SATHYABAMA
INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)
Accredited "A" Grade by NAAC | 12B Status by UGC | Approved by AICTE
www.sathyabama.ac.in

SCHOOL OF MECHANICAL ENGINEERING

DEPARTMENT OF MECHANICAL ENGINEERING

SMEA3009 –PRODUCT DESIGN AND DEVELOPMENT

COURSE MATERIAL

UNIT – I – SMEA3009 - INTRODUCTION

INTRODUCTION

A *product* is something sold by an enterprise to its customers. *Product development* is the set of activities beginning with the perception of a market opportunity and ending in the production, sale, and delivery of a product. Although much of the material in this book is useful in the development of any product, we explicitly focus on products that are engineered, discrete, and physical. Exhibit 1-1 displays several examples of products from this category. Because of the focus on physical products, we do not emphasize the specific issues involved in developing services or software. Even with these restrictions, the methods presented apply well to a broad range of products, including, for example, consumer electronics, sports equipment, scientific instruments, machine tools, and medical devices.

FIGURE 1.1 Examples of engineered, discrete, physical products

CHARACTERISTICS OF SUCCESSFUL PRODUCT DEVELOPMENT

From the perspective of the investors in a for-profit enterprise, successful product development results in products that can be produced and sold profitably, yet profitability is often difficult to assess quickly and directly. Five more specific dimensions, all of which ultimately relate to profit, are commonly used to assess the performance of a product development effort:

- ***Product quality:*** How good is the product resulting from the development effort? Does it satisfy customer needs? Is it robust and reliable? Product quality is ultimately reflected in market share and the price that customers are willing to pay.
- ***Product cost:*** What is the manufacturing cost of the product? This cost includes spending on capital equipment and tooling as well as the incremental cost of producing each unit of the product. Product cost determines how much profit accrues to the firm for a particular

sales volume and a particular sales price.

- ***Development time:*** How quickly did the team complete the product development effort? Development time determines how responsive the firm can be to competitive forces and to technological developments, as well as how quickly the firm receives the economic returns from the team's efforts.
- ***Development cost:*** How much did the firm have to spend to develop the product? Development cost is usually a significant fraction of the investment required to achieve the profits
- ***Development capability:*** Are the team and the firm better able to develop future products as a result of their experience with a product development project? Development capability is an asset the firm can use to develop products more effectively and eco- nominally in the future.

Who Designs and Develops Products?

Product development is an interdisciplinary activity requiring contributions from nearly all the functions of a firm; however, three functions are almost always central to a product development project:

- ***Marketing:*** The marketing function mediates the interactions between the firm and its customers. Marketing often facilitates the identification of product opportunities, the definition of market segments, and the identification of customer needs. Marketing also typically arranges for communication between the firm and its customers, sets tar- get prices, and oversee the launch and promotion of the product.
- ***Design:*** The design function plays the lead role in defining the physical form of the product to best meet customer needs. In this context, the design function includes engineering design (mechanical, electrical, software, etc.) and industrial design (aes- thetics, ergonomics, user interfaces).
- ***Manufacturing:*** The manufacturing function is primarily responsible for designing, operating, and/or coordinating the production system in order to produce the product. Broadly defined, the manufacturing function also often includes purchasing, distribution, and installation. This collection of activities is sometimes called the *supply chain.*

Different individuals within these functions often have specific disciplinary training in areas such as market research, mechanical engineering, electrical engineering, materials science, or manufacturing operations. Several other functions, including finance and sales, are frequently involved on a part-time basis in the development of a new product. Beyond these broad functional categories, the specific composition of a development team depends on the particular characteristics of the product.

Rarely are products developed by a single individual. The collection of individuals developing a product forms the *project team.* This team usually has a single team leader, who could be drawn from any of the functions of the firm. The team can be thought of as

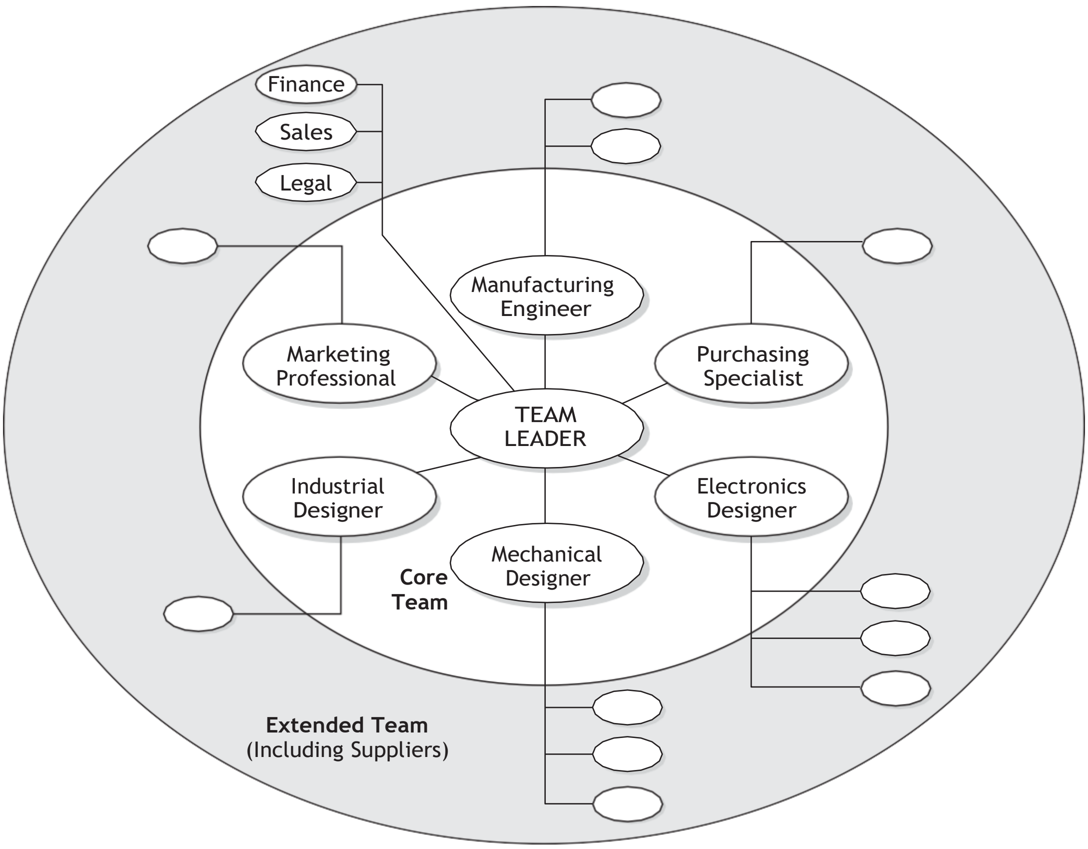


FIGURE 1-2 The composition of a product development team for an electromechanical product of modest complexity.

Consisting of a core team and an extended team. In order to work together effectively, the core team usually remains small enough to meet in a conference room, while the extended team may consist of dozens, hundreds, or even thousands of other members. (Even though the term team is inappropriate for a group of thousands, the word is often used in this context to emphasize that the group must work toward a common goal.) In most cases, a team within the firm will be supported by individuals or teams at partner companies, suppliers, and consulting firms. Sometimes, as is the case for the development of a new airplane, the number of external team members may be even greater than that of the team within the company whose name will appear on the final product. The composition of a team for the development of an electromechanical product of modest complexity is shown in Exhibit 1-2

Duration and Cost of Product Development

Most people without experience in product development are astounded by how much time and money are required to develop a new product. The reality is that very few products can be developed in less than 1 year, many require 3 to 5 years, and some take as long as 10 years. Exhibit 1-1 shows five engineered, discrete products. Table 1-1 is a table showing the approximate scale of the associated product development efforts along with some distinguishing characteristics of the products.

The cost of product development is roughly proportional to the number of people on the project team and to the duration of the project. In addition to expenses for development effort, a firm will almost always have to make some investment in the tooling and equipment required for production. This expense is often as large as the rest of the product development budget; however, it is sometimes useful to think of these expenditures as part of the fixed costs of production. For reference purposes, this production investment is listed in Table 1-1 along with the development expenditures.

The Challenges of Product Development

Developing great products is hard. Few companies are highly successful more than half the time. These odds present a significant challenge for a product development team. Some of the characteristics that make product development challenging is:

- Trade-offs: An airplane can be made lighter, but this action will probably increase manufacturing cost. One of the most difficult aspects of product development is recognizing, understanding, and managing such trade-offs in a way that maximizes the success of the product.
- Dynamics: Technologies improve, customer preferences evolve, competitors introduce new products, and the macroeconomic environment shifts. Decision making in an environment of constant change is a formidable task.
- Details: The choice between using screws or snap-fits on the enclosure of a computer can have economic implications of millions of dollars. Developing a product of even modest complexity may require thousands of such decisions.
- Time pressure: Any one of these difficulties would be easily manageable by itself given plenty of time, but product development decisions must usually be made quickly and without complete information.
- Economics: Developing, producing, and marketing a new product requires a large

investment. To earn a reasonable return on this investment, the resulting product must be both appealing to customers and relatively inexpensive to produce.

For many people, product development is interesting precisely because it is challenging. For others, several intrinsic attributes also contribute to its appeal:

- Creation: The product development process begins with an idea and ends with the production of a physical artifact. When viewed both in its entirety and at the level of individual activities, the product development process is intensely creative.
- Satisfaction of societal and individual needs: All products are aimed at satisfying needs of some kind. Individuals interested in developing new products can almost always find institutional settings in which they can develop products satisfying what they consider to be important needs.
- Team diversity: Successful development requires many different skills and talents. As a result, development teams involve people with a wide range of different training, experience, perspectives, and personalities.
- Team spirit: Product development teams are often highly motivated, cooperative groups. The team members may be collocated so they can focus their collective energy on creating the product. This situation can result in lasting camaraderie among team members.

TABLE.1.1 Attributes of five products and their associated development efforts.

	Belle-V Ice Cream Scoop	**AvaTech Avalanche Probe**	**iRobot Roomba Vacuum Cleaner**	**Tesla Model S Automobile**	**Boeing 787 Aircraft**
Annual production volume	10,000 units/year	1,000 units/year	2,000,000 units/year	50,000 units/year	120 units/year
Sales lifetime	10 years	3 years	2 years	5 years	40 years
Sales price	$40	$2,250	$500	$80,000	$250 million
Number of unique parts (part numbers)	2 parts	175 parts	1,000 parts	10,000 parts	130,000 parts
Development time	1 year	2 years	2 years	4 years	7 years
Internal development team (peak size)	4 people	6 people	100 people	1000 people	7,000 people
External development team (peak size)	2 people	12 people	100 people	1000 people	10,000 people
Development cost	$100,000	$1 million	$50 million	$500 million	$15 billion
Production investment	$20,000	$250,000	$10 million	$500 million	$15 billion

The Product 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 that 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 process. 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 check- points 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 that 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 includes 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 and ongoing review of an organization's development process and its results may help to identify opportunities for improvement.

The generic product development process consists of six phases, as illustrated in Exhibit 1-3. 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 avail- able 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 repeatedly 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, strategic opportunities, 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 1-4 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, project management, field service, and sales, also play key roles at particular points in the process.

The six phases of the generic development process are:

Planning: The planning activity is often referred to as “phase zero” because it precedes the project approval and launch of the actual product development process. This phase begins with opportunity identification guided by 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.

Identification, explains a process for gathering, evaluating, and choosing from a broad range of product opportunities.

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 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.

2. **System-level design:** The system-level design phase includes the definition of the product architecture, decomposition of the product into subsystems and components, preliminary design of key components, and allocation of detail design responsibility to both internal and external resources. Initial plans for the production system and final assembly are 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.

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. Three critical issues that are best considered throughout the product development process, but are finalized in the detail design phase, are materials selection, production cost, and robust performance.

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 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 to identify necessary engineering changes for the final product. 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 workforce 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. A post launch project review may occur shortly after the launch. This review includes an assessment of the project from both commercial and technical perspectives and is intended to identify ways to improve the development process for future projects.

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 1-3.

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 1-3 reflect the uncertain nature of progress in product development. At almost any stage, new information may become available or results learned that 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. Special attention is paid to the identification of latent needs, which are difficult for customers to articulate and unaddressed by existing products. A method for this activity is presented.

- **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.

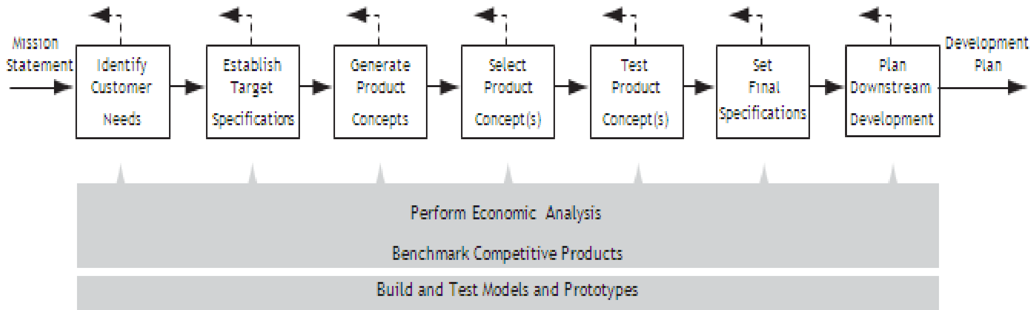


FIGURE 1-3 The many front-end activities comprising the concept development phase.

Firstly, what specifically is a consumer product? A consumer product is a product bought by final consumers for personal consumption. But not every consumer product is the same. There are four different types of consumer products. Marketers usually classify consumer products into these 4 types of consumer products:

- Convenience products
- Shopping products
- Specialty products
- Unsought products.

These 4 types of consumer products all have different characteristics and involve a different consumer purchasing behavior. Thus, the types of consumer products differ in the way consumers buy them and, for that reason, in the way they should be marketed.

(i) Convenience products

Among the four types of consumer products, the convenience product is bought most frequently. A convenience product is a consumer product or service that customers normally buy frequently, immediately and without great comparison or buying effort. Examples include articles such as laundry detergents, fast food, sugar and magazines. As you can see, convenience products are those types of consumer products that are usually low-priced and placed in many locations to make them readily available when consumers need or want them.

(ii) Shopping products

The second one of the 4 types of consumer products is the shopping product. Shopping products are a consumer product that the customer usually compares on attributes such as quality, price and style in the process of selecting and purchasing. Thus, a difference between the two types of consumer products presented so far is that the shopping product is usually less frequently purchased and more carefully compared. Therefore, consumers spend much more time and effort in gathering information and comparing alternatives. Types of consumer products that fall within the category of shopping products are: furniture, clothing, used cars, airline services etc. As a matter of fact marketers usually distribute these types of consumer products through fewer outlets, but provide deeper sales support in order to help customers in the comparison effort.

Number three of the types of consumer products is the specialty product. Specialty products are consumer products and services with unique characteristics or brand identification for which a significant group of consumers is willing to make a special purchase effort. As you can see, the types of consumer products involve different levels of effort in the purchasing process: the specialty product requires a special purchase effort, but applies only to certain consumers.

Examples include specific cars, professional and high-prices photographic equipment, designer clothes etc. A perfect example for these types of consumer products is a Lamborghini. In order to buy one, a certain group of buyers would make a special effort, for instance by travelling great distances to buy one. However, specialty products are usually less compared against each other. Rather, the effort must be understood in terms of other factors: Buyers invest for example the time needed to reach dealers that carry the wanted products. To illustrate this, look at the Lamborghini example: the one who wants one is immediately convinced of the choice for a Lamborghini and would not compare it that much against 10 other brands.

(iii) Unsought products

The 4 types of consumer products also include unsought products. Unsought products are those consumer products that a consumer either does not know about or knows about but does not consider buying under normal conditions. Thus, these types of consumer products consumers do not think about normally, at least not until they need them. Most new innovations are unsought until consumers become aware of them. Other examples of these types of consumer products are life insurance, pre-planned funeral services etc. As a consequence of their nature, unsought products require much more advertising, selling and marketing efforts than other types of consumer products.

Below you can find relevant marketing considerations for each of the 4 types of consumer products.

Table 1.2 Types of Consumer Products

Types of Consumer Products				
Marketing consideration	***Convenience***	***Shopping***	***Speciality***	***Unsought***
Customer buying behaviour	Frequent purchase, little effort (planning, comparison), low customer involvement	Less frequent purchase, much effort (planning and comparison of brands on price, quality, style etc.)	Strong brand preference and loyalty, special purchase effort, little comparison of brands, low price sensitivity	Little product awareness and knowledge or little interest
Price	Low price	Higher price	High price	Varies
Distribution	Widespread distribution, convenient locations	Selective distribution, fewer outlets	Exclusive distribution in only one or a few outlets	Varies
Promotion	Mass promotion	Advertising and personal selling	More carefully targeted promotion	Aggressive advertising and personal selling
Examples	Toothpaste, magazines, laundry detergent	Television, furniture, clothing	Luxury goods (e.g. Rolex watch), designer clothing	Life insurance and pre-planned funeral service

LEVELS OF PRODUCT

1.Core Product

This is the basic product and the focus is on the purpose for which the product is intended. For example, a warm coat will protect you from the cold and the rain.

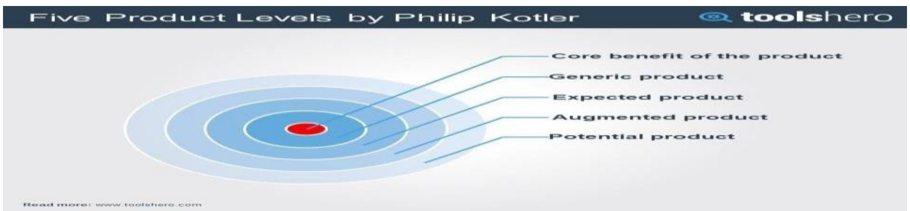


FIGURE 1.4 Levels of Product

1. **Generic Product**

This represents all the qualities of the product. For a warm coat this is about fit, material, rain repellent ability, high-quality fasteners, etc.

2. Expected Product

This is about all aspects the consumer expects to get when they purchase a product. That coat should be really warm and protect from the weather and the wind and be comfortable when riding a bicycle.

3. Augmented Product

This refers to all additional factors which sets the product apart from that of the competition. And this particularly involves brand identity and image. Is that warm coat in style, its color trendy and made by a well-known fashion brand. But also factors like service, warranty and good value for money play a major role in this.

4. Potential Product

This is about augmentations and transformations that the product may undergo in the future. For example, a warm coat that is made of a fabric that is as thin as paper and therefore light as a feather that allows rain to automatically slide down.

Product Development Organizations

In addition to crafting an effective development process, successful firms must organize their product development staff to implement the process in an effective manner. 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 a business unit or department within a firm.

- 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.

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 that 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 may 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 collocated 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 an autonomous "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 independently assign their shared staff, 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

What Are Specifications?

Customer needs are generally expressed in the "language of the customer." The primary customer needs for the suspension fork are listed .Customer needs such as "the suspension is easy to install" or "the suspension enables high-speed descents on bumpy trails" are typical in terms of the subjective quality of the expressions; however, while such expressions are helpful in developing a clear sense of the issues of interest to customers, they provide little specific guidance about how to design and engineer the product. They simply leave too much margin for subjective interpretation. For this reason, development teams usually establish a set of specifications, which spell out in precise, measurable detail what the product has to do. Product specifications do not tell the team how to address the customer needs, but they do represent an unambiguous agreement on what the team will attempt to achieve to satisfy the customer needs. For example, in contrast to the customer need that "the suspension is easy to install," the corresponding specification might be that "the average time to assemble the fork to the frame is less than 75 seconds."

When Are Specifications Established?

In an ideal world, the team would establish the product specifications once early in the development process and then proceed to design and engineer the product to exactly meet those specifications. For some products, such as soap or soup, this approach works quite well; the technologists on the team can reliably concoct a formulation that satisfies almost any reasonable specifications; however, for technology-intensive products this is rarely possible. For such products, specifications are established at least twice. Immediately after identifying the customer needs, the team sets target specifications. These specifications represent the hopes and aspirations of the team, but they are established before the team knows what constraints the product technology will place on what can be achieved. The team's efforts may fail to meet some of these specifications and may exceed others, depending on the product concept the team eventually selects. For this reason, the target specifications must be refined after a product concept has been selected. The team revisits the specifications while assessing the actual technological constraints and the expected production costs. To set the final specifications, the team must frequently make hard trade-offs among different desirable characteristics of the product. For simplicity, we present a two-stage process for establishing specifications, but we note that in some organizations specifications are revisited many times through- out the development process.

The two stages in which specifications are established are shown as part of the concept development process in Exhibit 1-5. Note that the final specifications are one of the key elements of the development plan, which is usually documented in the project's contract book. The Managing Projects specifies what the team agrees to achieve, the project schedule, the required resources, and the economic implications for the business. The list of product specifications is also one of the key information systems used by the team throughout the development process.

Establishing Target Specifications

The target specifications are established after the customer needs have been identified but before product concepts have been generated and the most promising one(s) selected. An arbitrary setting of the specifications may not be technically feasible. For example, in designing a suspension fork, the team cannot assume in advance that it will be able to achieve simultaneously a mass of 1 kilogram, a manufacturing cost of $30, and the best descent time on the test track, as these are three quite aggressive specifications. Actually meeting the specifications established at this point is contingent upon the details of the product concept the team eventually selects. For this reason, such preliminary specifications are labeled "target specifications." They are the goals of the development team, describing a product that the team believes would succeed in the marketplace. Later these specifications will be refined based on the limitations of the product concept actually selected.

The process of establishing the target specifications contains four steps:

1. Prepare the list of metrics.
2. Collect competitive benchmarking information.
3. Set ideal and marginally acceptable target values.
4. Reflect on the results and the process.

