched with an appropriate application.

The generic product development process can be used with minor modifications for technology-push products. The technology-push process begins with the planning phase, in which the given technology is matched with a market opportunity. Once this matching has occurred, the remainder of the generic development process can be followed. The team includes an assumption in the mission statement that the particular technology will be embodied in the product concepts considered by the team. Although many extremely successful products have arisen from technology-push development, this approach can be perilous. The product is unlikely to succeed unless (1) the assumed technology offers a clear competitive advantage in meeting customer needs, and (2) suitable alternative technologies are unavailable or very difficult for competitors to utilize. Project risk can possibly be minimized by simultaneously considering the merit of a broader set of concepts which do not necessarily incorporate the new technology. In this way the team verifies that the product concept embodying the new technology is superior to the alternatives.

Process Type	Description	Distinct Features	Examples
Generic (Market-Pull) Products	The team begins with a market opportunity and selects appropriate technologies to meet customer needs.	Process generally includes distinct planning, concept development, system-level design, detail design, testing and refinement, and production ramp-up phases.	Sporting goods, furniture, tools.
Technology-Push Products	The team begins with a new technology, then finds an appropriate market.	Planning phase involves matching technology and market. Concept development assumes a given technology.	Gore-Tex rainwear, Tyvek envelopes.
Platform Products	The team assumes that the new product will be built around an established technological subsystem.	Concept development assumes a proven technology platform.	Consumer electronics, computers, printers.
Process-Intensive Products	Characteristics of the product are highly constrained by the production process.	Either an existing production process must be specified from the start, or both product and process must be developed together from the start.	Snack foods, breakfast cereals, chemicals, semiconductors.
Customized Products	New products are slight variations of existing configurations.	Similarity of projects allows for a streamlined and highly structured development process.	Motors, switches, batteries, containers.
High-Risk Products	Technical or market uncertainties create high risks of failure.	Risks are identified early and tracked throughout the process. Analysis and testing activities take place as early as possible.	Pharmaceuticals, space systems.
Quick-Build Products	Rapid modeling and prototyping enables many design-build-test cycles.	Detail design and testing phases are repeated a number of times until the product is completed or time/budget runs out.	Software, cellular phones.
Complex Systems	System must be decomposed into several subsystems and many components.	Subsystems and components are developed by many teams working in parallel, followed by system integration and validation.	Airplanes, jet engines, automobiles.

EXHIBIT 2-4 Summary of variants of generic product development process.

Platform Products

A platform product is built around a preexisting technological subsystem (a technology *platform*). Examples of such platforms include the tape transport mechanism in the Sony Walkman, the Apple Macintosh operating system, and the instant film used in Polaroid cameras. Huge investments were made in developing these platforms, and therefore every attempt is made to incorporate them into several different products. In some sense, platform products are very similar to technology-push products in that the team begins the development effort with an assumption that the product concept will embody a particular technology. The primary difference is that a technology platform has already demonstrated its usefulness in the marketplace in meeting customer needs. The firm can in many cases assume that the technology will also be useful in related markets. Products built on technology platforms are much simpler to develop than if the technology were developed from scratch. For this reason, and because of the possible sharing of costs across several products, a firm may be able to offer a platform product in markets that could not justify the development of a unique technology.

Process-Intensive Products

Examples of process-intensive products include semiconductors, foods, chemicals, and paper. For these products, the production process places strict constraints on the properties of the product, so that the product design cannot be separated, even at the concept phase, from the production process design. In many cases, process-intensive products are produced in very high volumes and are bulk, as opposed to discrete, goods.

In some situations, a new product and new process are developed simultaneously. For example, creating a new shape of breakfast cereal or snack food will require both product and process development activities. In other cases, a specific existing process for making the product is chosen in advance, and the product design is constrained by the capabilities of this process. This might be true of a new paper product to be made in a particular paper mill or a new semiconductor device to be made in an existing wafer fabrication facility.