Step 1: Prepare the List of Metrics

The most useful metrics are those that reflect as directly as possible the degree to which the product satisfies the customer needs. The relationship between needs and metrics is central to the entire concept of specifications. The working assumption is that a translation from customer needs to a set of precise, measurable specifications is possible and that meeting specifications will therefore lead to satisfaction of the associated customer needs. A good way to generate the list of metrics is to contemplate each need in turn and to consider what precise, measurable characteristic of the product will reflect the degree to which the product satisfies that need. In the ideal case, there is one and only one metric for each need. In practice, this is frequently not possible. For example, consider the need that the suspension be "easy to install." The team may conclude that this need is largely captured by measuring the time required for assembly of the fork to the frame; however, note the possible subtleties in this translation. Is assembly time really identical to ease of installation? The installation could be extremely fast but require an awkward and painful set of finger actions, which ultimately may lead to worker injury or dealer frustration. Because of the imprecise nature of the translation process, those establishing the specifications should have been directly involved in identifying the customer needs. In this way the team can rely on its understanding of the meaning of each need statement derived from firsthand interactions with customers. The need for the fork to reduce vibration to the user's hands may be even more difficult to translate into a single metric, because there are many different conditions under which vibration can be transmitted, including small bumps on level roads and big bumps on rough trails. The team may conclude that several metrics are required to capture this need, including, for example, the metrics "attenuation from dropout to handlebar at 10 Hz" and "maximum value from the Monster." (The "Monster" is a suspension test developed by Mountain Bike magazine.)

A simple needs-metrics matrix represents the relationship between needs and metrics. An example needs-metrics matrix is shown in Exhibit 1-5. The rows of the matrix correspond to the customer needs, and the columns of the matrix correspond to the metrics. A mark in a cell of the matrix means that the need and the metric associated with the cell are related; performance relative to the metric will influence the degree to which the product satisfies the customer need. This matrix is a key element of the House of Quality, a graphical technique used in Quality Function Deployment, or QFD (Hauser and Clausing, 1988). In many cases, we find the information in the needs-metrics matrix is just as easily communicated by listing the numbers of the needs related to each metric alongside the list of metrics .There are some cases, however, in which the mapping from needs to metrics is complex, and the matrix can be quite useful for representing this mapping.

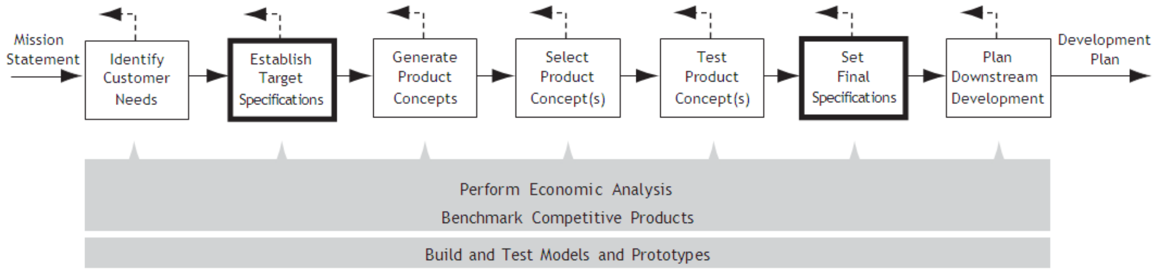


FIGURE1.5 The concept development process. The target specifications are set early in the process, but setting the final specifications must wait until after the product concept has been selected.

The process of establishing the target specifications contains four steps:

1. Prepare the list of metrics.
2. Collect competitive benchmarking information.
3. Set ideal and marginally acceptable target values.
4. Reflect on the results and the process.

Step 1: Prepare the List of Metrics

The most useful metrics are those that reflect as directly as possible the degree to which the product satisfies the customer needs. The relationship between needs and metrics is central to the entire concept of specifications. The working assumption is that a translation from customer needs to a set of precise, measurable specifications is possible and that meeting specifications will therefore lead to satisfaction of the associated customer needs.

A good way to generate the list of metrics is to contemplate each need in turn and to consider what precise, measurable characteristic of the product will reflect the degree to which the product satisfies that need. In the ideal case, there is one and only one metric for each need. In practice, this is frequently not possible.

For example, consider the need that the suspension be "easy to install." The team may conclude that this need is largely captured by measuring the time required for assembly of the fork to the frame; however, note the possible subtleties in this translation. Is assembly time really identical to ease of installation? The installation could be extremely fast but require an awkward and painful set of finger actions, which ultimately may lead to worker injury or dealer frustration. Because of the imprecise nature of the translation process, those establishing the specifications should have been directly involved in identifying the customer needs. In this way the team can rely on its understanding of the meaning of each need statement derived from firsthand interactions with customers.

The need for the fork to reduce vibration to the user's hands may be even more difficult to translate into a single metric, because there are many different conditions under which vibration can be transmitted, including small bumps on level roads and big bumps on rough trails. The team may conclude that several metrics are required to capture this need, including, for example, the metrics "attenuation from dropout to handlebar at 10 Hz" and "maximum value from the Monster." (The "Monster" is a suspension test developed by Mountain Bike magazine.)

A simple needs-metrics matrix represents the relationship between needs and metrics. The rows of the matrix correspond to the customer needs, and the columns of the matrix correspond to the metrics. A mark in a cell of the matrix means that the need and the metric associated with the cell are related; performance relative to the metric will influence the degree to which the product satisfies the customer need. This matrix is a key element of the House of Quality, a graphical technique used in Quality Function Deployment, or QFD (Hauser and Clausing, 1988). In many cases, we find the information in the needs-metrics matrix is just as easily communicated by listing the numbers of the needs related to each metric alongside the list of metrics .There are some cases, however, in which the mapping from needs to metrics is complex, and the matrix can be quite useful for representing this mapping.

TABLE.1.4 List of metrics for the suspension. The relative importance of each metric and the units for the metric are also shown.

Metric No.	Need Nos.	Metric	Imp.	Units
1	1, 3	Attenuation from dropout to handlebar at 10 Hz	3	dB
2	2, 6	Spring preload	3	N
3	1, 3	Maximum value from the Monster	5	g
4	1, 3	Minimum descent time on test track	5	s
5	4	Damping coefficient adjustment range	3	N-s/m
6	5	Maximum travel (26-in. wheel)	3	mm
7	5	Rake offset	3	mm
8	6	Lateral stiffness at the tip	3	kN/m
9	7	Total mass	4	kg
10	8	Lateral stiffness at brake pivots	2	kN/m
11	9	Headset sizes	5	in.
12	9	Steertube length	5	mm
13	9	Wheel sizes	5	List
14	9	Maximum tire width	5	in.
15	10	Time to assemble to frame	1	s
16	11	Fender compatibility	1	List
17	12	Instills pride	5	Subj.
18	13	Unit manufacturing cost	5	US$

19	14	Time in spray chamber without water entry	5	s
20	15	Cycles in mud chamber without contamination	5	k-cycles
21	16, 17	Time to disassemble/assemble for maintenance	3	s
22	17, 18	Special tools required for maintenance	3	List
23	19	UV test duration to degrade rubber parts	5	hr
24	19	Monster cycles to failure	5	Cycles
25	20	Japan Industrial Standards test	5	Binary
26	20	Bending strength (frontal loading)	5	kN

A few guidelines should be considered when constructing the list of metrics:

• Metrics should be complete. Ideally each customer need would correspond to a single metric, and the value of that metric would correlate perfectly with satisfaction of that need. In practice, several metrics may be necessary to completely reflect a single customer need.

• Metrics should be dependent, not independent, variables. This guideline is a variant of the what-not-how principle introduced. As do customer needs, specifications also indicate what the product must do, but not how the specifications will be achieved. Designers use many types of variables in product development; some are dependent, such as the mass of the fork, and some are independent, such as the material used for the fork. In other words, designers cannot control mass directly because it arises from other independent decisions the designers will make, such as dimensions and materials choices. Metrics specify the overall performance of a product and should therefore be the dependent variables (i.e., the performance measures or output variables) in the design problem. By using dependent variables for the specifications, designers are left with the freedom to achieve the specifications using the best approach possible.

Be achieved. Designers use many types of variables in product development; some are dependent, such as the mass of the fork, and some are independent, such as the material used for the fork. In other words, designers cannot control mass directly because it arises from other independent decisions the designers will make, such as dimensions and materials choices. Metrics specify the overall performance of a product and should therefore be the dependent variables (i.e., the performance measures or output variables) in the design problem. By using dependent variables for the specifications, designers are left with the freedom to achieve the specifications using the best approach possible.

• Metrics should be practical. It does not serve the team to devise a metric for a bicycle suspension that can only be measured by a scientific laboratory at a cost of $100,000. Ideally, metrics will be directly observable or analyzable properties of the product that can be easily evaluated by the team.

• Some needs cannot easily be translated into quantifiable metrics. The need that the suspension instills pride may be quite critical to success in the fashion-conscious mountain bike market, but how can pride be quantified? In these cases, the team simply repeats the need statement as a specification and notes that the metric is subjective. However, the team still has to decide how to confirm that the specification is satisfied; for example, by a panel of customers.

• The metrics should include the popular criteria for comparison in the marketplace. Many customers in various markets buy products based on independently published evaluations. Such evaluations are found, for example, in Popular Science, Consumer Reports, on various Internet sites, or, in our case, in Bicycling and Mountain Bike magazines. If the team knows that its product will be evaluated by the trade media and knows what the evaluation criteria will be, then it should include metrics corresponding to these criteria. Mountain Bike magazine uses a test machine called the Monster, which measures the vertical acceleration of the handlebars as a bicycle equipped with the fork runs over a block 50 millimeters tall. For this reason, the team included “maximum value from the Monster” as a metric. If the team cannot find a relationship between the criteria used by the media and the customer needs it has identified, then it should ensure that a need has not been overlooked and/or should work with the media to revise the criteria. In a few cases, the team may conclude that high performance in the media evaluations is in itself a customer need and choose to include a metric used by the media that has little intrinsic technical merit.

In addition to denoting the needs related to each metric, Table 1-4 contains the units of measurement and an importance rating for each metric. The units of measurement are most commonly conventional engineering units such as kilograms and seconds; however, some metrics will not lend themselves to numerical values. The need that the suspension “works with fenders” is best translated into a specification listing the models of fenders with which the fork is compatible. In this case, the value of the metric is actually a list of fenders rather than a number. For the metric involving the standard safety test, the value is pass/fail. (We indicate these two cases by entering “List” and “Binary” in the unit’s column.)

The importance rating of a metric is derived from the importance ratings of the needs it reflects. For cases in which a metric maps directly to a single need, the importance rating of the need becomes the importance rating of the metric. For cases in which a metric is related to more than one need, the importance of the metric is determined by considering the importance of the needs to which it relates and the nature of these relationships. We believe that there are enough subtleties in this process that importance weightings can best be determined through discussion among the team members, rather than through a formal algorithm. When there are relatively few specifications and establishing the relative importance of these specifications is critically important, conjoint analysis may be useful.

Conjoint analysis is described briefly later in this chapter and publications explaining the technique are referenced at the end of the chapter.

Step 2: Collect Competitive Benchmarking Information

Unless the team expects to enjoy a total monopoly, the relationship of the new product to competitive products is paramount in determining commercial success. While the team will have entered the product development process with some idea of how it wishes to compete in the marketplace, the target specifications are the language the team uses to discuss and agree on the detailed positioning of its product relative to existing products, both its own and competitors'. Information on competing products must be gathered to support these positioning decisions.

The columns of the chart correspond to the competitive products and the rows are the metrics established in step 1. Note that the competitive benchmarking chart can be constructed as a simple appendage to the spreadsheet containing the list of metrics. (This information is one of the "rooms" in the House of Quality, described by Hauser and Clausing.)

The benchmarking chart is conceptually very simple. For each competitive product, the values of the metrics are simply entered down a column. Gathering these data can be very time consuming, involving (at the least) purchasing, testing, disassembling, and estimating the production costs of the most important competitive products; however, this investment of time is essential, as no product development team can expect to succeed without having this type of information. A word of warning: Sometimes the data contained in competitors' catalogs and supporting literature are not accurate. Where possible, values of the key metrics should be verified by independent testing or observation.

An alternative competitive benchmarking chart can be constructed with rows corresponding to the customer needs and columns corresponding to the competitive products This chart is used to compare customers' perceptions of the relative degree to which the products satisfy their needs. Constructing this chart requires collecting customer perception data, which can also be very expensive and time consuming. Some techniques for measuring customers' perceptions of satisfaction of needs are contained in a book by Urban and Hauser (1993). Both charts can be useful and any discrepancies between the two are instructive. At a minimum, a chart showing the competitive values of the metrics should be created.

Step 3: Set Ideal and Marginally Acceptable Target Values

In this step, the team synthesizes the available information to actually set the target values for the metrics. Two types of target value are useful: an ideal value and a margin- ally acceptable value. The ideal value is the best result the team could hope for. The marginally acceptable value is the value of the metric that would just barely make the product commercially viable. Both of these targets are useful in guiding the subsequent stages of concept generation and concept selection, and for refining the specifications after the product concept have been selected.

There are five ways to express the values of the metrics:

- At least X: These specifications establish targets for the lower bound on a metric, but higher is still better. For example, the value of the brake mounting stiffness is specified to be at least 325 kilonewtons/meter.
- At most X: These specifications establish targets for the upper bound on a metric, with smaller values being better. For example, the value for the mass of the suspension fork is set to be at most 1.4 kilograms

Setting the Final Specifications

As the team finalizes the choice of a concept and prepares for subsequent design and development, the specifications are revisited. Specifications that originally were only targets expressed as broad ranges of values are now refined and made more precise.

Finalizing the specifications is difficult because of trade-offs—inverse relationships between two specifications that are inherent in the selected product concept. Trade-offs frequently occurs between different technical performances metrics and almost always occur between technical performance metrics and production cost. There may also be trade-offs between product performance and development time or cost. For example, one trade-off is between brake mounting stiffness and mass of the fork. Because of the basic mechanics of the fork structure, these specifications are inversely related, assuming other factors are held constant. Another trade-off is between cost and mass. For a given concept, the team may be able to reduce the mass of the fork by making some parts out of titanium instead of steel. Unfortunately, decreasing the mass in this way will most likely increase the manufacturing cost of the product. The difficult part of refining the specifications is choosing how such trade-offs will be resolved.

No.	**PART - A**	**CO (L)**
1	Compare the terms Durability and Tangibility	1(4)
2	Define Convenience products.	1(1)
3	Generalize the term Unsought products.	1(4)
4	Define product strategy	1 (1)
5	Describe the importance of product strategy.	1 (3)
6	Explain briefly the elements involved in product strategy.	1 (5)
7	Summarize the steps involved in customer involvement.	1 (5)
8	Define Product ideas	1 (1)
9	Explain the Needs of organization process management	1 (3)
10	Explain the importance of Product development.	1 (2)

11	Interpret the life cycle plant.	1 (5)
12	Define supplier integration.	1 (1)
13	Demonstrate Behavior analysis	1 (5)
No.	**PART - B**	**CO (L)**
1	Write short notes on New Product Development Process.	1(2)
2	Write short notes on Product life cycle.	1(2)
3	Write briefly on the following i) Characteristics of successful product development. ii) Challenges in new product development.	1 (3)
4	Discuss the methodology used in new product development.	1 (4)
5	Explain the various factors that promote innovation and continuous improvement in an organization.	1 (2)
6	Briefly explain the organizational policies for product planning, process management and improvement of product.	1 (2)
7	Explain the ways of involving customer in development of a new product.	1 (2)
8	Write briefly on the following, i) Steps to obtain target specifications. ii) Steps to obtain final specifications.	1 (2)
9	Describe about ideal and marginally acceptable target values in product specifications.	1 (4)

SCHOOL OF MECHANICAL ENGINEERING

DEPARTMENT OF MECHANICAL ENGINEERING

UNIT – II – SMEA3009 – BASIC CONCEPTS

UNIT 2

BASIC CONCEPTS

The product design specification (PDS) is a document created during the problem definition activity very early in the design process. It details the requirements that must be met in order for the product or process to be successful. The document lays the groundwork for all engineering design activities and ensures that all relevant factors are accounted for and all stakeholders are heard from. A typical PDS includes the following information:

FACTORS AFFECTING PRODUCT DESIGN

There is a large member of factors which influence product design. These factors belong to different fields in production and industrial engineering. Also these factors vary in degree of complexity and character.

These factors can be broadly classified in four groups:

(a) Technical factors

(b) Industrial design factors

(c) Designing for production - economic factors

(d) Other factors

The Activity of Concept Generation

A product concept is an approximate description of the technology, working principles, and form of the product. It is a concise description of how the product will satisfy the customer needs. A concept is usually expressed as a sketch or as a rough three-dimensional model and is often accompanied by a brief textual description. The degree to which a product satisfies customers and can be successfully commercialized depends to a large measure on the quality of the underlying concept. A good concept is sometimes poorly implemented in subsequent development phases, but a poor concept can rarely be manipulated to achieve commercial success. Fortunately, concept generation is relatively inexpensive and can be done relatively quickly in comparison to the rest of the development process. For example, concept generation had typically consumed less than 5 percent of the budget and 15 percent of the development time in previous nailer development efforts. Because the concept generation activity is not costly, there is no excuse for a lack of diligence and care in executing a sound concept generation method.

The concept generation process begins with a set of customer needs and target specifications and results in a set of product concepts from which the team will make a final selection. The relation of concept generation to the other concept development activities is shown in Exhibit 2-1. In most cases, an effective development team will generate hundreds of concepts, of which 5 to 20 will merit serious consideration during the concept selection activity.

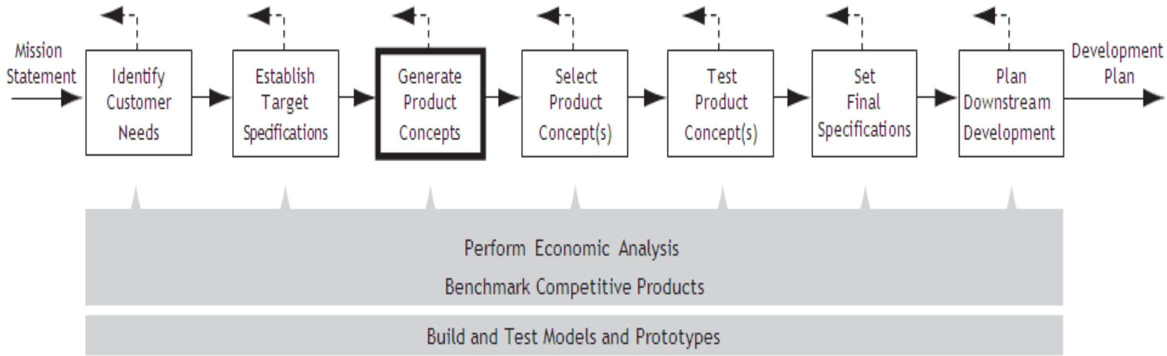


FIGURE 2-1. Concept generation is an integral part of the concept development phase.

Good concept generation leaves the team with confidence that the full space of alternatives has been explored. Thorough exploration of alternatives early in the development process greatly reduces the likelihood that the team will stumble upon a superior concept late in the development process or that a competitor will introduce a product with dramatically better performance than the product under development.

Structured Approaches Reduce the Likelihood of Costly Problems

Common dysfunctions exhibited by development teams during concept generation include:

- Consideration of only one or two alternatives, often proposed by the most assertive members of the team.
- Failure to consider carefully the usefulness of concepts employed by other firms in related and unrelated products.
- Involvement of only one or two people in the process, resulting in lack of confidence and commitment by the rest of the team.
- Ineffective integration of promising partial solutions.
- Failure to consider entire categories of solutions.

A structured approach to concept generation reduces the incidence of these problems by encouraging the gathering of information from many disparate information sources, by guiding the team in the thorough exploration of alternatives, and by providing a mechanism for integrating partial solutions. A structured method also provides a step-by-step procedure for those members of the team who may be less experienced in design-intensive activities, allowing them to participate actively in the process.

A Five-Step Method

This chapter presents a five-step concept generation method. The method, outlined in Exhibit 2-2, breaks a complex problem into simpler sub problems. Solution concepts are then identified for the sub problems by external and internal search procedures. Classification trees and concept combination tables are then used to systematically explore the space of solution concepts and to integrate the sub problem solutions into a total solution. Finally, the team takes a step back to reflect on the validity and applicability of the results, as well as on the process used.

This chapter will follow the recommended method and will describe each of the five steps in detail. Although we present the method in a linear sequence, concept generation is almost always iterative. Like our other development methods, these steps are intended to be a baseline from which product development teams can develop and refine their own unique problem-solving style.

Our presentation of the method is focused primarily on the overall concept for a new product; however, the method can and should be used at several different points in the development process. The process is useful not only for overall product concepts but also for concepts for subsystems and specific components as well. Also note that while the ex- ample in this chapter involves a relatively technical product, the same basic approach can be applied to nearly any product.

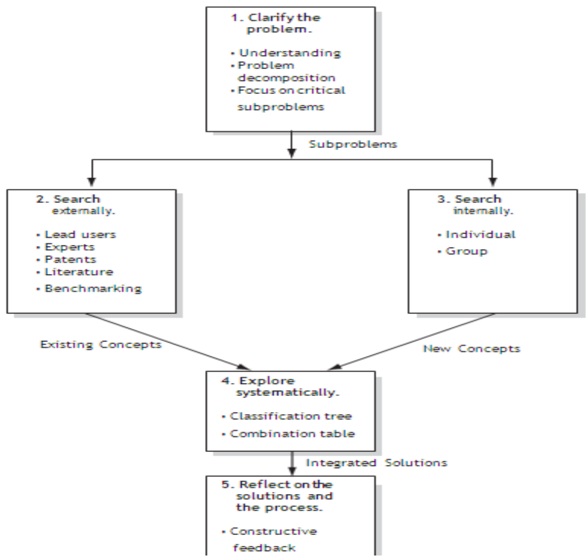


FIGURE 2-2. The five- step concept generation method.

.

Step 1: Clarify the Problem

Clarifying the problem consists of developing a general understanding and then breaking the problem down into sub problems if necessary.

The mission statement for the project, the customer needs list, and the preliminary product specification are the ideal inputs to the concept generation process, although often these pieces of information are still being refined as the concept generation phase begins. Ideally the team has been involved both in the identification of the customer needs and in the setting of the target product specifications. Those members of the team who were not involved in these preceding steps should become familiar with the processes used and their results before concept generation activities begin.

As stated before, the challenge was to “design a better handheld roofing nailer.” The scope of the design problem could have been defined more generally (e.g., “fasten roof- ing materials”) or more specifically (e.g., “improve the speed of the existing pneumatic tool concept”). Some of the assumptions in the team’s mission statement were:

- The nailer will use nails (as opposed to adhesives, screws, etc.).
- The nailer will be compatible with nail magazines on existing tools.
- The nailer will nail through roofing shingles into wood.
- The nailer will be handheld.

Based on the assumptions, the team had identified the customer needs for a handheld nailer. These included:

- The nailer inserts nails in rapid succession.
- The nailer is lightweight.
- The nailer has no noticeable nailing delay after tripping the tool.