Customized Products

Examples of customized products include switches, motors, batteries, and containers. Customized products are slight variations of standard configurations and are typically developed in response to a specific order by a customer. Development of customized products consists primarily of setting values of design variables such as physical dimensions and materials. When a customer requests a new product, the firm executes a structured design and development process to create the product to meet the customer's needs. Such firms typically have created a highly detailed development process involving a well-defined sequence of steps with a structured flow of information (analogous to a production process). For customized products, the generic process is augmented with a detailed description of the specific information-processing activities required within each of the phases. Such development processes may consist of hundreds of carefully defined activities.

High-Risk Products

The product development process addresses many types of risk. These include technical risk (Will the product function properly?), market risk (Will customers like what the team develops?), and budget and schedule risk (Can the team complete the project on time and within budget?). High-risk products are those that entail unusually large uncertainties related to the technology or market so that there is substantial technical or market risk. The generic product development process is modified to face high-risk situations by taking steps to address the largest risks in the early stages of product development. This usually requires completing some design and test activities earlier in the process. For example, when there is great uncertainty regarding customer acceptance of a new product, concept testing using renderings or user-interface prototypes may be done very early in the process in order to reduce the market uncertainty and risk. If there is high uncertainty related to technical performance of the product, it makes sense to build working models of the key features and to test these earlier in the process. Multiple solution paths may be explored in parallel to ensure that one of the solutions succeeds. Design reviews must assess levels of risk on a regular basis, with the expectation that risks are being reduced over time and not being postponed.

Quick-Build Products

For the development of some products, such as software and many electronics products, building and testing prototype models has become such a rapid process that the design-build-test cycle can be repeated many times. In fact, teams can take advantage of rapid iteration to achieve a more flexible and responsive product development process, sometimes called a *spiral product development process.* Following concept development in this process, the system-level design phase entails decomposition of the product into high-, medium-, and low-priority features. This is followed by several cycles of design, build, integrate, and test activities, beginning with the highest-priority items. This process takes advantage of the fast prototyping cycle by using the result of each cycle to learn how to modify the priorities for the next cycle. Customers may even be involved in the testing process after one or more cycles. When time or budget runs out, usually all of the high- and medium-priority features have been incorporated into the evolving product, and the low-priority features may be omitted until the next product generation.

Complex Systems

Larger-scale products such as automobiles and airplanes are complex systems comprised of many interacting subsystems and components. When developing complex systems, modifications to the generic product development process address a number of system-level issues. The concept development phase considers the architecture of the entire system, and multiple architectures may be considered as competing concepts for the overall system. The system-level design phase becomes critical. During this phase, the system is decomposed into subsystems and these further into many components. Teams are assigned to develop each component. Additional teams are assigned the special challenge of integrating components into the subsystems and these into the overall system.

Detail design of the components is a highly parallel process in which the many development teams work at once, usually separately. Managing the network of interactions across the components and subsystems is the task of system engineering specialists of many kinds. The testing and refinement phase includes not only system integration, but also extensive testing and validation at all levels.

Product Development Process Flows

The product development process generally follows a structured flow of activity and information flow. This allows us to draw *process flow diagrams* illustrating the process, as shown in Exhibit 2-5. The generic process flow diagram depicts the process used to develop market-pull, technology-push, platform, process-intensive, customized, and high-risk products. Each product development phase (or stage) is followed by a review (or gate) to confirm that the phase is completed and to determine whether the project proceeds. Quick-build products enable a spiral product development process whereby detail design, prototyping, and test activities are repeated a number of times. The process flow diagram for development of complex systems shows the decomposition into parallel stages of work on the many subsystems and components. Once the product development process has been established within an organization, a process flow diagram is used to explain the process to everyone on the team.

The AMF Development Process

AMF Bowling is a market-pull enterprise. AMF generally drives its development process with a market need and seeks out whatever technology is required to meet that need. Its competitive advantage arises from strong marketing channels, strong brand recognition, and a large installed base of equipment, not from any single proprietary technology. For this reason, the technology-push approach would not be appropriate. AMF products are assembled from components fabricated with relatively conventional processes such as molding, casting, and machining. So the AMF product is clearly not process intensive in the way a food product or a chemical is. Bowling equipment is rarely customized for a particular customer; most of the product development at AMF is aimed at new models of products, rather than at the customization of existing models. For this reason, the customization approach is also inappropriate.