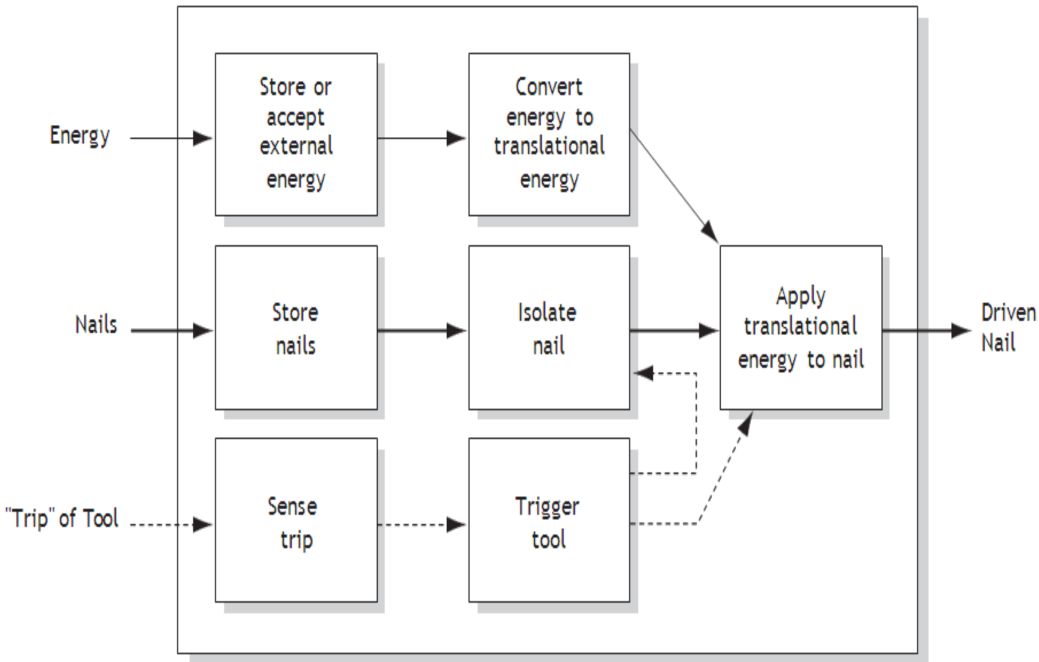
The team gathered supplemental information to clarify and quantify the needs, such as the approximate energy and speed of the nailing. These basic needs were subsequently translated into target product specifications. The target specifications included the following:

- Nail lengths from 25 millimeters to 38 millimeters.
- Maximum nailing energy of 40 joules per nail.
- Nailing forces of up to 2,000 newtons.
- Peak nailing rate of one nail per second.
- Average nailing rate of 12 nails per minute.

- Tool mass less than 4 kilograms.
- Maximum trigger delay of 0.25 second.

Decompose a Complex Problem into Simpler Sub problems

Many design challenges are too complex to solve as a single problem and can be use- fully divided into several simpler sub problems. For example, the design of a complex product like a document copier can be thought of as a collection of more focused design problems, including, for example, the design of a document handler, the design of a paper feeder, the design of a printing device, and the design of an image capture device. In some cases, however, the design problem cannot readily be divided into sub problems. For example, the problem of designing a paper clip may be hard to divide into sub problems. As a general rule, we feel that teams should attempt to decompose design problems, but should be aware that such decomposition may not be very useful for products with extremely simple functions. Dividing a problem into simpler sub problems is called problem decomposition. There are many schemes by which a problem can be decomposed. Here we demonstrate a functional decomposition and also list several other approaches that are frequently useful.



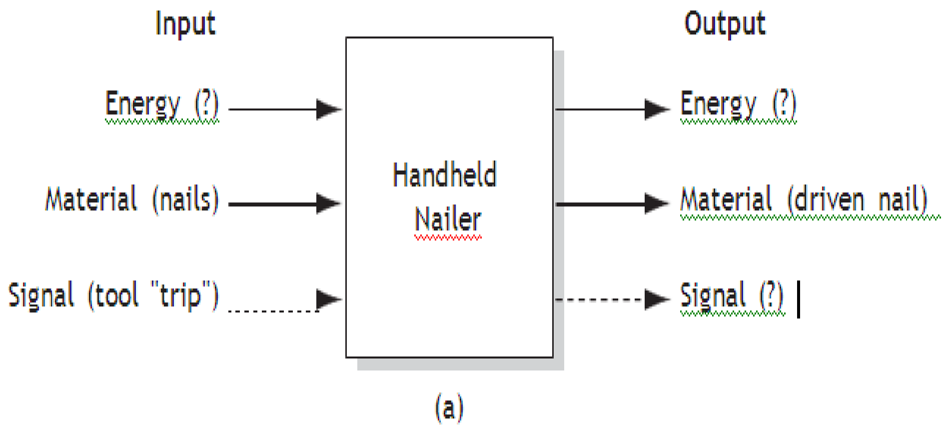


FIGURE 2-3 Function diagram of a handheld nailer arising from a functional decomposition: (a) overall “black box”; (b) refinement showing subfunctions.

The first step in decomposing a problem functionally is to represent it as a single black box operating on material, energy, and signal flows, as shown in Exhibit 2-2(a). Thin solid lines denote the transfer and conversion of energy, thick solid lines signify the movement of material within the system, and dashed lines represent the flows of control and feedback signals within the system. This black box represents the overall function of the product. The next step in functional decomposition is to divide the single black box into sub functions to create a more specific description of what the elements of the product might do to implement the overall function of the product. Each sub function can generally be further divided into even simpler sub functions. The division process is repeated until the team members agree that each sub function is simple enough to work with. A good rule of thumb is to create between 3 and 10 sub functions in the diagram. The end result, shown in Exhibit 2.2(b), is a function diagram containing sub functions connected by energy, material, and signal flows.

Note that at this stage the goal is to describe the functional elements of the product without implying a specific technological working principle for the product concept. For example, Exhibit 2.2(b) includes the sub function “isolate nail.” This sub function is ex- pressed in such a way that it does not imply any particular physical solution concept, such as indexing the coil of nails into a slot or breaking a nail sideways off of the stick. The team should consider each sub function in turn and ask whether it is expressed in a way that does not imply a particular physical solution principle.

There is no single correct way of creating a function diagram and no single correct functional decomposition of a product. A helpful way to create the diagram is to quickly create several drafts and then work to refine them into a single diagram that the team is comfortable with. Some useful techniques for getting started are:

- Create a function diagram of an existing product.
- Create a function diagram based on an arbitrary product concept already generated by the team or based on a known sub function technology. Be sure to generalize the diagram to the appropriate level of abstraction.
- Follow one of the flows (e.g., material) and determine what operations are required. The details of the other flows can be derived by thinking about their connections to the initial flow.

Note that the function diagram is typically not unique. In particular, sub functions can often be ordered in different ways to produce different function diagrams. Also note that in some applications the material, energy, and signal flows are difficult to identify. In these cases, a simple list of the sub functions of the product, without connections between them, is often sufficient.

Functional decomposition is most applicable to technical products, but it can also be applied to simple and apparently nontechnical products. For example, an ice cream scoop has material flow of ice cream being separated, formed, transported, and deposited. These sub functions could form the basis of problem decomposition.

Functional decomposition is only one of several possible ways to divide a problem into simpler sub problems. Two other approaches are:

- Decomposition by sequence of user actions: For example, the nailer problem might be broken down into three user actions: moving the tool to the gross nailing position, positioning the tool precisely, and triggering the tool. This approach is often useful for products with very simple technical functions involving a lot of user interaction.
- Decomposition by key customer needs: For the nailer, this decomposition might include the following sub problems: fires nails in rapid succession, is lightweight, and has a large nail capacity. This approach is often useful for products in which form, and not working principles or technology, is the primary problem. Examples of such products include toothbrushes (assuming the basic brush concept is retained) and storage containers.

Focus Initial Efforts on the Critical Sub problems

The goal of all of these decomposition techniques is to divide a complex problem into simpler problems such that these simpler problems can be tackled in a focused way. Once problem decomposition is complete, the team chooses the sub problems that are most critical to the success of the product and that are most likely to benefit from novel or creative solutions. This approach involves a conscious decision to defer the solution of some of the sub problems. For example, the nailer team chose to focus on the sub problems of storing/ accepting energy, converting the energy to translational energy, and applying the translational energy to the nail. The team felt confident that the nail handling and triggering issues could be solved after the energy storage and conversion issues were addressed. The team also deferred most of the user interaction issues of the tool. The team believed that the choice of a basic working principle for the tool would so constrain the eventual form of the tool that they had to begin with the core technology and then proceed to consider how to embody that technology in an attractive and user-friendly form. Teams can usually agree after a few minutes of discussion on which sub problems should be addressed first and which should be deferred for later consideration.

Step 2: Search Externally

External search is aimed at finding existing solutions to both the overall problem and the sub problems identified during the problem clarification step. While external search is listed as the second step in the concept generation method, this sequential labeling is deceptive; external search occurs continually throughout the development process. Implementing an existing solution is usually quicker and cheaper than developing a new solution. Liberal use of existing solutions allows the team to focus its creative energy on the critical sub problems for which there are no satisfactory prior solutions. Furthermore, a conventional solution to one sub problem can frequently be combined with a novel solution to another sub problem to yield a superior overall design. For this reason external search includes detailed evaluation not only of directly competitive products but also of technologies used in products with related sub functions.

The external search for solutions is essentially an information-gathering process. Avail- able time and resources can be optimized by using an expand-and-focus strategy: first expand the scope of the search by broadly gathering information that might be related to the problem and then focus the scope of the search by exploring the promising directions in more detail. Too much of either approach will make the external search inefficient.

There are at least five good ways to gather information from external sources: lead user interviews, expert consultation, patent searches, literature searches, and competitive benchmarking.

Interview Lead Users

While identifying customer needs, the team may have sought out or encountered lead users. Lead users are those users of a product who experience needs months or years before the majority of the market and stand to benefit substantially from a product innovation (von Hippel, 1988). Frequently these lead users will have already invented solutions to meet their needs. This is particularly true among highly technical user communities, such as those in the medical or scientific fields. Lead users may be sought out in the market for which the team is developing the new product, or they may be found in markets for products implementing some of the sub functions of the product.

In the handheld nailer case, the nailer team consulted with the building contractors from the PBS television series This Old House to solicit new concepts. These lead users, who are exposed to tools from many manufacturers, made many interesting observations about the weaknesses in existing tools, but in this case did not provide many new product concepts.

Consult Experts

Experts with knowledge of one or more of the sub problems not only can provide solution concepts directly but also can redirect the search in a more fruitful area. Experts may include professionals at firms manufacturing related products, professional consultants, university faculty, and technical representatives of suppliers. These people can be found by calling university- ties, by calling companies, and by looking up authors of articles. While finding experts can be hard work, it is almost always less time consuming than re-creating existing knowledge.

Most experts are willing to talk on the telephone or meet in person for an hour or so without charge. In general, consultants will expect to be paid for time they spend on a problem beyond an initial meeting or telephone conversation. Suppliers are usually willing to provide several days of effort without direct compensation if they anticipate that someone will use their product as a component in a design. Of course, experts at directly competing firms are in most cases unwilling to provide proprietary information about their product designs. A good habit to develop is to always ask people consulted to suggest others who should be contacted. The best information often comes from pursuing these “second generation” leads.

The nailer design team consulted dozens of experts, including a rocket fuel specialist, electric motor researchers at MIT, and engineers from a vendor of gas springs. Most of this consultation was done on the telephone, although the engineers from the spring vendor made two trips to visit the team, at their company’s expense.

Search Patents

Patents are a rich and readily available source of technical information containing detailed drawings and explanations of how many products work. The main disadvantage of patent searches is that concepts found in recent patents are protected (generally for 20 years from the date of the patent application), so there may be a royalty involved in using them; however, patents are also useful to see what concepts are already protected and must be avoided or licensed. Concepts contained in foreign patents without global coverage and in expired patents can be used without payment of royalties. Patents and Intellectual Property, for an explanation of patent rights and how to understand patent claims. The formal indexing scheme for patents is difficult for novices to navigate. Fortunately, several databases contain the actual text of all patents. These text databases can be searched electronically by key words. Key word searches can be conducted efficiently with only modest practice and are remarkably effective in finding patents relevant to a particular product. Copies of U.S. patents including illustrations can be obtained for a nominal fee from the U.S. Patent and Trademark Office and from several suppliers. (See the Web site www.ulrich-eppinger.net for a current list of online patent databases and

suppliers of patent documents.)

A U.S. patent search in the area of nailers revealed several interesting concepts. One of the patents described a motor-driven double-flywheel nailer. The design in this patent uses the accumulation of rotational kinetic energy in a flywheel, which is then suddenly converted into translational energy by a friction clutch. The energy is then delivered to the nail with a single impact of a drive pin.

Step 3: Search Internally

Internal search is the use of personal and team knowledge and creativity to generate solution concepts. Often called brainstorming, and based largely on the creativity methods developed by Osborn in the 1940s, this type of search is internal in that all of the ideas to emerge from this step are created from knowledge already in the pos- session of the team. This activity may be the most open-ended and creative of any task in product development. We find it useful to think of internal search as a process of retrieving a potentially useful piece of information from one's memory and then adapting that information to the problem at hand. This process can be carried out by individuals working in isolation or by a group of people working together.

Five guidelines are useful for improving both individual and group internal search:

1. Suspend judgment. In most aspects of daily life, success depends on an ability to quickly evaluate a set of alternatives and take action. For example, none of us would be very productive if deciding what to wear in the morning or what to eat for breakfast involved an extensive period of generating alternatives before making a judgment. Because most decisions in our day-to-day lives

have implications of only a few minutes or hours, we are accustomed to making decisions quickly and moving on. Concept generation for product development is fundamentally different. We have to live with the consequences of product concept decisions for years. As a result, suspending evaluation for the days or weeks required to generate a large set of alternatives is critical to success. The imperative to suspend judgment is frequently translated into the rule that during group concept generation sessions no criticism of concepts is allowed. A better approach is for individuals perceiving weaknesses in concepts to channel any judgmental tendencies into suggestions for improvements or alternative concepts.

2. Generate a lot of ideas. Most experts believe that the more ideas a team generates, the more likely the team is to explore fully the solution space. Striving for quantity lowers the expectations of quality for any particular idea and therefore may encourage people to share ideas they may otherwise view as not worth mentioning. Further, each idea acts as a stimulus for other ideas, so a large number of ideas have the potential to stimulate even more ideas.

3. Welcome ideas that may seem infeasible. Ideas that initially appear infeasible can often be improved, "debugged," or "repaired" by other members of the team. The more infeasible an idea, the more it stretches the boundaries of the solution space and encourages the team to think of the limits of possibility. Therefore, infeasible ideas are quite valuable and their expression should be encouraged.

4. Make plenty of sketches. Spatial reasoning about physical objects can be challenging. Text and verbal language are inherently inefficient vehicles for describing physical entities. Whether working as a group or as an individual, abundant sketching materials should be available. Sketch quality is not so critical here; it is the expression of the concept that matters (Yang and Cham, 2007). Moreover, adding key dimensions to concept sketches has been shown to correlate with successful concept development (Yang, 2009).

5. Build sketch models. Simple, physical models can quickly be created to express concepts using foam, clay, cardboard, 3-D printing, and other media. Three-dimensional sketch models are particularly helpful for problems requiring a deep understanding of form, user interface, and spatial relationships. Research on the timing of sketch models suggests that earlier exploration using simple physical models is linked to better design outcomes (Häggman et al., 2013). Further research found that parallel development of multiple, alternative sketch models, rather than working on a single prototype at a time, is linked to better concept development performance (Neeley et al., 2013).

Both Individual and Group Sessions Can Be Useful

Formal studies of group and individual problem solving suggest that a set of people working alone for a period of time will generate more and better concepts than the same people working together for the same time period (McGrath, 1984). This finding is contrary to the actual practices of the many firms that perform most of their concept generation activities in group sessions. Our observations confirm the formal studies, and we believe that team members should spend at least some of their concept generation time working alone. This is because each person in the group may excel at a different dimension of creativity. That is, some members may be more fluid (many ideas along a single line of thinking), while others are more flexible (many different types of ideas), and others can be more novel (offering fewer but highly divergent ideas). We also believe that group sessions are critical for building consensus, communicating information, and refining concepts. In an ideal setting, each individual on the team would spend several hours working alone and then the group would get together to discuss and improve the concepts generated by individuals.

However, we also know that there is a practical reason for holding group concept generation sessions: it is one way to guarantee that the individuals in the group will devote a certain amount of time to the task. Especially in very intense and demanding work environments, without scheduling a meeting, few people will allocate several hours for concentrated individual effort on generating new concepts. The phone rings, people interrupt, urgent problems and e-mails demand attention. In certain environments, scheduled group sessions may be the only way to guarantee that enough attention is paid to the concept generation activity.

The nailer team used both individual effort and group sessions for internal search. For example, during one particular week each member was assigned one or two sub problems and was expected to develop at least 10 solution concepts. This divided the concept generation work among all members. The group then met to discuss and expand on the individually generated concepts. The more promising concepts were investigated further.

Hints for Generating Solution Concepts

Experienced individuals and teams can usually just sit down and begin generating good concepts for a sub problem. Often these people have developed a set of techniques they use to stimulate their thinking, and these techniques have become a natural part of their problem-solving process. Novice product development professionals may be aided by a set of hints that stimulate new ideas or encourage relationships among ideas. VanGundy (1988), von Oech (1998), and McKim (1980) give dozens of helpful suggestions. Here are some hints we have found to be helpful:

- Make analogies. Experienced designers always ask themselves what other devices solve a related problem. Frequently they will ask themselves if there is a natural or biological analogy to the problem. They will think about whether their problem exists at a much larger or smaller dimensional scale than that which they are considering. They will ask what devices do something similar in an unrelated area of application. The nailer team, when posing these questions, realized that construction pile drivers are similar to nailers in some respects. In following up on this idea, they developed the concept of a multi blow tool.

• Wish and wonder. Beginning a thought or comment with “I wish we could . . .” or “I wonder what would happen if . . .” helps to stimulate oneself or the group to consider new possibilities. These questions cause reflection on the boundaries of the problem. For ex- ample, a member of the nailer team, when confronted with the required length of a rail gun (an electromagnetic device for accelerating a projectile) for driving a nail, said, “I wish the tool could be 1 meter long.” Discussion of this comment led to the idea that perhaps a long tool could be used like a cane for nailing decking, allowing users to remain on their feet.

• Distort ideas. It is often helpful to modify or rearrange fragments of different solutions to create new ones. Several methods exist to stimulate this type of thinking. For example, the SCAMPER method, derived from Osborn’s work, provides stimuli to do this in seven ways that form its acronym: substitute, combine, adapt, modify/magnify/ minimize, put to other uses, eliminate, and reverse/rearrange.

• Use related stimuli. Most individuals can think of a new idea when presented with a new stimulus. Related stimuli are those stimuli generated in the context of the problem at hand. For example, one way to use related stimuli is for each individual in a group session to generate a list of ideas (working alone) and then pass the list to his or her neighbor. Upon reflection on someone else’s ideas, most people are able to generate new ideas. Other related stimuli include customer needs statements and photographs of the use environment of the product.

• Use unrelated stimuli. Occasionally, random or unrelated stimuli can be effective in encouraging new ideas. An example of such a technique, known as synectics, is to choose, at random, one of a collection of photographs of objects, and then to think of some way that the randomly generated object might relate to the problem at hand (Gordon, 1961). In a variant of this idea, individuals can be sent out on the streets with a digital camera to capture random images for subsequent use in stimulating new ideas. (This may also serve as a good change of pace for a tired group.)

• Set quantitative goals. Generating new ideas can be exhausting. Near the end of a ses- sion, individuals and groups may find quantitative goals useful as a motivating force. The nailer team frequently issued individual concept generation assignments with quantitative targets of 10 to 20 concepts.

• Use the gallery method. The gallery method is a way to display a large number of concepts simultaneously for discussion. Sketches, usually one concept to a sheet, are taped or pinned to the walls of the meeting room. Team members circulate and look at each concept. The creator of the concept may offer explanation, and the group sub- sequently makes suggestions for improving the concept or spontaneously generates related concepts. This method is a good way to merge individual and group efforts.

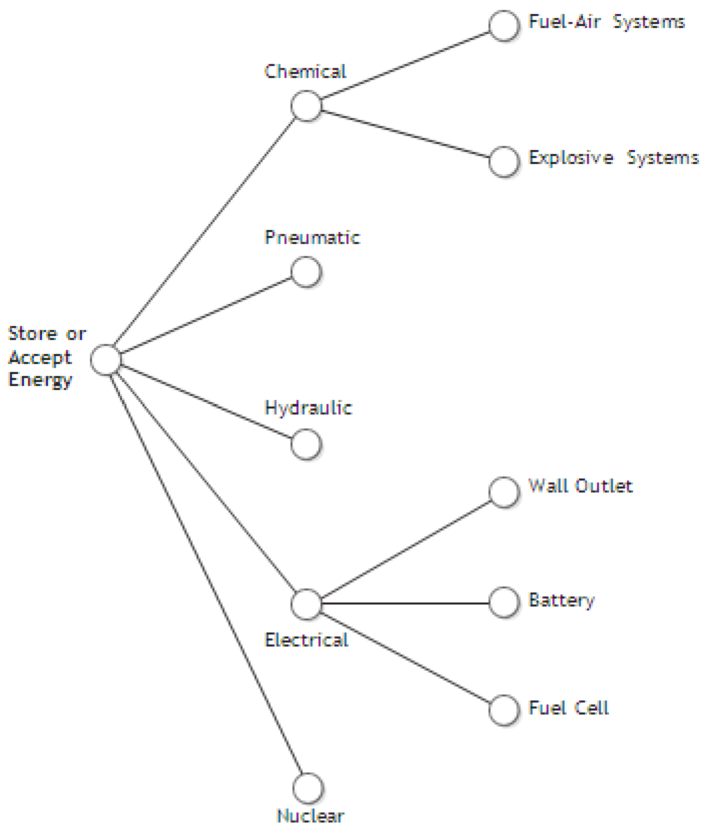
In the 1990s, a Russian problem-solving methodology called TRIZ (a Russian acronym for theory of inventive problem solving) began to be disseminated in Europe and in the United States. The methodology is primarily useful in identifying physical working principles to solve technical problems. The key idea underlying TRIZ is to identify a contradiction that is implicit in a problem. For example, a contradiction in the nailer problem might be that increasing power (a desirable characteristic) would also tend to increase weight (an undesired- able characteristic). One of the TRIZ tools is a matrix of 39 by 39 characteristics with each cell corresponding to a particular conflict between two characteristics. In each cell of the matrix, up to four physical principles are suggested as ways of resolving the corresponding conflict. There are 40 basic principles, including, for example, the periodic action principle (i.e., replace a continuous action with a periodic action, like an impulse). Using TRIZ, the nailer team might have arrived at the concept of using repeated smaller impacts to drive the nail. The idea of identifying a conflict in the design problem and then thinking about ways to resolve the conflict appears to be a very useful problem-solving heuristic. This approach can be useful in generating concepts even without adopting the entire TRIZ methodology.