AMF chose to establish a development process similar to the generic process. The process proposed by the AMF engineering manager is illustrated in Exhibit 2-6. The representation of the development process used by AMF is a hybrid of those used in Exhibits 2-2 and 2-5, in that it shows the individual activities in the development process as well as the roles of the different development functions in those activities. Note that AMF defines the key functions in product development as marketing, engineering/design, manufacturing, quality assurance, purchasing, and customer service. Also note that there are three major milestones in the process: the project approval, the beginning of tooling fabrication, and the production release. Each of these milestones follows a major review.

Although AMF established a standard process, its managers realized that this process would not necessarily be suitable in its entirety for all AMF products. For example, a few of AMF's new products are based on technology platforms. When platform products are developed, the team assumes the use of an existing technology platform during concept development. Nevertheless, the standard development process is the baseline from which a particular project plan begins.

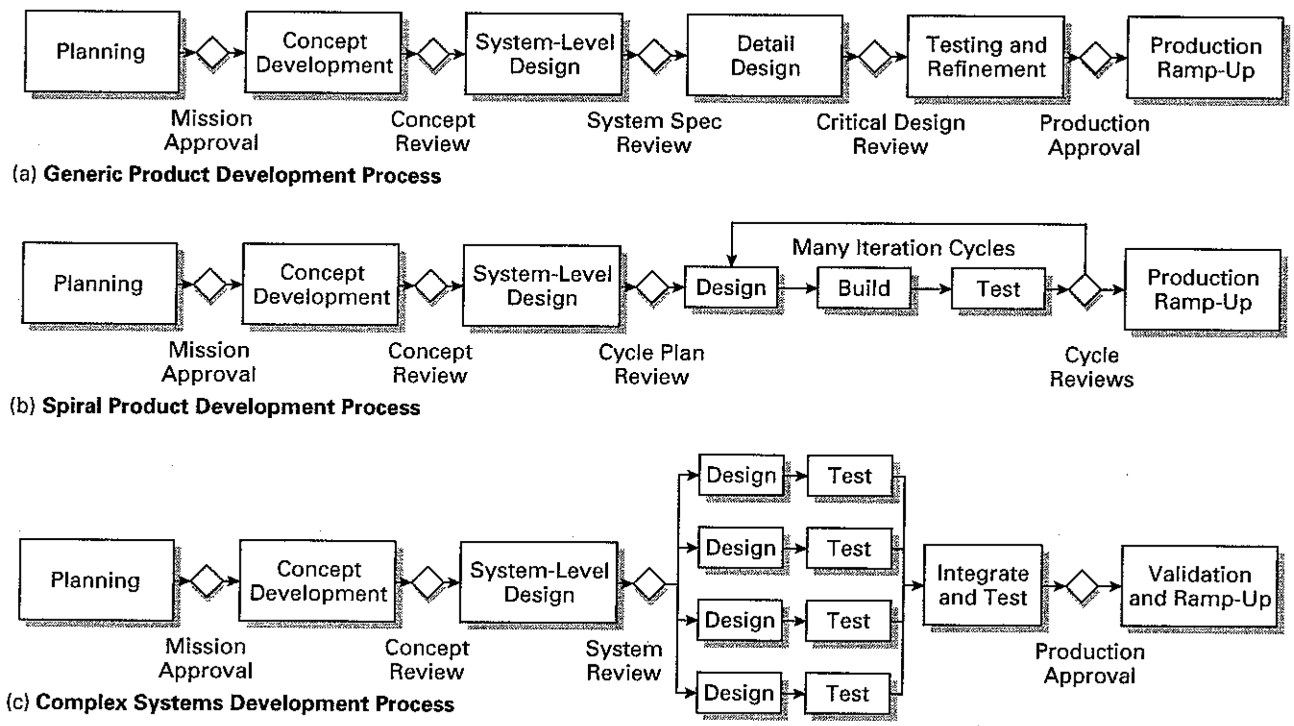


EXHIBIT 2-5 Process flow diagrams for three product development processes.

Product Development Organizations

In addition to crafting an effective development process, successful firms must organize their product development staffs effectively. In this section, we describe several types of organizations used for product development and offer guidelines for choosing among these options.