Concept Classification Tree

The concept classification tree is used to divide the entire space of possible solutions into several distinct classes that will facilitate comparison and pruning. An example of a tree for the nailer example is shown in Exhibit 2-3. The branches of this tree correspond to different energy sources.

The classification tree provides at least four important benefits:

1. Pruning of less promising branches: If by studying the classification tree the team is able to identify a solution approach that does not appear to have much merit, then this approach can be pruned and the team can focus its attention on the more promising branches of the tree. Pruning a branch of the tree requires some evaluation and judgment and should therefore be done carefully, but the reality of product development is that there are limited.



.

FIGURE-2.4. A classification tree for the nailer energy source concept fragments.

Resources and that focusing the available resources on the most promising directions is an important success factor. For the nailer team, the nuclear energy source was pruned from consideration. Although the team had identified some very intriguing nuclear devices for use in powering artificial hearts, they felt that these devices would not be economically practical for at least a decade and would probably be hampered by regulatory requirements indefinitely.

2. Identification of independent approaches to the problem: Each branch of the tree can be considered a different approach to solving the overall problem. Some of these approaches may be almost completely independent of each other. In these cases, the team can cleanly divide its efforts among two or more individuals or task forces. When two approaches both look promising, this division of effort can reduce the complexity of the concept generation activities. It also may engender some healthy competition among the approaches under consideration. The nailer team found that both the chemical/explosive branch and the electrical branch appeared quite promising. They assigned these two approaches to two different sub teams and pursued them independently for several weeks.

3. Exposure of inappropriate emphasis on certain branches: Once the tree is con- structed, the team is able to reflect quickly on whether the effort applied to each branch has been appropriately allocated. The nailer team recognized that they had applied very little effort to thinking about hydraulic energy sources and conversion technologies. This recognition guided them to focus on this branch of the tree for a few days.

4. Refinement of the problem decomposition for a particular branch: Sometimes problem decomposition can be usefully tailored to a particular approach to the problem. Consider the branch of the tree corresponding to the electrical energy source. Based on additional investigation of the nailing process, the team determined that the instantaneous power delivered during the nailing process was about 10,000 watts for a few milliseconds and so exceeds the power that is available from a wall outlet, a battery, or a fuel cell (of reasonable size, cost, and mass). They concluded, therefore, that energy must be accumulated over a substantial period of the nailing cycle (say 100 milliseconds) and then suddenly released to sup- ply the required instantaneous power to drive the nail. This quick analysis led the team to add a sub function ("accumulate translational energy") to their function diagram (see Exhibit 7-8). They chose to add the sub function after the conversion of electrical energy to mechanical energy, but briefly considered the possibility of accumulating the energy in the electrical domain with a capacitor. This kind of refinement of the function diagram is quite common as the team makes more assumptions about the approach and as more information is gathered.

The classification tree in Exhibit 2-3 shows the alternative solutions to the energy source sub problem; however, there are other possible trees. The team might have chosen to use a tree classifying the alternative solutions to the energy delivery sub problem, showing branches for single impact, multiple impacts, or pushing. Trees can be constructed with branches corresponding to the solution fragments of any of the sub problems, but certain classifications are more useful. In general, a sub problem whose solution highly constrains the possible solutions to the remaining sub problems is a good candidate for a classification tree. For ex- ample, the choice of energy source (electrical, nuclear, pneumatic, etc.) constrains whether a motor or a piston-cylinder can be used to convert the energy to translational energy. In contrast, the choice of energy delivery mechanism (single impact, multiple impacts, etc.) does not greatly constrain the solutions to the other sub problems. Reflection on which sub problem is likely to most highly constrain the solutions to the remaining sub problems will usually lead to one or two clear ways to construct the classification tree.

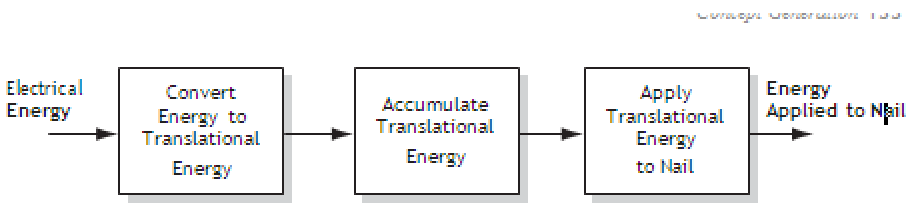


FIGURE-2.5. A new problem decomposition assuming an electrical energy source.

Concept Combination Table

The concept combination table provides a way to consider combinations of solution fragments systematically. Exhibit 2.5 shows an example of a combination table that the nailer team used to consider the combinations of fragments for the electrical branch of the classification tree. The columns in the table correspond to the sub problems identified in Exhibit 2.5. The entries in each column correspond to the solution fragments for each of these sub problems derived from external and internal search. For example, the sub problem of converting electrical energy to translational energy is the heading for the first column. The entries in this column are a rotary motor with a transmission, a linear motor, a solenoid, and a rail gun.

Potential solutions to the overall problem are formed by combining one fragment from each column. For the nailer example, there are 24 possible combinations (4 × 2 × 3). Choosing a combination of fragments does not lead spontaneously to a solution to the over- all problems. The combination of fragments must usually be developed and refined before an integrated solution emerges. This development may not even be possible or may lead to more than one solution, but at a minimum it involves additional creative thought. In some ways, the combination table is simply a way to make forced associations among fragments to stimulate further creative thinking; in no way does the mere act of selecting a combination yield a complete solution.

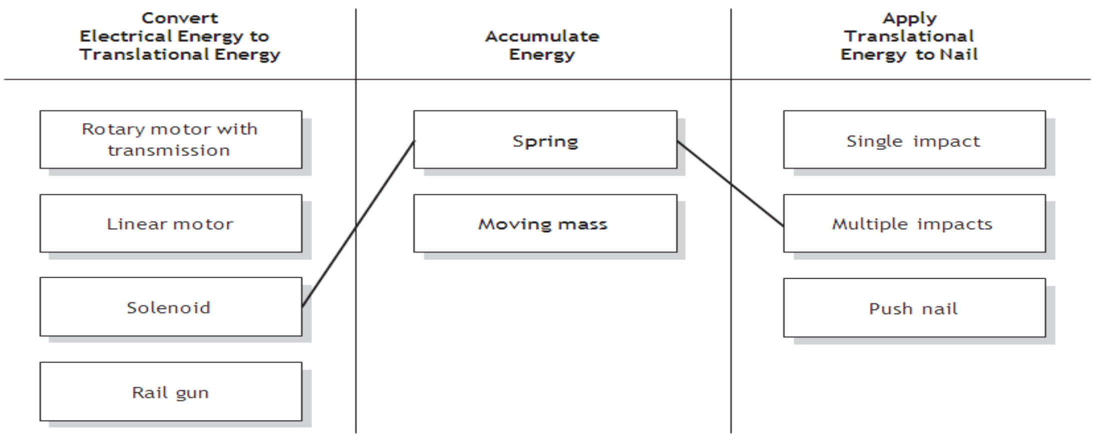


FIGURE-2.6. Concept combination table for the handheld nailer..

Concept Selection Is an Integral Part of the Product Development Process

Concept selection is the process of evaluating concepts with respect to customer needs and other criteria, com- paring the relative strengths and weaknesses of the concepts, and selecting one or more concepts for further investigation, testing, or development. Exhibit 2-6 illustrates how the concept selection activity is related to the other activities that make up the concept development phase of the product development process. Although this chapter focuses on the selection of an overall product concept at the beginning of the development process, the method we present is also useful later in the development process when the team must select subsystem concepts, components, and production processes. While many stages of the development process benefit from unbounded creativity and divergent thinking, concept selection is the process of narrowing the set of concept alternatives under consideration. Although concept selection is a convergent process, it is frequently iterative and may not produce a dominant concept immediately. A large set of concepts is initially winnowed down to a smaller set, but these concepts may subsequently be combined and improved to temporarily enlarge the set of concepts under consideration. Through several iterations a dominant concept is finally chosen. Exhibit 8-4 illustrates the successive narrowing and temporary widening of the set of options under consideration during the concept selection activity.

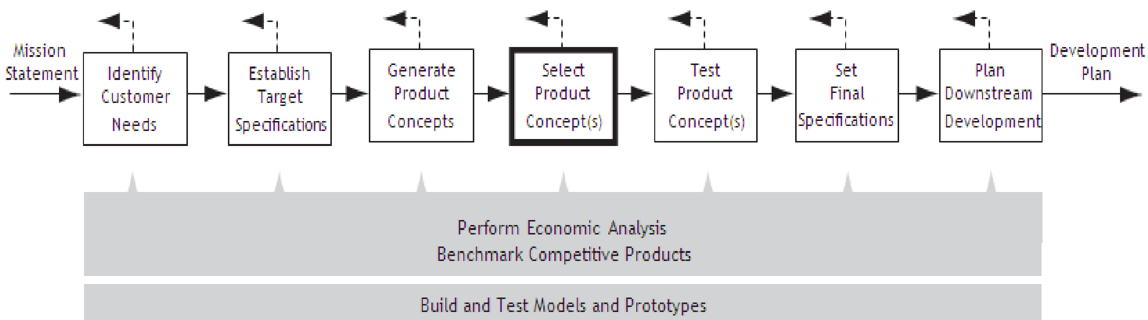


FIGURE 2.7. Concept selection is part of the overall concept development phase.

All Teams Use Some Method for Choosing a Concept

Whether or not the concept selection process is explicit, all teams use some method to choose among concepts. (Even those teams generating only one concept are using a method: choosing the first concept they think of.) The methods vary in their effectiveness and include the following:

- External decision: Concepts are turned over to the customer, client, or some other external entity for selection.
- Product champion: An influential member of the product development team chooses a concept based on personal preference.

- Intuition: The concept is chosen by its feel. Explicit criteria or trade-offs are not used. The concept just seems better.

- Multivoting: Each member of the team votes for several concepts. The concept with the most votes is selected.

- Web-based survey: Using an online survey tool, each concept is rated by many people to find the best ones.

- Pros and cons: The team lists the strengths and weaknesses of each concept and makes a choice based upon group opinion.

- Prototype and test: The organization builds and tests prototypes of each concept, making a selection based upon test data.

- Decision matrices: The team rates each concept against prespecified selection criteria, which may be weighted.

Concept Screening

Concept screening is based on a method developed by the late Stuart Pugh in the 1980s and is often called Pugh concept selection (Pugh, 1990). The purposes of this stage are to narrow the number of concepts quickly and to improve the concepts.

Step 1: Prepare the Selection Matrix

To prepare the matrix, the team selects a physical medium appropriate to the problem at hand. Individuals and small groups with a short list of criteria may use matrices on paper similar to Exhibit 2.1 or Appendix A for their selection process. For larger groups a chalkboard or flip chart is desirable to facilitate group discussion.

Table 2.1 The concept-screening matrix. For the syringe example, the team rated the concepts against the reference concept using a simple code (1 for "better than," 0 for "same as," 2 for "worse than") to identify some concepts for further consideration.

	Concepts						
Selection Criteria	A Master Cylinder	B Rubber Brake	C Ratchet	D (Reference) Plunge Stop	E Swash Ring	F Lever Set	G Dial Screw
Ease of handling	0	0	-	0	0	-	-
Ease of use	0	-	-	0	0	+	0
Readability of settings	0	0	+	0	+	0	+
Dose metering accuracy	0	0	0	0	-	0	0
Durability	0	0	0	0	0	+	0
Ease of manufacture	+	-	-	0	0	-	0
Portability	+	+	0	0	+	0	0
Sum +'s	2	1	1	0	2	2	1
Sum 0's	5	4	3	7	4	3	5
Sum -'s	0	2	3	0	1	2	1
Net Score	2	-1	-2	0	1	0	0
Rank	1	6	7	3	2	3	3
Continue?	Yes	No	No	Combine	Yes	Combine	Revise

Next, the inputs (concepts and criteria) are entered on the matrix. Although possibly generated by different individuals, concepts should be presented at the same level of detail for meaningful comparison and unbiased selection. The concepts are best portrayed by both a written description and a graphical representation. A simple one-page sketch of each concept greatly facilitates communication of the key features of the concept. The concepts are entered along the top of the matrix, using graphical or textual labels of some kind.

If the team is considering more than about 12 concepts, the multivoting technique may be used to quickly choose the dozen or so concepts to be evaluated with the screening matrix. Multivoting is a technique in which members of the team simultaneously vote for three to five concepts by applying “dots” to the sheets describing their preferred concepts. Opportunity Identification, for a description of multivoting applied to a broad set of product opportunities. The concepts with the most dots are chosen for concept screening. It is also possible to use the screening matrix method with a large number of concepts. This is facilitated by a spreadsheet and it is then useful to transpose the rows and columns. (Arrange the concepts in this case in the left column and the criteria along the top.)

The selection criteria are listed along the left-hand side of the screening matrix. These criteria are chosen based on the customer needs the team has identified, as well as on the needs of the enterprise, such as low manufacturing cost or minimal risk of product liability. The criteria at this stage are usually expressed at a fairly high level of abstraction and typically include from 5 to 10 dimensions. The selection criteria should be chosen to differentiate among the concepts; however, because each criterion is given equal weight in the concept screening method, the team should be careful not to list many relatively unimportant criteria in the screening matrix. Otherwise, the differences among the concepts relative to the more important criteria will not be clearly reflected in the outcome.

After careful consideration, the team chooses a concept to become the benchmark, or reference concept, against which all other concepts are rated. The reference is generally either an industry standard or a straightforward concept with which the team members are very familiar. It can be a commercially available product, a best-in-class benchmark product that the team has studied, an earlier generation of the product, any one of the concepts under consideration, or a combination of subsystems assembled to represent the best features of different products.

Step 2: Rate the Concepts

A relative score of “better than” is placed in each cell of the matrix to represent how each concept rates in comparison to the reference concept relative to the particular criterion. It is generally advisable to rate every concept on one criterion before moving to the next criterion; however, with a large number of concepts, it is faster to use the opposite approach—to rate each concept completely before moving on to the next concept.

Some people find the coarse nature of the relative ratings difficult to work with; how- ever, at this stage in the design process, each concept is only a general notion of the ultimate product, and more detailed ratings are largely meaningless. In fact, given the imprecision of the concept descriptions at this point, it is very difficult to consistently compare concepts to one another unless one concept (the reference) is consistently used as a basis for comparison. When available, objective metrics can be used as the basis for rating a concept. For example, a good approximation of assembly cost is the number of parts in a design. Similarly, a good approximation of ease of use is the number of operations required to use the device. Such metrics help to minimize the subjective nature of the rating process. Some objective metrics suitable for concept selection may arise from the process of establishing target specifications for the product. (Product Specifications, for a discussion of metrics.) Absent objective metrics, ratings are established by team consensus, although secret ballot or other methods may also be useful. At this point the team may also wish to note which selection criteria need further investigation and analysis.

Step 3: Rank the Concepts

After rating all the concepts, the team sums the number of "better than," "same as," and "worse than" scores and enters the sum for each category in the lower rows of the matrix. Once the summation is completed, the team rank-orders the concepts. Obviously, in general those concepts with more pluses and fewer minuses are ranked higher. Often at this point the team can identify one or two criteria that really seem to differentiate the concepts.

Step 4: Combine and Improve the Concepts

Having rated and ranked the concepts, the team should verify that the results make sense and then consider if there are ways to combine and improve certain concepts. Two issues to consider are:

- Is there a generally good concept that is degraded by one bad feature? Can a minor modification improve the overall concept and yet preserve a distinction from the other concepts?
- Are there two concepts that can be combined to preserve the "better than" qualities while annulling the "worse than" qualities?

Combined and improved concepts are then added to the matrix, rated by the team, and ranked along with the original concepts. In our example, the team noticed that concepts D and F could be combined to remove several of the "worse than" ratings to yield a new concept, DF, to be considered in the next round. Concept G was also considered for revision. The team decided that this concept was too bulky, so the excess storage space was removed while retaining the injection technique. These revised concepts are shown in Exhibit 8-6.

Step 5: Select One or More Concepts

Once the team members are satisfied with their understanding of each concept and its relative quality, they decide which concepts are to be selected for further refinement and analysis. Based upon previous steps, the team will likely develop a clear sense of which is the most promising concepts. The number of concepts selected for further review will be limited by team resources (personnel, money, and time). In our example, the team selected concepts A and E to be considered along with the revised concept G1 and the new concept DF. Having determined the concepts for further analysis, the team must clarify which issues need to be investigated further before a final selection can be made. The team must also decide whether another round of concept screening will be per- formed or whether concept scoring will be applied next. If the screening matrix is not seen to provide sufficient resolution for the next step of evaluation and selection, then the concept-scoring stage with its weighted selection criteria and more detailed rating scheme would be used

Step 6: Reflect on the Results and the Process

All of the team members should be comfortable with the outcome. If an individual is not in agreement with the decision of the team, then perhaps one or more important criteria are missing from the screening matrix, or perhaps a particular rating is in error, or at least is not clear. An explicit consideration of whether the results make sense to everyone reduces the likelihood of making a mistake and increases the likelihood that the entire team will be solidly committed to the subsequent development activities.

Concept Scoring

Concept scoring is used when increased resolution will better differentiate among competing concepts. In this stage, the team weighs the relative importance of the selection criteria and focuses on more refined comparisons with respect to each criterion. The concept scores are determined by the weighted sum of the ratings.

Concept testing

Concept testing is defined as a research method that involves asking customers questions about your concepts and ideas for a product or service before actually launching it. Thus, you can gauge your customers' acceptance and their willingness to buy and therefore make critical decisions before the launch. we will talk about the benefits and different methods of concept testing. You will also learn how to decide which method will be best suited for your research. We will then summarize with some real-world examples of how concept testing was vital in helping companies to launch their products successfully.

Benefits of concept testing

I always assume that every new feature or product idea that I come up with will be successful. However, that’s seldom the case. Only customers can determine whether an idea will succeed, or will it crash and burn. That is why it’s vital to test your ideas and concepts before launching to your customers. The insights gathered using concept testing will help you launch effective and successful products.

Using concept testing, you can also get in-depth insights into different aspects of your idea. You can ask questions about a specific feature, look and feel, pricing, and more. Thus you can assure the validity of every detail before launching the product.

Organizations and businesses use surveys to carry out concept testing making it a simple proposition for brands of all sizes to utilize. In the following section, we will discuss the different methods of concept testing.

Concept testing methods

Over the years, researchers have designed and applied many different methods of concept testing. These methods are categorized based on how the concepts are displayed. Each of these methods is suitable for different types of research. Concept testing is easily achieved with the help of a research platform. Here are the four primary methods of concept testing:

Comparison testing

Monadic testing

Sequential monadic testing

Proto-monadic testing

Comparison testing

In comparison testing, two or more concepts are presented to the respondents. The respondents compare these concepts by using rating or ranking questions or merely asking to select the best concept displayed.

Comparison tests give clear and easily understandable results. It’s easy to determine which concept is the winner. However, the results lack context. There is no way to tell why the respondents choose one concept over others. It is essential to understand these details before successfully launching a product.

Monadic testing

In a monadic test, the target audience is broken down into multiple groups. Each group gets shown only one concept. These tests focus on analyzing a single concept in-depth. A monadic test survey is usually short and highly targeted. Since each group of respondents sees a single concept, it is possible to go in-depth without making the survey lengthy. Researchers can ask follow-up questions about the various attributes of a concept, such as what they liked about the concept, it's look and feel, price point, etc. Though each group of respondents sees different concepts in isolation, each concept's follow-up questions will be the same.

Monadic test surveys are short and give researchers the flexibility to ask multiple follow-up questions. Thus the results provide more contexts around why a specific concept is better than the others. However, since the target audience is split into multiple groups, the sample size required to conduct a monadic test is extensive. Since various concepts need testing, more significant is the sample size. The increase in sample size considerably increases the cost of research.

Sequential monadic testing

Like the monadic test, in sequential monadic tests, the target audience is split into multiple groups. However, instead of showing one concept in isolation, each group is presented with all the concepts. The order in the concepts is randomized to avoid bias. The respondents are asked the same set of follow-up questions for each of the concepts to get further insights.Since each group of respondents sees all concepts, the target audience's size required to perform a sequential monadic test is relatively small. Multiple concepts can be tested in a single round. Thus sequential monadic tests are more cost-effective and easy to field. This concept testing method makes it ideal for research with budget constraints or when only a small target audience is available. However, since all the concepts are presented to each group of respondents, the questionnaire's length is fairly long. This affects the completion rate and might introduce non response bias. Researchers can reduce the length of the questionnaire by limiting the number of questions. However, this affects the depth of the collected insights. Sequential monadic tests are also subject to other biases, such as interaction bias or order bias.

Protomonadic testing

A protomonadic test includes a sequential monadic test followed by a comparison test. Here, respondents first evaluate multiple concepts and then ask to choose the concept they prefer. This design is useful to validate the results from the sequential monadic test. Researchers can verify if the concept selected in the comparison test is compatible with the insights collected about each concept. This article explains how to choose the best-suited concept testing method for research. Once you have finalized the method you will be using; you must design a survey for conducting your test. Creating a survey and then effectively using a block randomizer offers the best results. The following section will discuss the guidelines and best practices for creating an effective concept testing survey.

Concept testing survey design

Concept testing is achieved by using an online survey. The survey needs to be designed to analyze how respondents feel about your concepts or ideas. The data collected using these surveys is then used to determine what customers prefer or reject your idea. Here are a few tips to help you design a useful concept testing survey.

Set an objective for your survey

Once you set an overall objective for your survey, it becomes easy to come up with questions that will collect pertinent insights about your concept. It helps to think about the actual motive of the test and the particular details that you want to learn from your customers. Thus you can design a survey with relevant questions and gather meaningful information about your customers' viewpoint.

Consistent survey design

It's always a good practice to group related questions using survey blocks. Survey blocks help create a well-ordered flow for your surveys and make it easier for the respondents to answer them. Respondents can easily focus on one area of your concept without any distractions and provide accurate and insightful feedback.

Likert scales

Likert scales are rating scales with an odd-numbered series of answer choices, usually between five to seven. You can include Likert scale questions in your survey to ask the respondents to rate their opinion on a five- or seven-point scale from "strongly agree" to "strongly disagree." Using Likert scale questions creates a consistent design for your survey, making it easier for respondents to answer them. Moreover, it's easier to analyze the data collected using Likert scales.

Include images

"A picture is worth a thousand words." This idiom is true when you want respondents to provide feedback about a visual concept. Logo testing is a good example where it makes sense to use images instead of text. You can display different concepts of your logo design to your respondents and select the one they like best. This negates any bias and provides easily digestible results.

Demographic questions

It’s essential to include demographic questions in your survey to ensure that the respondents are part of your target audience. You may receive negative feedback about your concept. However, it may not be a reflection on the concept itself. Rather the respondent may not be part of your customer base and isn’t interested in your product. It’s essential to have demographic survey questions to ensure your concept will be successful with your ideal customers. Now that you know how to design a useful concept testing survey let’s look at some use cases where concept testing is applicable.

Concept testing use cases

Here are some of the most common use cases where concept testing can be applied:

Product development

Concept testing is widely used by companies to make decisions while developing new products. You can find out which features customers care about and which ones are to be given a miss. You can also get an idea of what pain points customers face with existing features. Using a usability testing survey and concept testing, you can gauge customers’ expectations, make adjustments, and launch your product successfully. If you wish to save time, you can use one of our expertly designed survey templates for product concept testing.

New homepage design

Redesigning the homepage for your website can be tricky. For most ecommerce businesses, the homepage is the first touch point with potential customers. That’s why you must get everything right while redesigning your website.

Using concept testing, you can present your designs to customers who will interact with them and get a clear idea of what they feel. Using these results, you can iron out flaws in the design and be ready for a perfect launch. You can use our website feedback software and the subsequent guidelines to design a survey to test your homepage.

Testing a new logo

Your logo is a vital part of your company’s brand. More often than not, it’s the first thing that customers notice about your business. Therefore, while designing a new logo, it’s essential to know how customers might react to the new design and visually communicate your brand.

Concept testing is a great way to test different designs and develop a logo that resonates with your customers.

Offers and pricing

Concept testing comes in handy when you plan to offer discounts for a new product or are implementing a new pricing structure altogether. It's important to test your customers' initial response and identify the features and perks that will get them excited. You can run a concept test on your upgrade pages, or discount offers to gauge if your customers are interested. You can use the monadic test design to conduct your pricing research.

Ad testing

It's common practice to test ads, banners, and images on websites to identify the best possible combination. Concept testing can provide insights such as which ad is grabbing the most attention or resulting in most conversions.

No.	PART - A
1	Write the importance of concept generation?
2	Define idea concept testing?
3	Prepare the flow chart for concept generation.
4	Prepare the road map for concept generation process.
5	Give the basic methods involved in concept Generation.
6	Explain the problems that can be explored in concept generation process
7	Define Team work.
8	Infer the internal approach in concept generation
9	Describe the external approach in concept generation.
10	Define concept scoring.
11	Interpret the product performance in concept testing.
12	Discuss survey formats in testing.
No.	PART - B
1	Describe in detail about different types of Concept testing Method.
2	Draw and Explain the Flowchart for Concept Generation.
3	Describe the methods used for concept communication.
4	Explain the steps to measure customer response.
5	List the some different ways you could communicate a concept for a new user interface for an automotive audio system.

SCHOOL OF MECHANICAL ENGINEERING

DEPARTMENT OF MECHANICAL ENGINEERING

UNIT – 3 – SMEA3009 – PRODUCT ARCHITECHTURE

What Is Product Architecture?

A product can be thought of in both functional and physical terms. The functional elements of a product are the individual operations and transformations that contribute to the overall performance of the product. For a printer, some of the functional elements are “store paper” and “communicate with host computer.” Functional elements are usually described in schematic form before they are reduced to specific technologies, components, or physical working principles.

The physical elements of a product are the parts, components, and subassemblies that ultimately implement the product’s functions. The physical elements become more defined as development progresses. Some physical elements are dictated by the product concept, and others become defined during the detail design phase. For example, the DeskJet embodies a product concept involving a thermal ink delivery device, implemented by a print cartridge. This physical element is inextricably linked to the product concept and was essentially an assumption of the development project. The physical elements of a product are typically organized into several major physical building blocks, which we call chunks. Each chunk is then made up of a collection of components that implement the functions of the product. The architecture of a product is the scheme by which the functional elements of the product are arranged into physical chunks and by which the chunks interact.

Perhaps the most important characteristic of a product’s architecture is its modularity. Consider the two different designs for bicycle braking and shifting controls shown in Exhibit 3-1. In the traditional design (left), the shift control function and the brake control function are allocated to separate chunks, which in fact are mounted in separate locations on the bicycle. This design exhibits a modular architecture. In the design on the right, the shift and brake control functions are allocated to the same chunk. This design exhibits an integral architecture—in this case motivated by aerodynamic and ergonomic concerns.

A modular architecture has the following two properties:

•Chunks implement one or a few functional elements in their entirety.

•The interactions between chunks are well defined and are generally fundamental to the primary functions of the product.

The most modular architecture is one in which each functional element of the product is implemented by exactly one physical chunk and in which there are a few well-defined interactions between the chunks. Such a modular architecture allows a design change to be made to one chunk without requiring a change to other chunks for the product to function correctly. The chunks may also be designed quite independently of one another. The opposite of a modular architecture is an integral architecture. An integral architecture exhibits one or more of the following properties:

FIGURE 3.1 Two designs of bicycle brake and shift controls. The levers on the left exemplify a modular architecture; the lever on the right uses an integral architecture.

- Functional elements of the product are implemented using more than one chunk.
- A single chunk implements many functional elements.
- The interactions between chunks are ill defined and may be incidental to the primary functions of the products.

A product embodying an integral architecture will often be designed with the highest possible performance in mind. Implementation of functional elements may be distributed across multiple chunks. Boundaries between the chunks may be difficult to identify or may be nonexistent. Many functional elements may be combined into a few physical components to optimize certain dimensions of performance; however, modifications to any one particular component or feature may require extensive redesign of the product.

Modularity is a relative property of product architecture. Products are rarely strictly modular or integral. Rather, we can say that they exhibit either more or less modularity than a comparative product, as in the brake and shift controls example in Exhibit 3-2.

Types of Modularity

Modular architectures comprise three types: slot, bus, and sectional (Ulrich, 1995). Each type embodies a one-to-one mapping from functional elements to chunks and well- defined interfaces. The differences between these types lie in the way the interactions between chunks are organized.

Exhibit 3-2 illustrates the conceptual differences among these types of architectures.

- Slot-modular architecture: Each of the interfaces between chunks in a slot-modular architecture is of a different type from the others, so that the various chunks in the product cannot be interchanged. An automobile radio is an example of a chunk in a slot-modular architecture. The radio implements exactly one function, but its interface is different from any of the other components in the vehicle (e.g., radios and speedometers have different types of interfaces to the instrument panel).
- Bus-modular architecture: In a bus-modular architecture, there is a common bus to which the other chunks connect via the same type of interface. A common example of a chunk in a bus-modular architecture would be an expansion card for a personal computer. Non electronic products can also be built around a bus-modular architecture. Track lighting, shelving systems with rails, and adjustable roof racks for automobiles all embody a bus-modular architecture.

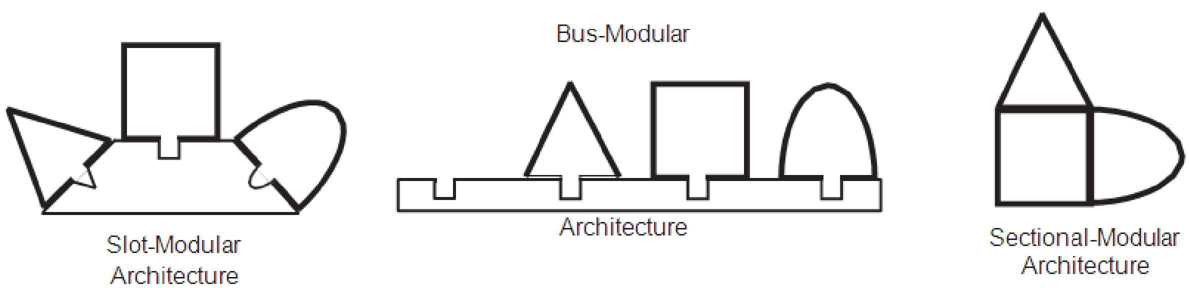


FIGURE-3.2 Three types of modular architectures.

- Sectional-modular architecture: In sectional-modular architecture, all interfaces are of the same type, but there is no single element to which all the other chunks attach. The assembly is built up by connecting the chunks to each other via identical inter- faces. Many piping systems adhere to sectional-modular architecture, as do sectional sofas, office partitions, and some computer systems.

Slot-modular architectures are the most common of the modular architectures because for most products each chunk requires a different interface to accommodate unique interactions between that chunk and the rest of the product. Bus-modular and sectional- modular architectures are particularly useful for situations in which the overall product must vary widely in configuration, but whose chunks can interact in standard ways with the rest of the product. These situations can arise when all of the chunks can use the same type of power, fluid connection, structural attachment, or exchanges of signals.

When Is the Product Architecture Defined?

A product's architecture begins to emerge during concept development. This happens informally—in the sketches, function diagrams, and early prototypes of the concept development phase. Generally, the maturity of the basic product technology dictates whether the product architecture is fully defined during concept development or during system-level design. When the new product is an incremental improvement on an existing product concept, then the product architecture is defined within the product concept. This is for two reasons. First, the basic technologies and working principles of the product are predefined, and so conceptual-design efforts are generally focused on better ways to embody the given concept. Second, as a product category matures, supply chain (i.e., production and distribution) considerations and issues of product variety begin to become more prominent. Product architecture is one of the development decisions that most impacts a firm's ability to efficiently deliver high product variety. Architecture therefore becomes a central element of the product concept; however, when the new product is the first of its kind, concept development is generally concerned with the basic working principles and technology on which the product will be based. In this case, the product architecture is often the initial focus of the system-level design phase of development.

Implications of the Architecture

Decisions about how to divide the product into chunks and about how much modularity to impose on the architecture are tightly linked to several issues of importance to the entire enterprise: product change, product variety, component standardization, product performance, manufacturability, and product development management. The architecture of the product therefore is closely linked to decisions about marketing strategy, manufacturing capabilities, and product development management.

Product Change

Chunks are the physical building blocks of the product, but the architecture of the product defines how these blocks relate to the function of the product. The architecture therefore also defines how the product can be changed. Modular chunks allow changes to be made to a few isolated functional elements of the product without necessarily affecting the design of other chunks. Changing an integral chunk may influence many functional elements and require changes to several related chunks.

Some of the motives for product change are:

- Upgrade: As technological capabilities or user needs evolve, some products can accommodate this evolution through upgrades. Examples include changing the processor board in a computer printer or replacing a pump in a cooling system with a more powerful model.
- Add-ons: Many products are sold by a manufacturer as a basic unit, to which the user adds components, often produced by third parties, as needed. This type of change is common in the personal computer industry (e.g., third-party mass storage devices may be added to a basic computer).
- Adaptation: Some long-lived products may be used in several different use environments, requiring adaptation. For example, machine tools may need to be converted from 220-volt to 110-volt power. Some engines can be converted from a gasoline to a propane fuel supply.
- Wear: Physical elements of a product may deteriorate with use, necessitating replacement of the worn components to extend the useful life of the product. For example, many razors allow dull blades to be replaced, tires on vehicles can usually be replaced, most rotational bearings can be replaced, and many appliance motors can be replaced.
- Consumption: Some products consume materials, which can then be easily replenished. For example, copiers and printers frequently contain print cartridges, cameras take film cartridges, glue guns consume glue sticks, torches have gas cartridges, and watches contain batteries, all of which are generally replaceable.
- Flexibility in use: Some products can be configured by the user to provide different capabilities. For example, many cameras can be used with different lens and flash options, some boats can be used with several awning options, and fishing rods may accommodate several rod-reel configurations.
- Reuse: In creating subsequent products, the firm may wish to change only a few functional elements while retaining the rest of the product intact. For example, consumer electronics manufacturers may wish to update a product line by changing only the user interface and enclosure while retaining the inner workings from a previous model.

In each of these cases, a modular architecture allows the firm to minimize the physical
Changes required achieving a functional change.

Product Variety

Variety refers to the range of product models the firm can produce within a particular time period in response to market demand. Products built around modular product architectures can be more easily varied without adding tremendous complexity to the manufacturing system. For example, Swatch produces hundreds of different watch models, but can achieve this variety at relatively low cost by assembling the variants from different combinations of standard chunks (Exhibit 3-3). A large number of different hands, faces, and wristbands can be combined with a relatively small selection of movements and cases to create seemingly endless combinations.

FIGURE 3.3 . Swatch uses a modular architecture to enable high-variety manufacturing

Component Standardization

Component standardization is the use of the same component or chunk in multiple products. If a chunk implements only one or a few widely useful functional elements, then the chunk can be standardized and used in several different products. Such standardization allows the firm to manufacture the chunk in higher volumes than would otherwise be possible. This in turn may lead to lower costs and increased quality. For example, the watch movement shown in Exhibit 3-3 is identical for many Swatch models. Component standardization may also occur outside the firm when several manufacturers' products all use a chunk or component from the same supplier. For example, the watch battery shown in Exhibit 3-3 is made by a supplier and standardized across several manufacturers' product lines.

Multiple functions using a single physical element is called function sharing. An integral architecture allows for redundancy to be eliminated through function sharing (as in the case of the motorcycle) and allows for geometric nesting of components to minimize the volume a product occupies. Such function sharing and nesting also allow material use to be minimized, potentially reducing the cost of manufacturing the product.

Manufacturability

In addition to the cost implications of product variety and component standardization described above, the product architecture also directly affects the ability of the team to design each chunk to be produced at low cost. One important design-for-manufacturing (DFM) strategy involves the minimization of the number of parts in a product through component integration; however, to maintain a given architecture, the integration of physical components can only be easily considered within each of the chunks. Component integration across several chunks is difficult, if not impossible, and would alter the architecture dramatically. Because the product architecture constrains subsequent detail design decisions in this way, the team must consider the manufacturing implications of the architecture. For this reason DFM begins during the system-level design phase while the layout of the chunks is being planned.

Product Development Management

Responsibility for the detail design of each chunk is usually assigned to a relatively small group within the firm or to an outside supplier. Chunks are assigned to a single individual or group because their design requires careful resolution of interactions, geometric and otherwise, among components within the chunk. With a modular architecture, the group assigned to design a chunk deals with known, and relatively limited, functional interactions with other chunks. If a functional element is implemented by two or more chunks, as in some integral architecture, detail design will require close coordination among different groups. This coordination is likely to be substantially more involved and challenging than the limited coordination required among groups designing different chunks in a modular design. For this reason, teams relying on outside suppliers or on a geographically dispersed team often opt for a modular architecture in which development responsibilities can be split according to the chunk boundaries. Another possibility is to have several functional elements allocated to the same chunk. In this case, the work of the group assigned to that chunk involves a great deal of internal coordination across a larger group. Modular and integral architectures also demand different project management styles. Modular approaches require very careful planning during the system-level design phase, but detail design is largely concerned with ensuring that the teams assigned to chunks are meeting the performance, cost, and schedule requirements for their chunks. An integral architecture may require less planning and specification during system-level design, but such architecture requires substantially more integration, conflict resolution, and coordination during the detail design phase.

Establishing the Architecture

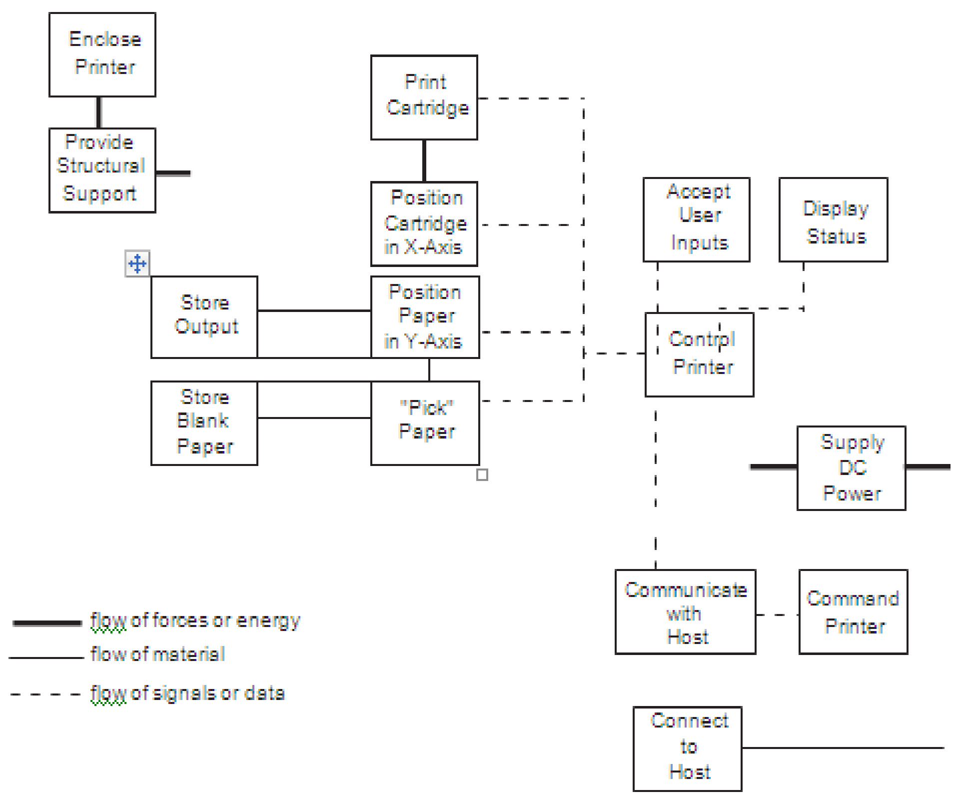
Because the product architecture will have profound implications for subsequent product development activities and for the manufacturing and marketing of the completed product, it should be established in a cross-functional effort by the development team. The end result of this activity is an approximate geometric layout of the product, descriptions of the major chunks, and documentation of the key interactions among the chunks. We recommend a four-step method to structure the decision process, which is illustrated using the DeskJet printer example. The steps are:

1. Create a schematic of the product.
2. Cluster the elements of the schematic.
3. Create a rough geometric layout.
4. Identify the fundamental and incidental interactions.

Step 1: Create a Schematic of the Product

A schematic is a diagram representing the team's understanding of the constituent elements of the product. A schematic for the DeskJet is shown in Exhibit 3.4. At the end of the concept development phase, some of the elements in the schematic are physical concepts, such as the front-in/front-out paper path. Some of the elements correspond to critical components, such as the print cartridge the team expects to use; however, some of the elements remain described only functionally. These are the functional elements of the product that have not yet been reduced to physical concepts or components. For example, "display status" is a functional element required for the printer, but the particular approach of the display has not yet been decided. Those elements that have been reduced. to physical concepts or components are usually central to the basic product concept the team has generated and selected. Those elements that remain unspecified in physical terms are usually ancillary functions of the product.

The schematic should reflect the team best understands of the state of the product, but it does not have to contain every imaginable detail, such as "sense out-of-paper condition" or "shield radio frequency emissions." These and other more detailed functional elements are deferred to a later step. A good rule of thumb is to aim for fewer than 30 elements in the schematic, for the purpose of establishing the product architecture. If the product is a complex system, involving hundreds of functional elements, then it is useful to omit some of the minor ones and to group some others into higher-level functions to be decomposed later. (See Defining Secondary Systems, later in this chapter.)The schematic created will not be unique. The specific choices made in creating the schematic, such as the choice of functional elements and their arrangement, partly define the product architecture. For example, the functional element "control printer" is represented as a single centralized element in Exhibit 3.4. An alternative would be to distribute the control of each of the other elements of the product throughout the system and have coordination done by the host computer. Because there is usually substantial latitude in the schematic, the team should generate several alternatives and select an approach that will facilitate the consideration of several architectural options.



.

FIGURE 3.4 Schematic of the DeskJet printer. Note the presence of both functional elements (e.g., "Store Output") and physical elements (e.g., "Print Cartridge"). For clarity, not all connections among elements are shown

Step 2: Cluster the Elements of the Schematic

The challenge of step 2 is to assign each of the elements of the schematic to a chunk. One possible assignment of elements to chunks is shown in Exhibit 3.5, where nine chunks are used. Although this was the approximate approach taken by the DeskJet team, there are several other viable alternatives. At one extreme, each element could be assigned to its own chunk, yielding 15 chunks. At the other extreme, the team could decide that the product would have only one major chunk and then attempt to physically integrate all of the elements of the product. In fact, consideration of all possible clustering's of elements would yield thousands of alternatives. One procedure for managing the complexity of the alternatives is to begin with the assumption that each element of the schematic will be assigned to its own chunk, and then to successively cluster elements where advantageous. To determine when there are advantages to clustering, consider these factors, which echo the implications discussed in the previous section:

- Geometric integration and precision: Assigning elements to the same chunk allows a single individual or group to control the physical relationships among the elements. Elements requiring precise location or close geometric integration can often be best designed if they are part of the same chunk. For the DeskJet printer, this would suggest clustering the elements associated with positioning the cartridge in the x-axis and positioning the paper in the y-axis.
- Function sharing: When a single physical component can implement several functional elements of the product, these functional elements are best clustered together. This is the situation exemplified by the BMW motorcycle transmission .For the DeskJet printer, the team believed that the status display and the user controls could be incorporated into the same component, and so clustered these two elements together.
- Capabilities of vendors: A trusted vendor may have specific capabilities related to a project, and to best take advantage of such capabilities a team may choose to cluster those elements about which the vendor has expertise into one chunk. In the case of the DeskJet printer, an internal team did the majority of the engineering design work, and so this was not a major consideration.
- Similarity of design or production technology: When two or more functional elements are likely to be implemented using the same design and/or production technology, then incorporating these elements into the same chunk may allow for more economical design and/or production. A common strategy, for example, is to combine all functions that are likely to involve electronics in the same chunk. This allows the possibility of implementing all of these functions with a single circuit board.
- Localization of change: When a team anticipates a great deal of change in some element, it

makes sense to isolate that element into its own modular chunk, so that required changes to the element can be carried out without disrupting any of the other chunks. The Hewlett-Packard team anticipated changing the physical appearance of the product over its life cycle, and so chose to isolate the enclosure element into its own chunk.