Organizations Are Formed by Establishing Links among Individuals

A product development organization is the scheme by which individual designers and developers are linked together into groups. The links among individuals may be formal or informal and include, among others, these types:

- ***Reporting relationships:*** Reporting relationships give rise to the classic notion of *supervisor* and *subordinate.* These are the formal links most frequently shown on an organization chart.
- ***Financial arrangements:*** Individuals are linked by being part of the same financial entity, such as that defined by a particular budget category or profit-and-loss statement.
- ***Physical layout:*** Links are created between individuals when they share the same office, floor, building, or site. These links are often informal, arising from spontaneous encounters while at work.

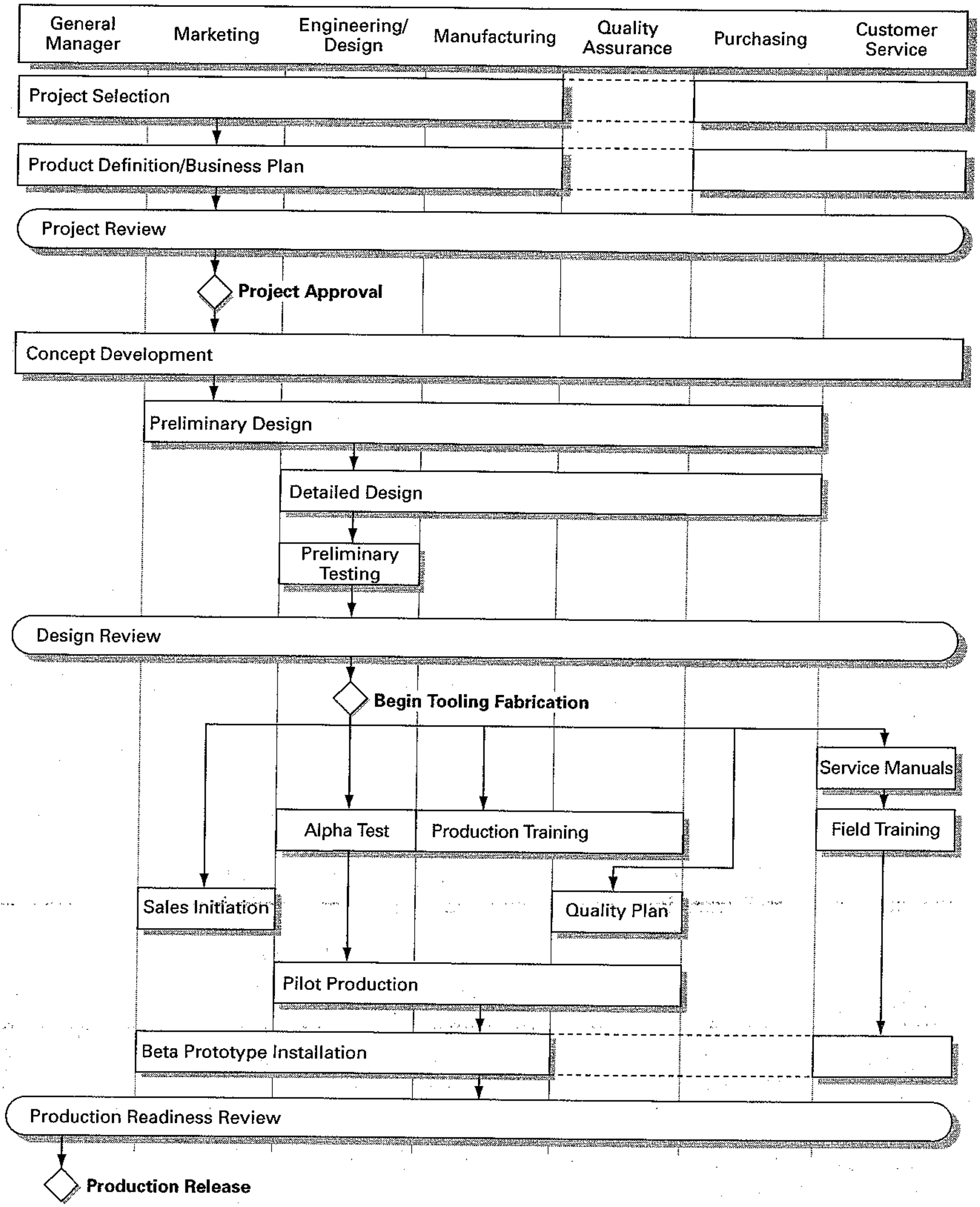


EXHIBIT 2-6 AMF Bowling's standard development process.