- Accommodating variety: Elements should be clustered together to enable the firm to vary the product in ways that will have value for customers. The printer was to be sold around the world in regions with different electrical power standards. As a result, the team created a separate chunk for the element associated with supplying DC power.
- Enabling standardization: If a set of elements will be useful in other products, they should be clustered together into a single chunk. This allows the physical elements of the chunk to be produced in higher quantities. Hewlett-Packard's internal standardization was a key motive for using an existing print cartridge, and so this element is pre- served as its own chunk.
- Portability of the interfaces: Some interactions are easily transmitted over large distances. For example, electrical signals are much more portable than are mechanical forces and motions. As a result, elements with electronic interactions can be easily separated from one another. This is also true, but to a lesser extent, for fluid connections. The flexibility of electrical interactions allowed the Hewlett-Packard team to cluster the control and communication functions into the same chunk. Conversely, the elements related to paper handling are much more geometrically constrained by their necessary mechanical interactions.

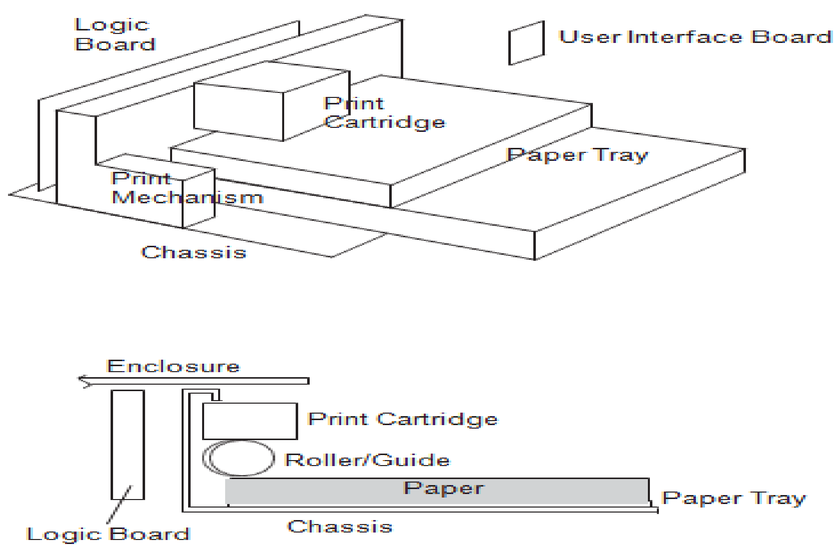


FIGURE 3.5 Layout of printer

Step 3: Create a Rough Geometric Layout

A geometric layout can be created in two or three dimensions, using drawings, com- puter models, or physical models (of cardboard or foam, for example). Exhibit 3.6 shows a geometric layout of the DeskJet printer, positioning the major chunks. Creating a geometric layout forces the team to consider whether the geometric interfaces among the chunks are feasible and to work out the basic dimensional relationships among the chunks. By considering a cross section of the printer, the team realized that there was a fundamental trade-off between how much paper could be stored in the paper tray and the height of the machine. In this step, as in the previous step, the team benefits from generating several alternative layouts and selecting the best one. Layout decision criteria are closely related to the clustering issues in step 2. In some cases, the team may discover that the clustering derived in step 2 is not geometrically feasible and thus some of the elements would have to be reassigned to other chunks. Creating the rough layout should be coordinated with the industrial designers on the team in cases where the aesthetic and human interface issues of the product are important and strongly related to the geometric arrangement of the chunks.

Step 4: Identify the Fundamental and Incidental Interactions Most likely a different person or group will be assigned to design each chunk. Because the chunks interact with one another in both planned and unintended ways, these different groups will have to coordinate their activities and exchange information. To better manage this coordination process, the team should identify the known interactions between chunks during the system-level design phase.

There are two categories of interactions between chunks. First, fundamental interactions are those corresponding to the lines on the schematic that connect the chunks to one another. For example, a sheet of paper flows from the paper tray to the print mechanism. This interaction is planned, and it should be well understood, even from the very earliest schematic, as it is fundamental to the system's operation. Second, incidental interactions are those that arise because of the particular physical implementation of functional elements or because of the geometric arrangement of the chunks. For example, vibrations induced by the actuators in the paper tray could interfere with the precise location of the print cartridge in the x-axis.

While the fundamental interactions are explicitly represented by the schematic showing the clustering of elements into chunks, the incidental interactions must be documented in some other way. For a small number of interacting chunks (fewer than about 10), an interaction graph is a convenient way to represent the incidental interactions. Exhibit 3.6 shows a possible interaction graph for the DeskJet printer, representing the known incidental interactions. For larger systems this type of graph becomes confusing, and an interaction matrix is useful instead and can be used to display both fundamental and incidental interactions. See Eppinger (1997) for an example of using such a matrix, which is also used to cluster the functional elements into chunks based on quantification of their interactions.

The interaction graph in Exhibit 3.6 suggests that vibration and thermal distortion are incidental interactions among the chunks that create heat and involve positioning motions. These interactions represent challenges in the development of the system, requiring focused coordination efforts within the team. We can use the mapping of the interactions between the chunks to provide guidance for structuring and managing the remaining development activities. Chunks with important interactions should be designed by groups with strong communication and coordination between them. Conversely, chunks with little interaction can be designed by groups with less coordination. Eppinger (1997) describes a matrix-based method for pre- scribing such system-level coordination needs in larger projects.

It is also possible, through careful advance coordination, to develop two interacting chunks in a completely independent fashion. This is facilitated when the interactions between the two chunks can be reduced in advance to a completely specified interface that will be implemented by both chunks. It is relatively straightforward to specify interfaces to handle the fundamental interactions, while it can be difficult to do so for incidental interactions.

Knowledge of the incidental interactions (and sometimes of the fundamental interactions as well) develops as system-level and detail design progress. The schematic and the interaction graph or matrix can be used for documenting this information as it evolves. The network of interactions among subsystems, modules, and components is sometimes called the system architecture

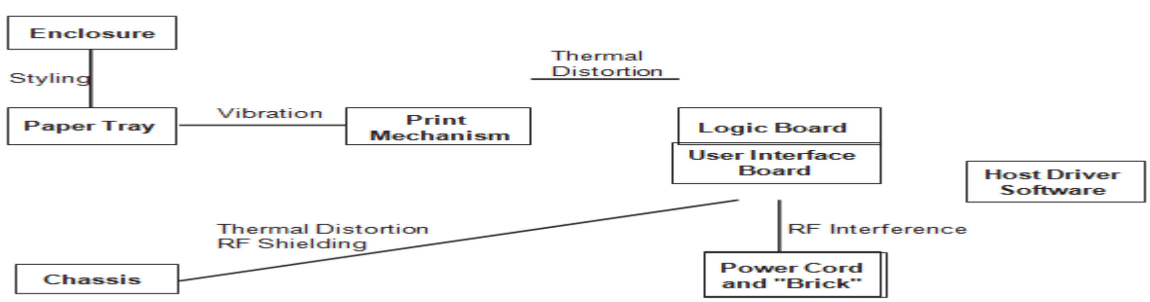


FIGURE 3.6 incidental interaction graphs

Managing the Trade-Off between Differentiation and Commonality

The challenge in platform planning is to resolve the tension between the desires to differentiate the products and the desire for these products to share a substantial fraction of their components. Examination of the differentiation plan and the commonality plan reveals several trade-offs. For example, the student printer has the potential to offer the benefit of a small footprint, which is likely to be important to space-conscious college students; however, this differentiating attribute implies that the student printer would require a different print mechanism chunk, which is likely to add substantially to the investment required to design and produce the printer. This tension between a desire to tailor the benefits of a product to the target market segment and the desire to minimize investment is highlighted when the team attempts to make the differentiation plan and the commonality plan consistent. We offer several guidelines for managing this tension.

- Platform planning decisions should be informed by quantitative estimates of cost and revenue implications: Estimating the profit contribution from a one-percentage- point increase in market share is a useful benchmark against which to measure the potential increase in manufacturing and supply-chain costs of additional versions of a chunk. In estimating supply-chain costs, the team must consider the extent to which the differentiation implied by the differentiation plan can be postponed or whether it must be created early in the supply chain.
- Iteration is beneficial: In our experience, teams make better decisions when they make several iterations based on approximate information than when they agonize over the details during relatively less iteration.
- The product architecture dictates the nature of the trade-off between differentiation and commonality: The nature of the trade-off between differentiation and commonality is not fixed. Generally, modular architectures enable a higher proportion of components to be shared than integral architectures. This implies that when confronted with a seemingly intractable conflict between differentiation and commonality, the team should consider alternative architectural approaches, which may provide opportunities to enhance both differentiation and commonality.

For the printer example, the tension between differentiation and commonality might be resolved by a compromise. The revenue benefits of a slightly narrower student printer are not likely to exceed the costs associated with creating an entirely different, and narrower, print mechanism. The costs of different print mechanisms are likely to be especially high given that the print mechanism involves substantial tooling investments. Also, because the print mechanism is created early in the supply chain, postponement of differentiation would be substantially less feasible if it required different print mechanisms. For these reasons, the team would most likely choose to use a single, common print mechanism and forgo the possible revenue benefits of a narrower footprint for the student printer.

Related System-Level Design Issues

The four-step method for establishing the product architecture guides the early system- level design activities, but many more detailed activities remain. Here we discuss some of the issues that frequently arise during subsequent system-level design activities and their implications for the product architecture.

Defining Secondary Systems

The schematic in Exhibit 3.7 shows only the key elements of the product. There are many other functional and physical elements not shown, some of which will only be conceived and detailed as the system-level design evolves. These additional elements make up the secondary systems of the product. Examples include safety systems, power systems, status monitors, and structural supports. Some of these systems, such as safety systems, will span several chunks. Fortunately, secondary systems usually involve flexible connections such as wiring and tubing and can be considered after the major architectural decisions have been made. Secondary systems cutting across the boundaries of chunks present a special management challenge: Should a single group or individual be assigned to design a secondary system even though the system will be made up of components re-siding in several different chunks? Or should the group or individuals responsible for the chunks be responsible for coordinating among themselves to ensure that the secondary systems will work as needed? The former approach is more typical, where specific individuals or suteams are assigned to focus on the secondary systems.

Establishing the Architecture of the Chunks

Some of the chunks of a complex product may be very complex systems in their own right. For example, many of the chunks in the DeskJet printer involve dozens of parts. Each of these chunks may have its own architecture—the scheme by which it is divided into smaller chunks. This problem is essentially identical to the architectural challenge posed at the level of the entire product. Careful consideration of the architecture of the chunks is nearly as important as the creation of the architecture of the overall product. For example, the print cartridge consists of the subfunctions store ink and delivers ink for each of four colors of ink. Several architectural approaches are possible for this chunk, including, for example, the use of independently replaceable reservoirs for each ink color.

Creating Detailed Interface Specifications

As the system-level design progresses, the fundamental interactions indicated by lines on the schematic in Exhibit 3.7 are specified as much more detailed collections of signals, material flows, and exchanges of energy. As this refinement occurs, the specification of the interfaces between chunks should also be clarified. For example, an overview of a possible specification of an interface between a black print cartridge and a logic board for a printer. Such interfaces represent the "contracts" between chunks and are often detailed in formal specification documents.

Line	Name	Properties
1	PWR-A	112VDC, 5mA
2	PWR-B	15VDC, 10mA
3	STAT	TTL
4	LVL	100KV-1MV
5	PRNT1	TTL
6	PRNT2	TTL
7	PRNT3	TTL
8	PRNT4	TTL
9	PRNT5	TTL
10	PRNT6	TTL
11	GND	

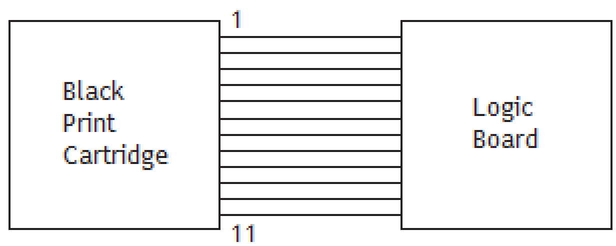


FIGURE 3.7 Specification of interface between black print cartridge

Product architecture is the scheme by which the functional elements of the product are arranged into physical chunks. The architecture of the product is established during the concept development and system-level design phases of development.

- Product architecture decisions have far-reaching implications, affecting such things as product change, product variety, component standardization, product performance, manufacturability, and product development management.
- A key characteristic of product architecture is the degree to which it is modular or integral.
- Modular architectures are those in which each physical chunk implements a specific set of functional elements and has well-defined interactions with the other chunks.
- There are three types of modular architectures: slot-modular, bus-modular, and sectional-modular.

• Integral architectures are those in which the implementation of functional elements is spread across chunks, resulting in ill-defined interactions between the chunks.

• We recommend a four-step method for establishing the product architecture:

1. Create a schematic of the product.
2. Cluster the elements of the schematic.
3. Create a rough geometric layout.
4. Identify the fundamental and incidental interactions.

• This method leads the team through the preliminary architectural decisions. Subsequent system-level and detail design activities will contribute to a continuing evolution of the architectural details.

•The product architecture can enable postponement, the delayed differentiation of the product, which offers substantial potential cost savings.

•Architectural choices are closely linked to platform planning, the balancing of differentiation and commonality when addressing different market segments with different versions of a product.

•Due to the broad implications of architectural decisions, inputs from marketing, manufacturing, and design are essential in this aspect of product development

Architecture portfolio

An architecture portfolio is one of the most important tools an architect and/or architecture student should possess. Presented through the careful selection of drawings, images, text and photographs it represents a timeline and record of experience that demonstrates its creators architectural skills, methods and capabilities. Without a portfolio it is almost impossible to gain an architectural position within a practice, or an architecture school placement at a college or university. In this guide we aim to broadly cover all aspects of an architecture portfolios creation and presentation, discussing under the below chapters; what should and shouldn’t be included, design and layout techniques, formats, and methods of presentation.

PART - A
Define product architecture.
Write short notes on chunks.
Give a few illustrations for chunks.
List the types of modularity.
Define product variety.
Express the Product changes.
Express the need for Product development management.
Define Manufacturability.
Explain the two categories of integration process.
Define add-on.
Define upgrade.
Explain the steps involved in establishing product architecture.
Illustrate slot modular architecture.
PART - B
Describe the need for chunks in product architecture.
Explain the types of modularity with example.
Describe the implications of architecture in product development.
Explain the importance of component standardization.
Explain the Product development management related to Modular and integral architectures.

SCHOOL OF MECHANICAL ENGINEERING

DEPARTMENT OF MECHANICAL ENGINEERING

UNIT – 4 – SMEA3009 - DESIGN FOR MANUFACTURING & ECONOMICS

DESIGN FOR MANUFACTURABILITY

Introduction

Design for manufacturability (also sometimes known as design for manufacturing or DFM) is the general engineering practice of designing products in such a way that they are easy to manufacture. DFM describes the process of designing or engineering a product in order to facilitate the manufacturing process to reduce its manufacturing costs. DFM will allow potential problems to be fixed in the design phase which is the least expensive place to address them. DFM Requires a Cross-Functional Team. DFM utilizes information of several types, including (1) sketches, drawings, product specifications, and design alternatives; (2) a detailed understanding of production and assembly processes; and (3) estimates of manufacturing costs, production volumes, and ramp-up timing. DFM therefore requires the contributions of most members of the development team as well as outside experts.

DFM Is Performed throughout the Development Process. DFM begins during the concept development phase, when the product's functions and specifications are being determined. When choosing a product concept, cost is almost always one of the criteria on which the decision is made even though cost estimates at this phase are highly subjective and approximate. When product specifications are finalized, the team makes trade-offs between desired performances characteristics. For example, weight reduction may increase manufacturing costs. At this point, the team may have an approximate bill of materials (a list of parts) with estimates of costs. During the system-level design phase of development, the team makes decisions about how to break up the product into individual components, based in large measure on the expected cost and manufacturing complexity implications. Accurate cost estimates finally become available during the detail- design phase of development, when many more decisions are driven by manufacturing concerns.

Overview of the DFM Process

DFM method is illustrated in Fig.4.1. It consists of five steps plus iteration:

1. Estimate the manufacturing costs.
2. Reduce the costs of components.
3. Reduce the costs of assembly.
4. Reduce the costs of supporting production.

5. Consider the impact of DFM decisions on other factors.

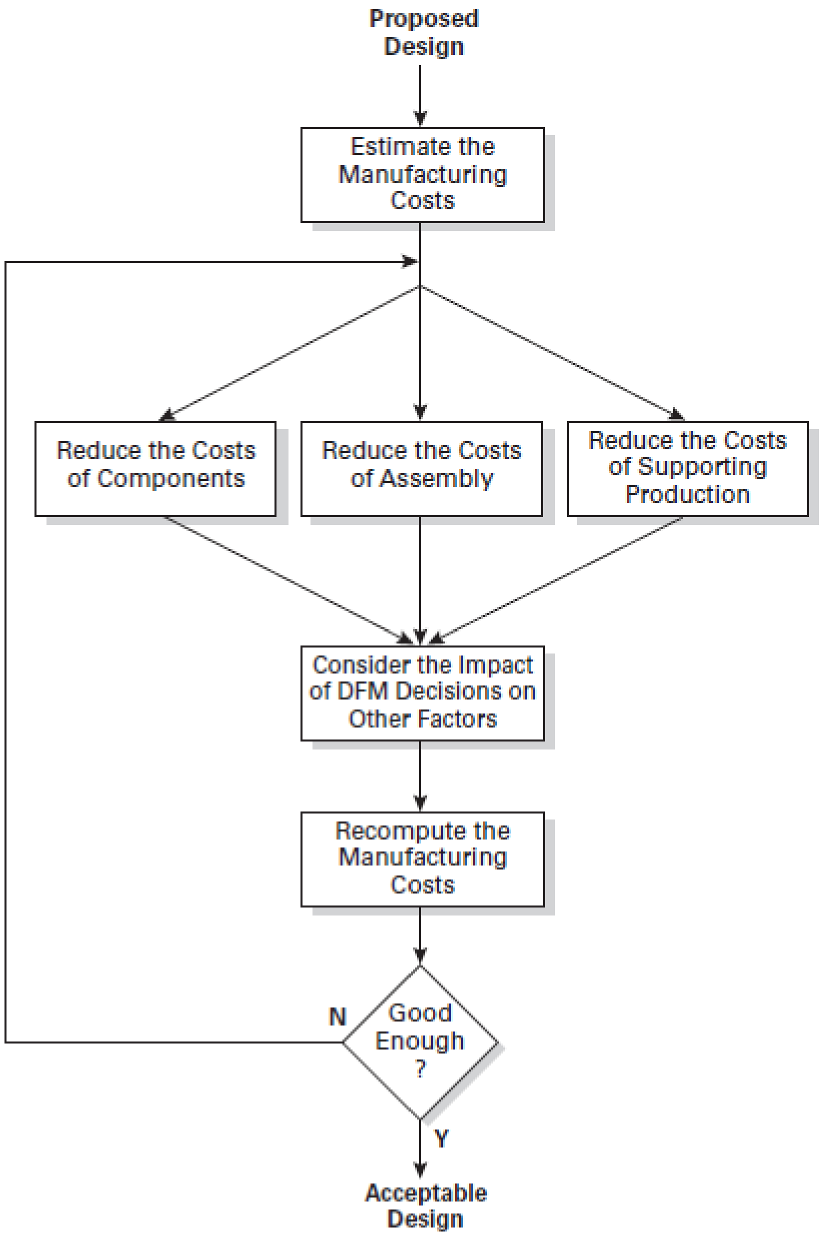


FIGURE. 4.1: The design for manufacturing (DFM) method.

GENERAL DESIGN PRINCIPLES FOR MANUFACTURABILITY

A.) Basic principles of designing for economical production

1. ***Simplicity*:** Other factors being equal, the product with the fewest parts, the least intricate shape, the fewest precision adjustments, and the shortest manufacturing sequence will be the least costly to produce. Additionally, it usually will be the most reliable and the easiest to service.

2. ***Standard materials and components*****:** Use of widely available materials and off-the-shelf parts enables the benefits of mass production to be realized by even low-unit-quantity products. Use of such standard components also simplifies inventory management, eases purchasing, avoids tooling and equipment investments, and speeds the manufacturing cycle.

3. ***Standardized design of the product itself*****:** When several similar products are to be produced, specify the same materials, parts, and subassemblies for each as much as possible. This procedure will provide economies of scale for component production, simplify process control and operator training, and reduce the investment required for tooling and equipment.

4. ***Liberal tolerances***: Although the extra cost of producing too tight tolerances has been well documented, this fact is often not appreciated well enough by product designers. The higher costs of tight tolerances stem from factors such as (a) extra operations such as grinding, honing, or lapping after primary machining operations, (b) higher tooling costs from the greater precision needed initially when the tools are made and the more frequent and more careful maintenance needed as they wear, (c) longer operating cycles, (d) higher scrap and rework costs, (e) the need for more skilled and highly trained workers, (f) higher materials costs, and (g) more sizable investments for precision equipment.

Fig.4.2 graphically illustrates how manufacturing cost is multiplied when close tolerances are specified. Table 4.1 illustrates the extra cost of producing fine surface finishes. Fig.4.3 illustrates the range of surface finishes obtainable with a number of machining processes. It shows how substantially the process time for each method can increase if a particularly smooth surface finish must be provided.