Any particular individual may be linked in several different ways to other individuals. For example, an engineer may be linked by a reporting relationship to another engineer in a different building, while being linked by physical layout to a marketing person sitting in the next office. The strongest organizational links are typically those involving performance evaluation, budgets, and other resource allocations.

Organizational Links May Be Aligned with Functions, Projects, or Both

Regardless of their organizational links, particular individuals can be classified in two different ways: according to their *function* and according to the *projects* they work on.

- A function (in organizational terms) is an area of responsibility usually involving specialized education, training, or experience. The classic functions in product development organizations are marketing, design, and manufacturing. Finer divisions than these are also possible and may include, for example, market research, market strategy, stress analysis, industrial design, human factors engineering, process development, and operations management.
- Regardless of their functions, individuals apply their expertise to specific projects. In product development, a project is the set of activities in the development process for a particular product and includes, for example, identifying customer needs and generating product concepts.

Note that these two classifications must overlap: individuals from several different functions will work on the same project. Also, while most individuals are associated with only one function, they may contribute to more than one project. Two classic organizational structures arise from aligning the organizational links according to function or according to projects. In *functional organizations,* the organizational links are primarily among those who perform similar functions. In *project organizations,* the organizational links are primarily among those who work on the same project.

For example, a strict functional organization might include a group of marketing professionals, all sharing similar training and expertise. These people would all report to the same manager, who would evaluate them and set their salaries. The group would have its own budget and the people would sit in the same part of a building. This marketing group would be involved in many different projects, but there would be no strong organizational links to the other members of each project team. There would be similarly arranged groups corresponding to design and to manufacturing.

A strict project organization would be made up of groups of people from several different functions, with each group focused on the development of a specific product (or product line). These groups would each report to an experienced project manager, who might be drawn from any of the functional areas. Performance evaluation would be handled by the project manager, and members of the team would typically be colocated as much as possible so that they all work in the same office or part of a building. New ventures, or "start-ups," are among the most extreme examples of project organizations: every individual, regardless of function, is linked together by a single project—the growth of the new company and the creation of its product(s). In these settings, the president or CEO can be viewed as the project manager. Established firms will sometimes form a "tiger team" with dedicated resources for a single project when special focus is required to complete an important development project.

The *matrix organization* was conceived as a hybrid of functional and project organizations. In the matrix organization, individuals are linked to others according to both the project they work on and their function. Typically each individual has two supervisors, one a project manager and one a functional manager. The practical reality is that either the project or the function tends to have stronger links. This is because, for example, both functional and project managers cannot have independent budget authority, they cannot independently evaluate and determine the salaries of their subordinates, and both functional and project organizations cannot easily be grouped together physically. As a result, either the functional or the project organization tends to dominate.

Two variants of the matrix organization are called the *heavyweight project organization* and *lightweight project organization* (Hayes et al., 1988). A heavyweight project organization contains strong project links. The heavyweight project manager has complete budget authority, is heavily involved in performance evaluation of the team members, and makes most of the major resource allocation decisions. Although each participant in a project also belongs to a functional organization, the functional managers have relatively little authority and control. A heavyweight project team in various industries may be called an *integrated product team* (IPT), a *design-build team* (DBT), or simply a *product development team* (PDT). Each of these terms emphasizes the cross-functional nature of these teams.

A lightweight project organization contains weaker project links and relatively stronger functional links. In this scheme, the project manager is more of a coordinator and administrator. The lightweight project manager updates schedules, arranges meetings, and facilitates coordination, but the manager has no real authority and control in the project organization. The functional managers are responsible for budgets, hiring and firing, and performance evaluation. Exhibit 2-7 illustrates the pure functional and project organizations, along with the heavyweight and lightweight variants of the matrix organization.

In this book we refer to the *project team* as the primary organizational unit. In this context, the team is the set of all people involved in the project, regardless of the organizational structure of the product development staff. In a functional organization, the team consists of individuals distributed throughout the functional groups without any organizational linkages other than their common involvement in a project. In the other organizations, the team corresponds to a formal organizational entity, the project group, and has a formally appointed manager. For this reason the notion of a team has much more meaning in matrix and project organizations than it does in functional organizations.

Choosing an Organizational Structure

The most appropriate choice of organizational structure depends on which organizational performance factors are most critical to success. Functional organizations tend to breed specialization and deep expertise in the functional areas. Project organizations tend to enable rapid and effective coordination among diverse functions. Matrix organizations, being hybrids, have the potential to exhibit some of each of these characteristics. The following questions help guide the choice of organizational structure:

- ***How important is cross-functional integration?*** Functional organizations may exhibit difficulty in coordinating project decisions which span the functional areas. Project

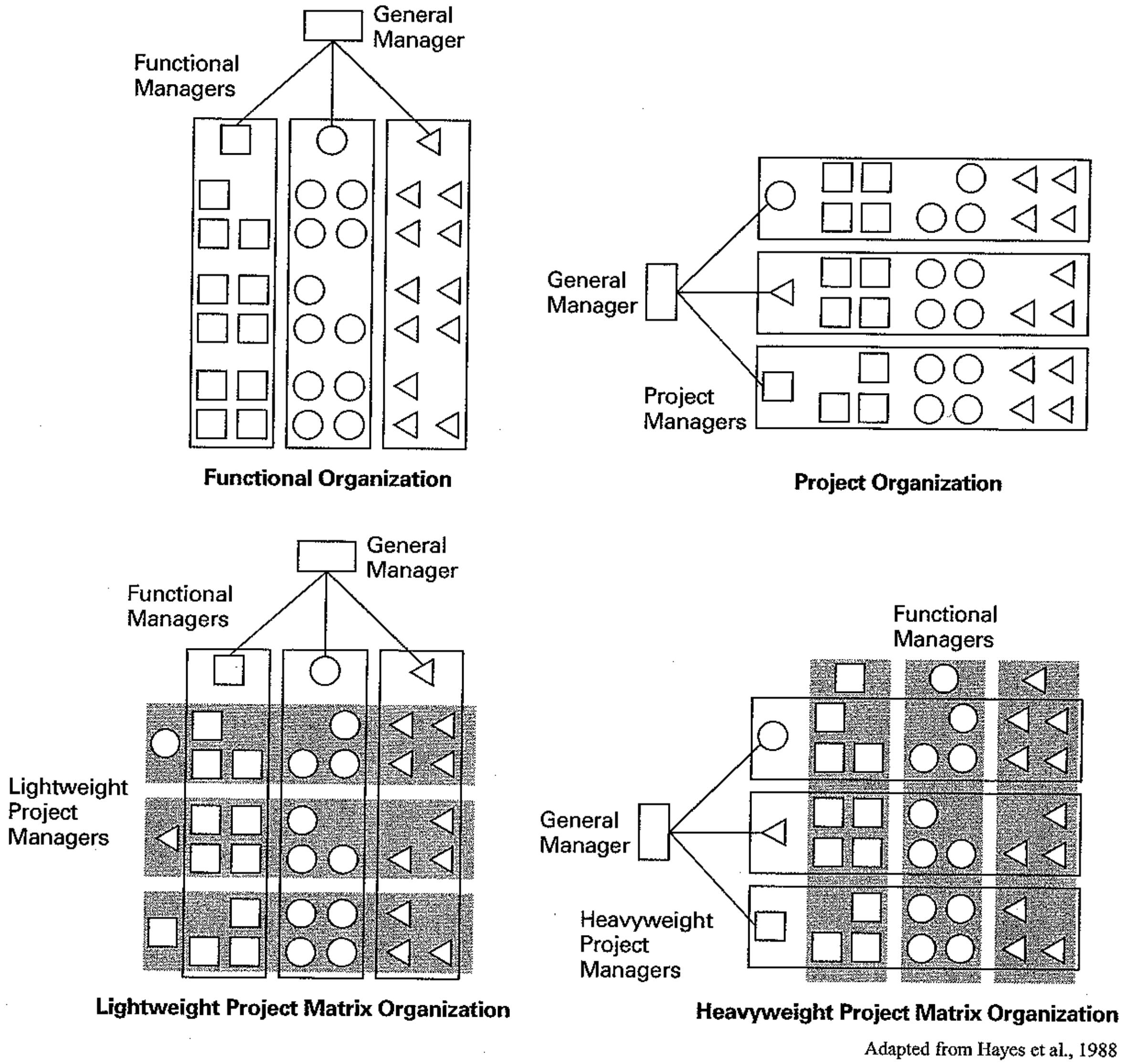


EXHIBIT 2-7 Various product development organizations. For simplicity, three functions and three projects are shown.

organizations tend to enable strong cross-functional integration because of the organizational links of the team members across the functions.

- ***How critical is cutting-edge functional expertise to business success?*** When disciplinary expertise must be developed and retained over several product generations, then some functional links are necessary. For example, in some aerospace companies, computational fluid dynamics is so critical that the fluid dynamicists are organized functionally to ensure the firm will have the best possible capability in this area.
- ***Can individuals from each function be fully utilized for most of the duration of a project?*** For example, a project may require only a portion of an industrial designer's time for a fraction of the duration of a project. In order to use industrial design

resources efficiently, the firm may choose to organize the industrial designers functionally, so that several projects can draw on the industrial design resource in exactly the amount needed for a particular project.