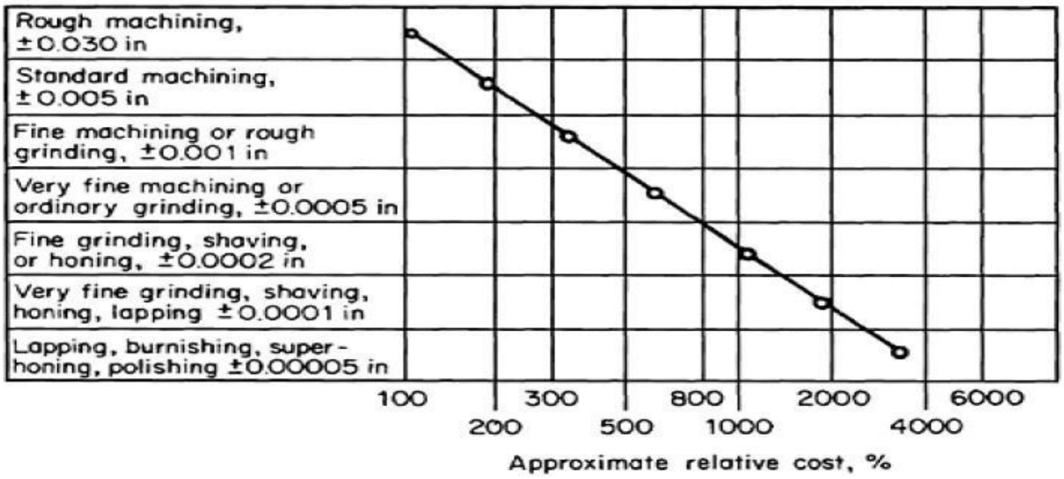


FIGURE.4.2. Approximate relative cost of progressively tighter dimensional tolerances.

Table 4 .1: Cost of Producing Surface Finishes

Surface symbol designation	Surface roughness, µin	Approximate relative cost, %
Case, rough-machined	250	100
Standard machining	125	200
Fine machining, rough-ground	63	440
Very fine machining, ordinary grinding	32	720
Fine grinding, shaving, and honing	16	1400
Very fine grinding, shaving, honing, and lapping	8	2400
Lapping, burnishing, superhoning, and polishing	2	4500

1. ***Use of the most processible materials***: Use the most processible materials available as long as their functional characteristics and cost are suitable. There are often significant differences in processibility (cycle time, optimal cutting speed, flowability, etc.) between conventional material grades and those developed for easy processibility. However, in the long run, the most economical material is the one with the lowest combined cost of materials, processing, and warranty and service charges over the designed life of the product.

2. ***Teamwork with manufacturing personnel***: The most producible designs are provided when the designer and manufacturing personnel, particularly manufacturing engineers, work closely together as a team or otherwise collaborate from the outset.

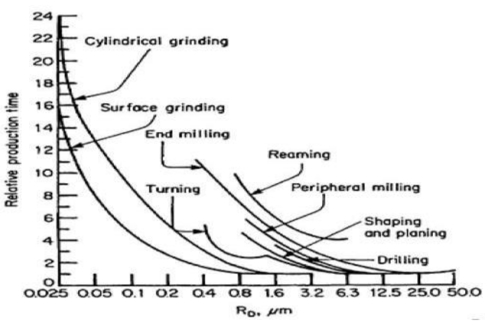


FIGURE.4 3: Typical relationships of productive time and surface roughness for various machining processes

5. ***Avoidance of secondary operations***: Consider the cost of operations, and design in order to eliminate or simplify them whenever possible. Such operations as deburring, inspection, plating and painting, heat treating, material handling, and others may prove to be as expensive as the primary manufacturing operation and should be considered as the design is developed. For example, firm, non-ambiguous gauging points should be provided; shapes that require special protective trays for handling should be avoided.

6. ***Design appropriate to the expected level of production***: The design should be suitable for a production method that is economical for the quantity forecast. For example, a product should not be designed to utilize a thin-walled die casting if anticipated production quantities are so low that the cost of the die cannot be amortized. Conversely, it also may be incorrect to specify a sand-mould aluminum casting for a mass-produced part because this may fail to take advantage of the labour and materials savings possible with die castings.

7. ***Utilizing special process characteristics***: Wise designers will learn the special capabilities of the manufacturing processes that are applicable to their products and take advantage of them. For example, they will know that injection-molded plastic parts can have color and surface texture incorporated in them as they come from the mould, that some plastics can provide "living hinges," that powder-metal parts normally have a porous nature that allows lubrication retention and obviates the need for separate bushing inserts, etc. Utilizing these special capabilities can eliminate many operations and the need for separate, costly components.

8. ***Avoiding process restrictiveness*****:** On parts drawings, specify only the final characteristics needed; do not specify the process to be used. Allow manufacturing engineers as much latitude as possible in choosing a process that produces the needed dimensions, surface finish, or other characteristics required.

B.) GENERAL DESIGN RULES

1. First in importance, simplify the design. Reduce the number of parts required. This can be done most often by combining parts, designing one part so that it performs several functions.

2. Design for low-labour-cost operations whenever possible. For example, a punch press pierced hole can be made more quickly than a hole can be drilled. Drilling, in turn, is quicker than boring. Tumble deburring requires less labour than hand deburring.

3. Avoid generalized statements on drawings that may be difficult for manufacturing personnel to interpret. Examples are “Polish this surface….Corners must be square,” “Tool marks are not permitted,” and “Assemblies must exhibit good workmanship.” Notes must be more specific than these.

4. Dimensions should be made not from points in space but from specific surfaces or points on the part itself if at all possible. This facilitates fixture and gauge making and helps avoid tooling, gauge, and measurement errors.

5. Dimensions should all be from one datum line rather than from a variety of points to simplify tooling and gauging and avoid overlap of tolerances.

6. Once functional requirements have been fulfilled, the lighter the part, the lower its cost is apt to be. Designers should strive for minimum weight consistent with strength and stiffness requirements. Along with a reduction in materials costs, there usually will be a reduction in labor and tooling costs when less material is used.

7. Whenever possible, design to use general-purpose tooling rather than special tooling (dies, form cutters, etc.). The well-equipped shop often has a large collection of standard tooling that is usable for a variety of parts. Except for the highest levels of production, where the labour and materials savings of special tooling enable their costs to be amortized, designers should become familiar with the general-purpose and standard tooling that is available and make use of it.

8. Avoid sharp corners; use generous fillets and radii. This is a universal rule applicable to castings and molded, formed, and machined parts. Generously rounded corners provide a number of advantages. There is less stress concentration on the part and on the tool; both will last longer. Material will flow better during manufacture. There may be fewer operational steps. Scrap rates will be reduced.

There are some exceptions to this “no sharp corner” rule, however. Two intersecting machined surfaces will leave a sharp external corner, and there is no cost advantage in trying to prevent it. The external corners of a powder-metal part, where surfaces formed by the punch face intersect surfaces formed by the die walls, will be sharp. For other corners, however, generous radii and fillets are greatly preferable.

9. Design a part so that as many manufacturing operations as possible can be performed without repositioning it. This reduces handling and the number of operations but, equally important, promotes accuracy, since the needed precision can be built into the tooling and equipment. This principle is illustrated by Fig. 4.4.

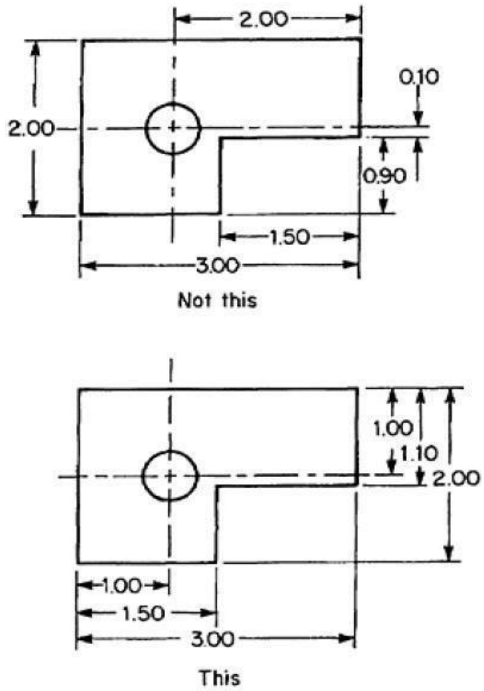


FIGURE.4 4: Dimensions should be made from points on the part itself rather than from points in space.

10. Whenever possible, cast, molded, or powder-metal parts should be designed so that stepped parting lines are avoided. These increase mould and pattern complexity and cost.

11. With all casting and molding processes, it is a good idea to design work pieces so that wall thicknesses are as uniform as possible. With high-shrinkage materials (e.g., plastics and aluminum), the need is greater.

12. Space holes in machined, cast, molded, or stamped parts so that they can be made in one operation without tooling weakness. Most processes have limitations on the closeness with which holes can be made simultaneously because of the lack of strength of thin die sections, material-flow problems in moulds, or the difficulty in putting multiple machining spindles close together.

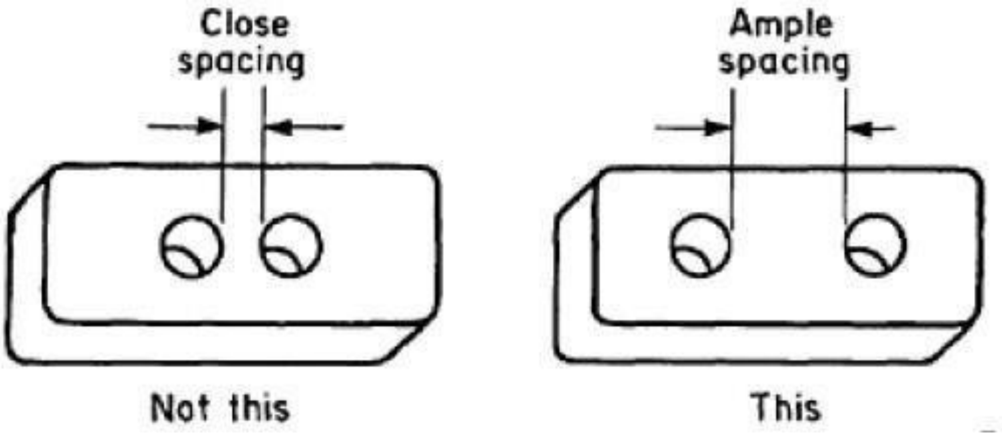


FIGURE. 4.5: Most manufacturing processes for producing multiple holes have limitations of minimum hole spacing.

C.) EFFECTS OF SPECIAL-PURPOSE, AUTOMATIC, NUMERICALLY CONTROLLED AND OMPUTER-CONTROLLED EQUIPMENT

For simplicity of approach, most design recommendations in this handbook refer to single operations performed on general-purpose equipment. However, conditions faced by design engineers may not always be this simple. Special-purpose, multiple-operation tooling and equipment are and should be the normal approach for many factories. Progressive designers must allow for and take advantage of the manufacturing economies such approaches provide whenever they are available or justifiable.

Types Available

Types of special-purpose and automatic equipment and tooling suitable for operations within the scope of this handbook include

1. Compound, progressive, and transfer dies for metal stamping and four-slide machines
2. Form-ground cutting tools
3. Automatic screw machines
4. Tracer-controlled turning, milling, and shaping machines
5. Multiple-spindle drilling, boring, reaming, and tapping machines
6. Various other multiple-headed machine tools
7. Index-table or transfer-line machine tools (which are also multiple-headed)
8. Automatic flame-, laser-, or other contour-cutting machines that are controlled by opticalor template tracing or from a computer memory
9. Automatic casting equipment, automatic sand-mould-making machines, automatic ladling, part-ejection, and shakeout equipment, etc.
10. Automatic assembly and parts-feeding apparatus including both robotic equipment and that dedicated to a specific product

11. Program-controlled, numerically controlled (NC), and computer-controlled (CNC) machining and other equipment

12. Robotic painting and other automatic plating and/or other finishing equipment

Some high levels of automation are already inherent in methods covered by certain handbook chapters; for example, four-slide forming, roll forming, die casting, injection molding, impact extrusion, cold heading, powder metallurgy, screw machining, and broaching are all high- production processes.

Effects on Materials Selection

The choice of material is seldom affected by the degree to which the manufacturing process is made automatic. Those materials which are most machinable, most castable, most moldable, etc., are equally favorable whether the process is manual or automatic. There are two possible exceptions to this statement:

1. When production quantities are large, as is normally the case when automatic equipment is used, it may be economical to obtain special formulations and sizes of material that closely fit the requirements of the part to be produced and which would not be justifiable if only low quantities were involved.

2. When elaborate interconnected equipment is employed (e.g., transfer lines, index tables, multiple-spindle tapping machines), it may be advisable to specify free-machining or other highly processible materials, beyond what might be normally justifiable, to ensure that the equipment runs continuously. It may be economical to spend slightly more than normal for material if this can avoid downtime for tool sharpening or replacement in an expensive multiple-machine tool.

Effects on Economic Production Quantities

The types of special-purpose equipment listed above generally require significant investment. This, in turn, makes it necessary for production levels to be high enough so that the investment can be amortized. The equipment listed, then, is suited by and large only for mass-production applications. In return, however, it can yield considerable savings in unit costs.

Savings in labor cost are the major advantage of special-purpose and automatic equipment, but there are other advantages as well: reduced work-in-process inventory, reduced tendency of damage to parts during handling, reduced throughput time for production, reduced floor space, and fewer rejects.

Computer-controlled, numerically controlled, and program-controlled equipment noted in item 11 is an exception. The advantage of such equipment is that it permits automatic operation without being limited to any particular part or narrow family of parts and with little or no specialized tooling. Automation at low and medium levels of production is economically justifiable with numerical control and computer control. As long as the equipment is utilized, it is not necessary in achieving unit-cost savings to produce a substantial quantity of any particular part.

Effects on Design Recommendations

There are few or no differences in design recommendations for products made automatically as compared with those made with the same processes under manual control. When there are limitations to automatic processes, these are generally pointed out in this handbook (e.g., design limitations of parts to be assembled automatically). In the preponderance of cases, however, the design recommendations included apply to both automatic and non-automatic methods. In some cases, however, the cost effect of disregarding a design recommendation can be minimized if an automatic process is used. With automatic equipment, an added operation, not normally justifiable, may be feasible, with the added cost consisting mainly of that required to add some element to the equipment or tooling.

Effects on Dimensional Accuracy

Generally, special machines and tools produce with higher accuracy than general-purpose equipment. This is simply a result of the higher level of precision and consistency inherent in purely machine-controlled operations compared with those which are manually controlled.

Compound and progressive dies and four-slide tooling for sheet-metal parts, for example, provide greater accuracy than individual punch-press operations because the work is contained by the tooling for all operations, and manual positioning variations are avoided. Form-ground lathe or screw-machine cutting tools, if properly made, provide a higher level of accuracy for diameters, axial dimensions, and contours than can be expected when such dimensions are produced by separate manually controlled cuts. Form-ground milling cutters, shaper and planer tools, and grinding wheels all have the same advantage.

Multiple-spindle and multiple-head machines can be built with high accuracy for spindle location, parallelism, squareness, etc. They have a definite accuracy advantage over single- operation machines, in that the work piece is positioned only once for all operations. The location of one hole or surface in relation to another depends solely on the machine and not on the care exercised in positioning the work piece in a number of separate fixtures. Somewhat tighter tolerances therefore can be expected than would be the case with a process employing single-operation equipment.

Automatic parts-feeding devices generally have little effect on the precision of components produced. They are normally more consistent than manual feeding except when parts have burrs, flashing, or some other minor defect that interferes with the automatic feeding action. No special dimensional allowances or changed tolerances should be applied if production equipment is fed automatically.

D) COMPUTER AND NUMERICAL CONTROL: OTHER FACTORS

Computer-controlled and numerically controlled equipment has other advantages for production design in addition to those noted above:

1. Lead time for producing new parts is greatly reduced. Designers can see the results of their work sooner, evaluate their designs, and incorporate necessary changes at an early stage.

2. Parts that are not economically produced by conventional methods sometimes are

quite straightforward with computer or numerical control. Contoured parts such as cams and turbine blades are examples.

3. Computer control can optimize process conditions such as cutting feeds and speeds as the operation progresses.

4. Computer-aided design (CAD) of the product can provide data directly for control of manufacturing processes, bypassing the cost and lead time required for engineering drawings and process programming. Similarly, the process-controlling computer can provide data for the production and managerial control system.

5. Setup and changeover times are greatly reduced. Processing times are also being reducedas high-velocity computer control is being developed.

To achieve these advantages, an investment in the necessary equipment is require, and this can be substantial. More vital and even more costly in many cases is the training of personnel capable of developing, debugging, and operating the necessary control programs.

Mechanisms Selection

General Requirements for Early Materials and Process Selection

In order to be of real design value, the information on which the initial selection of material/ process combinations and their ranking is to be based should be available at the early concept design stage of a new product. Such information might include, for example:

- ✓ Product life volume
- ✓ Permissible tooling expenditure levels
- ✓ Possible part shape categories and complexity levels
- ✓ Service or environment requirements
- ✓ Appearance factors
- ✓ Accuracy factors

It is important to realize that for many processes the product and process are so intimately related that the product design must use an anticipated process as a starting point. In other words, many design details of a part cannot be defined without a consideration of processing. For this reason, it is crucial that an economic evaluation of competing processes be performed while the product is still at the conceptual stage. Such an early evaluation ensures that every economically feasible process is investigated further before the product design evolves to a level where it becomes process-specific.

As a design progresses from the conceptual stage to production, different methods can be used to perform the cost modeling of the product. At the conceptual stage, rough comparisons of the costs of products of similar size and complexity may be sufficient. While this procedure contains a certain degree of uncertainty, it only requires conceptual design information and is useful for the purpose of early economic comparison.

As the design progresses and specific materials and processes are selected, more advanced cost modelling methods may be employed. These may be particularly useful in establishing the relationship between design features and manufacturing costs for the chosen process. The basis of several cost-estimation procedures for different processes is outlined in later chapters.

Relationship to Process and Operations Planning

There is an obvious relationship between the initial selection of process/material combinations and process planning. During process planning, the detailed elements of the sequence of manufacturing operations and machines are determined. It is at this stage that the final detailed cost estimates for the manufacture of the part are determined. Considerable work has been done in the area of computer-aided process planning (CAPP) systems, although closer examination shows that the majority of this work has been devoted to machining processes only. These systems are utilized after a detailed design of the part has been carried out, and the manufacturing processes are evident. The initial decision on the material and process combination to be used for the part is most important, as this determines the majority of subsequent manufacturing costs. The goal of systematic early material and process selection is to influence this initial decision on which combination to use, before a detailed design of the part is carried out and before detailed process planning is attempted.

Selection of Manufacturing Processes

The selection of appropriate processes for the manufacture of a particular part is based on a matching of the required attributes of the part and the various process capabilities. Once the overall function of a part is determined, a list can be formulated giving the essential geometrical features, material properties, and other attributes that are required. This represents a "shopping list" that must be filled by the material properties and process capabilities. The attributes on the "shopping list" are related to the final function of the part and are determined by geometric and service conditions. Most component parts are not produced by a single process, but require a sequence of different processes to achieve all the required attributes of the final part. This is particularly the case when forming or shaping processes are used as the initial process, and material removal and finishing processes are required to produce some of the final part features.

Even when using moulding or casting processes, which can produce extremely complex geometries, there may be a number of features that are impossible to form and require subsequent machining operations. In other cases some of the features may be assigned to separate machining operations, because otherwise the die or mould may be uneconomically expensive. However, one of the goals of DFMA analysis is product structure simplification and parts consolidation. Experience shows that it is generally most economical to make best use of the capabilities of the initial manufacturing process in order to provide as many of the required attributes of a part as possible. As discussed in the introduction, the alternative approach of following guidelines to ensure that individual parts are as easy as possible to manufacture typically leads to an unnecessarily large number of separate parts, some of which add little value to the product. There are hundreds of processes and thousands of individual materials.

Moreover, new processes and materials are being developed continually. Fortunately, the following observations help to simplify the overall selection problem:

1. Many combinations of processes and materials are not possible. Figure 4.6 shows a compatibility matrix for a selected range of processes and material types.

2. Many combinations of processes are not possible and, therefore, do not appear in any processing sequences.

3. Some processes affect only one attribute of the part, particularly surface treatment and heat-treatment processes.

4. Sequences of processes have a natural order of shape generation, followed by feature addition or refinement by material removal and then material property or surface enhancement.

Processes can be categorized as:

- Primary processes
- Primary/secondary processes
- Tertiary processes

Some texts refer to primary processes as those used for producing the raw materials for manufacturing such as flat rolling, tube sinking, and wire drawing. In the context of producing component parts in this text, the term primary process refers to the main shape generating process, assuming that the material has been purchased in the appropriate stock form (wire, tube, sheet, etc.). Such processes should be selected to produce as many of the required attributes of the part as possible and usually appear first in a sequence of operations. Casting, forging, and injection moulding are examples of primary shape generating processes. Primary/secondary processes, on the other hand, can generate the main shape of the part, form features on the part, or refine features on the part. These processes appear at the start or later in a sequence of processes. This category includes material removal processes such as machining, grinding, and broaching.

Tertiary processes do not affect the geometry of the part and always appear after primary and primary/secondary processes. This category consists of finishing processes such as surface treatments and heat treatments. The selection of tertiary processes is simplified, because many tertiary processes only affect a single attribute of the part. For instance, lapping is employed to achieve a very good surface finish, and plating is often used to improve the appearance or corrosion resistance.