- ***How important is product development speed?*** Project organizations tend to allow for conflicts to be resolved quickly and for individuals from different functions to coordinate their activities efficiently. Relatively little time is spent transferring information, assigning responsibilities, and coordinating tasks. For this reason, project organizations are usually faster than functional organizations in developing innovative products. For example, portable computer manufacturers almost always organize their product development teams by project. This allows the teams to develop new products within the extremely short periods required by the fast-paced computer market.

Dozens of other issues confound the choice between functional and project organizations. Exhibit 2-8 summarizes some of the strengths and weaknesses of each organizational type, examples of the types of firms pursuing each strategy, and the major issues associated with each approach.

The AMF Organization

AMF chose to organize its product development staff in a matrix structure. The functions involved in product development at AMF include engineering, manufacturing, marketing, sales, purchasing, and quality assurance. Each of these functions has a manager who reports to the general manager of the division. However, product development projects are led by project managers, and project teams are drawn from each of the functional areas. The AMF matrix organization is probably closest to the lightweight project organization. This is because the project managers are not typically the most senior managers in the division and do not have direct control of resources and staffing for the project teams. While in general a lightweight project organization tends to strengthen the functions at the expense of project efficiency, several characteristics of the AMF organization make the lightweight organization a wise choice and have led to good product development performance.

The most significant factor leading to the choice of a lightweight project organization is that AMF carries out many small product development projects along with one or two large projects. The result of this mix of projects is that many of the team members on smaller projects contribute on a part-time basis. By having relatively strong functional links between individuals, the assignment of staff to smaller projects and the balancing of workload within a function are more easily accomplished.

Another factor allowing AMF to use a lightweight project organization and still achieve high performance in product development is that AMF is an extraordinarily lean company. The Capital Equipment Division has fewer than 100 salaried employees generating and supporting sales of over $100 million per year. Everyone in the division works in the same building, and most of the key employees earn substantial financial rewards when the division is highly profitable. As a result, members of project teams are motivated to look beyond their own functions and work together to develop successful products.

	Functional Organization	Matrix Organization: Lightweight Product Organization	Matrix Organization: Heavyweight Project Organization	Project Organization
Strengths	Fosters development of deep specialization and expertise.	Coordination and administration of projects is explicitly assigned to a single project manager. Maintains development of specialization and expertise.	Provides integration and speed benefits of the project organization. Some of the specialization of a functional organization is retained.	Resources can be optimally allocated within the project team. Technical and market trade-offs can be evaluated quickly.
Weaknesses	Coordination among different functional groups can be slow and bureaucratic.	Requires more managers and administrators than a nonmatrix organization.	Requires more managers and administrators than a nonmatrix organization.	Individuals may have difficulty maintaining cutting-edge functional capabilities.
Typical Examples	Customization development—firms in which development involves slight variations to a standard design (e.g., custom motors, bearings, packaging).	Traditional automobile, electronics, and aerospace companies.	Many recently successful projects in automobile, electronics, and aerospace companies.	Start-up companies. "Tiger teams" and "skunk works" intended to achieve breakthroughs. Firms competing in extremely dynamic markets.
Major Issues	How to integrate different functions (e.g., marketing and design) to achieve a common goal.	How to balance functions and projects. How to simultaneously evaluate project and functional performance.		How to maintain functional expertise over time. How to share technical learning from one project to another.

EXHIBIT 2-8 Characteristics of different organizational structures.

A slight deviation from the standard lightweight project organization also facilitates project completion. The engineering manager is held personally responsible for all aspects of successful completion of projects and not for engineering excellence alone. Although he is responsible for the engineering function, he is primarily responsible for developing successful products. He therefore works daily to ensure that the appropriate coordination occurs, for example, between marketing and engineering.

Finally, the emphasis that the senior management places on product development encourages effective teamwork. The general manager takes a personal interest in every product development project and devotes several days each month to monitoring the progress of these projects. The message communicated to the project teams is that successful products are more important than strong functions.

Summary

An enterprise must make two important decisions about the way it carries out product development. It must define both a product development process and a product development organization.

- A product development process is the sequence of steps an enterprise employs to conceive, design, and commercialize a product.
- A well-defined development process helps to ensure product quality, facilitate coordination among team members, plan the development project, and continuously improve the process.
- The generic process presented in this chapter includes six phases: planning, concept development, system-level design, detail design, testing and refinement, and production ramp-up.
- The concept development phase requires tremendous integration across the different functions on the development team. This front-end process includes identifying customer needs, analyzing competitive products, establishing target specifications, generating product concepts, selecting one or more final concepts, setting final specifications, testing the concept(s), performing an economic analysis, and planning the remaining project activities. The results of the concept development phase are documented in a contract book.
- The development process employed by a particular firm may differ somewhat from the generic process described here. The generic process is most appropriate for market-pull products. Other types of products, which may require variants of the generic process, include technology-push products, platform products, process-intensive products, customized products, high-risk products, quick-build products, and complex systems.
- Regardless of the development process, tasks are completed by individuals residing in organizations. Organizations are defined by linking individuals through reporting relationships, financial relationships, and/or physical layout.
- Functional organizations are those in which the organizational links correspond to the development functions. Project organizations are those in which the organizational links correspond to the development projects. Two types of hybrid, or matrix, organization are the heavyweight project organization and the lightweight project organization.
- The classic trade-off between functional organizations and project organizations is between deep functional expertise and coordination efficiency.

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Exercises

1. Diagram a process for planning and cooking a family dinner. Does your process resemble the generic product development process? Is cooking dinner analogous to a market-pull, technology-push, platform, process-intensive, customization, high-risk, quick-build, or complex system process?
2. Define a process for finding a job. For what types of endeavor does a well-defined process enhance performance?
3. What type of development process would you expect to find in an established company successful at developing residential air-conditioning units? How about for a small company that is trying to break into the market for racing wheelchairs?

4. Sketch the organization (in some appropriate graphical representation) of a consulting firm that develops new products for clients on a project-by-project basis. Assume that the individuals in the firm represent all of the different functions required to develop a new product. Would this organization most likely be aligned with functions, be aligned by projects, or be a hybrid?

Thought Questions

1. What role does basic technological research play in the product development process? How would you modify Exhibit 2-3 to better represent the research and technology development activities in product development?
2. Is there an analogy between a university and a product development organization? Is a university a functional or project organization?
3. What is the product development organization for students engaged in projects as part of a product development class?
4. Is it possible for some members of a product development organization to be organized functionally, while others are organized by project? If so, which members of the team would be the most likely candidates for the functional organization?