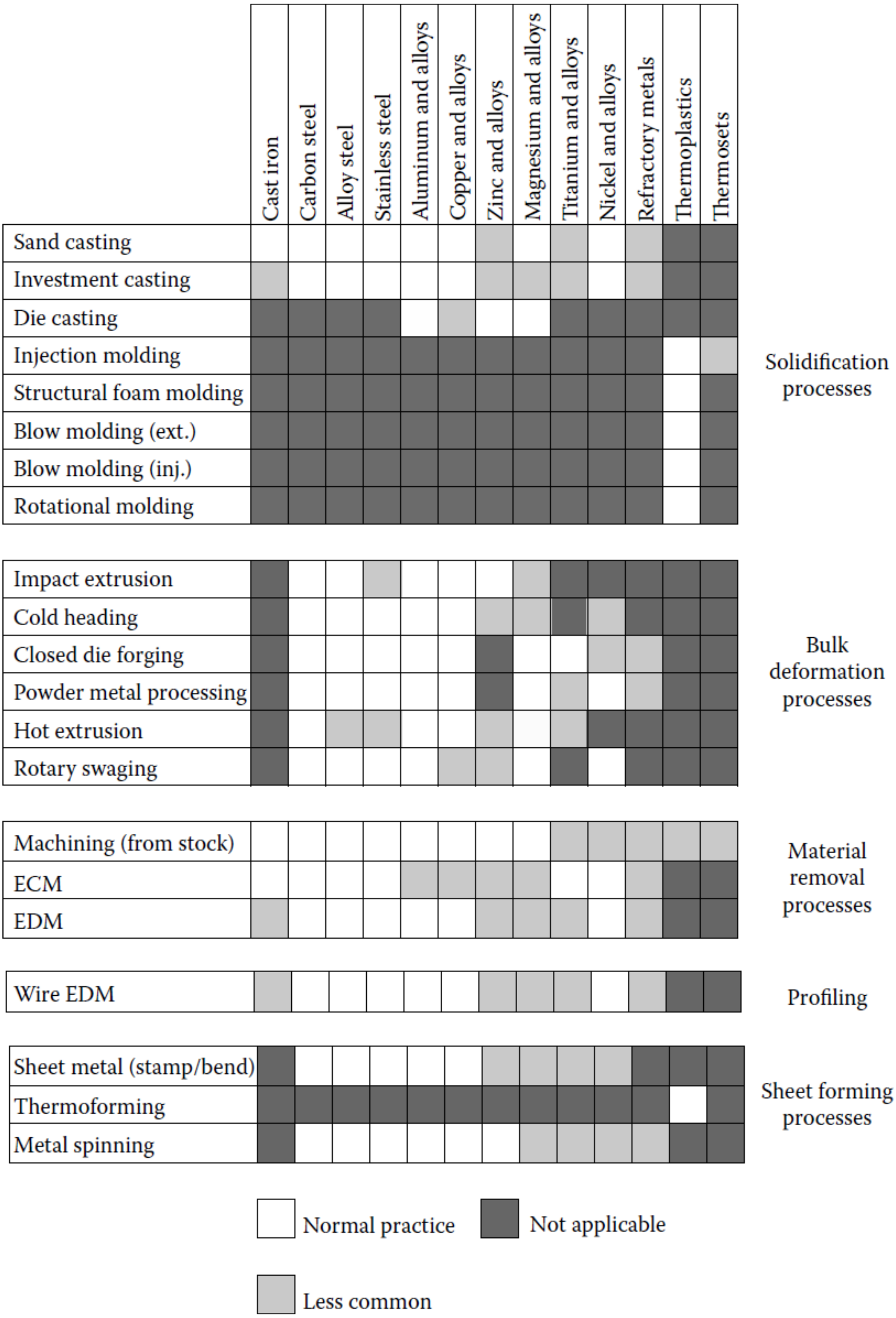


FIGURE.4.6. Compatibility Matrix for Processes and Materials

Process Capabilities

A great deal of general information is available on manufacturing processes in a wide range of textbooks, handbooks, and so on. Each process can be analyzed to determine the range of its capabilities in terms of attributes of the parts that can be produced. Included in these capabilities are shape features that can be produced, natural tolerance ranges, surface roughness capabilities, and so on. These capabilities determine whether a process can be used to produce the corresponding part attributes.

General Shape Attributes

Depressions (Depress): The ability to form recesses or grooves in the surfaces of the part. The first column entry refers to the possibility of forming depressions in a single direction, while the second entry refers to the possibility of forming depressions in more than one direction. These two entries refer to depressions in the direction of tooling motion and those in other directions. The following are some examples of tooling motion directions.

Processes with split moulds—the direction of mould opening.

Processes that generate continuous profiles—normal to the direction of extrusion or normal to the axis of the cutting medium.

Forging (impact) processes-the direction of impact of the tooling onto the part.

Uniform wall (UniWall): Uniform wall thickness. Any non-uniformity arising from the natural tendency of the process, such as material stretching or build up behind projections in centrifugal processes is ignored, and the wall is still considered uniform.

Uniform cross-section (UniSect): Parts where any cross-sections normal to a part axis are identical, excluding draft (slight taper) in the axial direction for die or mold release if required.

Axis of rotation (AxisRot): Parts whose shapes can be generated by rotation about a single axis: a solid of revolution.

Regular cross-section (RegXSec): Cross-sections normal to the part’s axis contain a regular pattern (e.g., a hexagonal or splined shaft). Changes in shape that maintain a regular pattern are permissible (e.g., a splined shaft with a hexagonal head).

Captured cavities (CaptCav)*:* The ability to form cavities with reentrant surfaces (e.g., a bottle).

Enclosed (Enclosed): Parts that are hollow and completely enclosed.

Draft-free surfaces (NoDraft): The capability of producing constant cross-sections in the direction of tooling motion. Many processes can approach this capability when less than ideal draft allowances are specified, but this designation is reserved for processes where this capability is a basic characteristic and no draft can be obtained without cost penalty.

DFA Compatibility Attributes

Manufacturing processes have varying levels of compatibility with the basic goals of the DFA of simplified product structure and ease of assembly. This relative compatibility is measured in the following key areas.

Part consolidation (PConsol): The ability to incorporate several functional requirements into a single piece, eliminating the need for multipart assemblies.

Alignment features (Alignmt): The ease of incorporating in the part positive alignment or location features that aid in the assembly of mating parts.

Integral fasteners (IntFast): The cost-effectiveness and scope of fastening elements that can be designed into the part. The ability to incorporate features such as threads, which generally involve separate fasteners, is not given as much consideration as elements such as snap features.

Geometric Tolerance

***Conventional or Coordinate Tolerancing* System:**

Coordinate tolerance is a dimensioning system where a part feature is located (or defined) by means of a rectangular dimension with the given tolerance.

Geometric Tolerancing:

Geometric tolerance of a feature (point, line, axis, surface or medium plane) specifies the tolerance zone within which the feature is required to be contained. The geometric tolerance feature provides a precise and brief method of indicating brief geometric requirements on engineering drawings. The symbols being internationally been accepted are very useful when overseas manufacture is involved. Geometric tolerancing is very useful especially when conventional dimensioning and drawing methods are inadequate and doesn't ensure that parts will assemble satisfactorily after manufacture.

Basic Definitions

Maximum Material Condition (MMC)

It is that condition of a feature or a part, which contains the maximum amount of material, e.g. minimum hole size or maximum shaft size. In certain cases its use allows an increase in the specifies tolerance if it is indicated that the tolerance applies to the feature at its MMC.

Straightness

It is the shortest distance between two points. The tolerance value is the specified distance between two parallel straight lines.

Datum

A datum feature may be a plane or axis. For practical purposes the plane surface or axis is used for manufacture or inspection.

Flatness

Flatness tolerance controls the deviation of the surface from the true plane and is the space between the two parallel planes

Roundness

It is the condition where the feature is a continuous curved surface, any point on the surface is at a constant distance from the centre or axis. The roundness tolerance zone is the annular space between two co-planar, concentric circles.

Cylindricity

It is a combination of parallelism, straightness and roundness, applied to the surface of a cylinder. The Cylindricity tolerance zone is the annular space between two coaxial cylinders and its value is the radial distance between them.

Concentricity

It is the relationship between two cylinders, which have the same axis or common centre. Concentricity tolerance is the deviation of the axis from the true position.

Squareness

It is the condition where a line, plane or surface lies at 90 degrees to the another. It is the space between the two parallel lines or surfaces.

Parallelism

This is the condition where two lines or surfaces are separated by a uniform distance. Parallelism tolerances control the parallelism between the two lines or surfaces and the tolerance zone is the distance between them.

Angularity

It defines the position between two lines or surfaces which are nor parallel or perpendicular to each other.

Position

The positional tolerance controls the position between a feature and a datum or from another feature. The tolerance value is the specified deviation from the true position.

Symmetry

It is the feature where a feature is divided into identical parts by means of a line or plane. Symmetry tolerances control the area between the parallel lines or planes, which are parallel to the datum feature, and there value is the distance between them.

Circular Runout

It is the permissible variation of position of any point fixed on a surface, which occurs when a part is rotated through 360 degrees about its own axis. The resultant indications include errors of other characteristics without differentiating them. The combined errors must not exceed the stated tolerance value.

Total Runout

The difference between simple Runout and total Runout is that in the former, one measurement is taken during one revolution while in the later the measuring instrument is moved along the component during several revolutions.

Datum

A datum is the origin from which the location or geometric shape of features of a part are established. It is a theoretically perfect point, line or plane. Tolerance specifications will reference these datum.

Table 4.2 Symbols of Toleranced Characteristics

Type of Tolerµ sance	Characteristics to be toleranced	Symbols
FORM	Straightness	⏤
	Flatness	⏥
	Circularity (Roundness)	○
	Profile of any line	⌒
	Profile of any surface	⌓
ORIENTATION	Parallelism	//
	Perpendicularity	⊥
	Angularity	∠
LOCATION	Position	⌖
	Concentricity and coaxiality	◎
	Symmetry	⌯
RUNOUT	Simple runout	↗
	Total Runout	⌰

Datum Reference Frame

Positioning the part with relation to three mutually perpendicular planes: the datum reference frame. This reference frame exist in theory only. In some cases a single datum may be sufficient. Features of size are often classified as datum features. Examples are: holes, slots, tabs and shafts. Placement of a datum feature symbol with a size dimension indicates that the feature of size is a datum feature.

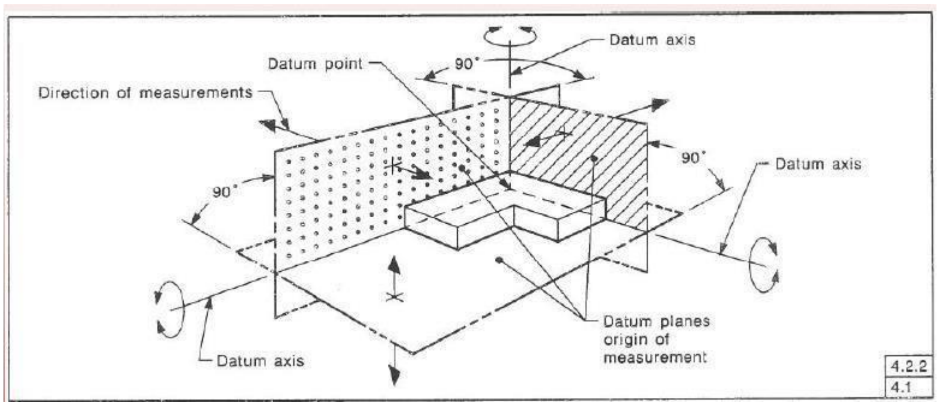


FIGURE 4.7. Datum Reference Frame

External Feature (Datum Call-Out)

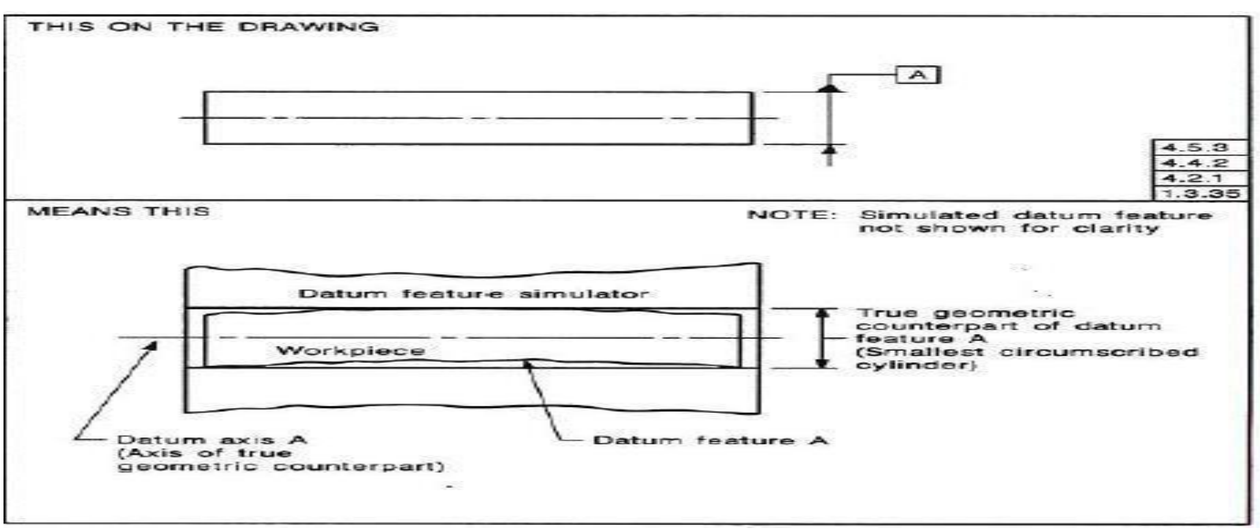


FIGURE 4.8: Primary External Datum Diameter-RFS

Internal Feature (Datum Call-Out)

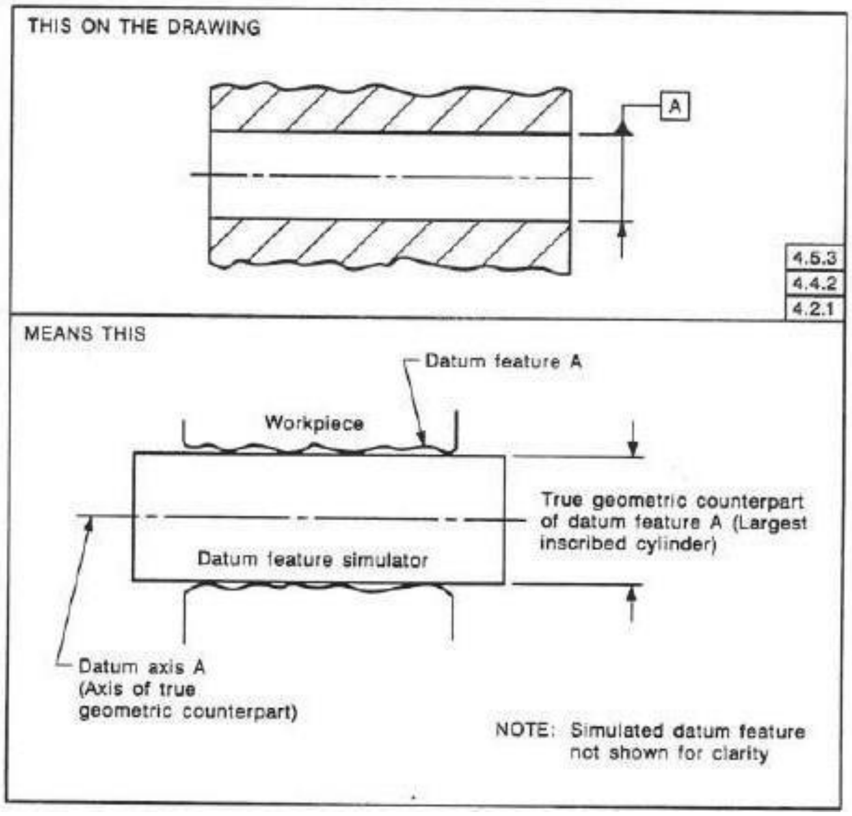


FIGURE 4.9: Primary Internal Datum Diameter-RFS

Tolerance Stack-Up

Product manufacturers utilize an organized flow of information to translate customer requirements into product requirements.

Tolerance Stack-Ups are vital to address mechanical fit and mechanical performance requirements. Mechanical fit is simply answering the question, “Do the parts that make up the assembly always go together?” Mechanical performance requirements would include the performance of mechanisms, like switches, latches, actuators, and the like. Otherperformance requirements could include optical alignments or motor efficiency. So what is a “stack-up”?

Tolerance stack-up calculations represent the cumulative effect of part tolerance with respect to an assembly requirement. The idea of tolerances “stacking up” would refer to adding tolerances to find total part tolerance, then comparing that to the available gap or performance limits in order. This process for mechanical requirements is generalized in the flow diagram below.

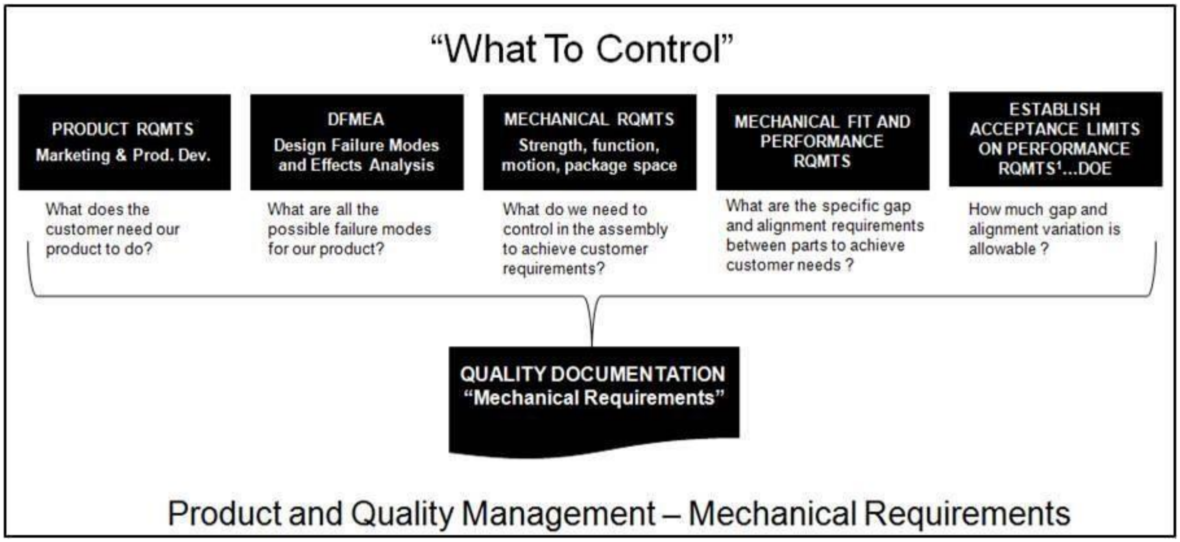


FIGURE 4.10. Product and Quality Management

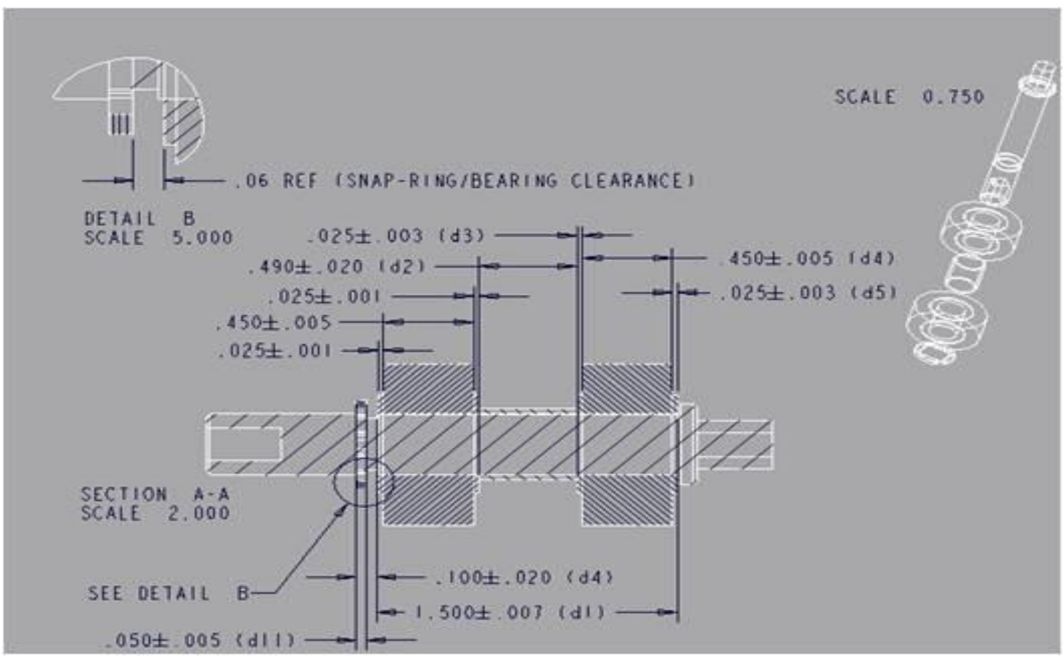


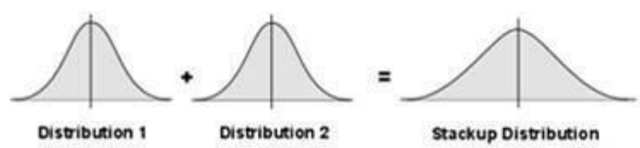
FIGURE 4.11. Tolerance Stackup

This simple comparison is also referred to as worst case analysis. Worst case analysis is appropriate for certain requirements where failure would represent catastrophe for a company. It is also useful and appropriate for problems that involve a low number of parts. Low being defined as three or four parts. Worst case analysis is most often done in a single direction, i.e. a 1D analysis. If the analysis involves part dimensions that are not parallel to the assembly measurement being studied, the stack-up approach must be modified since 2D variation such as angles, or any variation that is not parallel with the 1D direction, does not affect the assembly measurement with a 1-to-1 ratio.

Many companies utilize a statistical method for tolerance analysis. One approach involves a simple calculation using the RSS Method, Root-Sum-Squared. Instead of summing tolerances, as in worst-case analysis, statistical analysis sums dimension distributions. It is important to understand that the inputs values for a worst-case analysis are design tolerances, but the inputs for a statistical analysis are process distribution moments (e.g., standard deviation). Worst-case analysis (also called tolerance stack-up analysis) can be used to validate a design. Statistical analysis (also called variation analysis) can be used to predict the actual variation of an assembly based on the variation of the part dimensions. Comparing the assembly standard deviation to the assembly limits allow for the calculation of quality metrics like sigma, % yield, DPMU, etc. This approach requires distributions to be normal with all parts at the same quality level, i.e. +/- 3σ.

1D RSS:

$$\sigma_{ASM} = \left(\sum_{i=1}^{n} \sigma_i^{\,2} \right)^{1/2}$$



σ_i = Standard deviation of the "ith" dimension

Given the limitations of RSS, other methods for calculating assembly variation have been developed. One such method that is incorporated into CETOL 6 Sigma is called the Method of System Moments. This method eliminates the limitations stated above. Analyses of all complexities, i.e. 1D, 2D, and 3D, can be created with no restriction on distribution type or quality level. Companies can now do full Assembly Variation Analysis with tolerance analysis software.

Assembly variation analysis provides insight required to identify the key part characteristics, (KPCs) that must be controlled in order to produce a product that meets the expectation of the customer. The product development process should then become focused on defining and validating part manufacturing and assembly processes that are capable of achieving high producibility levels. Goals of Cpk = 1.67 for key features and Cp = 1.33 for non-key features are commonly quoted. Utilizing the insight for variation analysis allows design engineers to allocate tolerance budgets strategically. Critical features will be held to tighter tolerances. Looser tolerance can be applied to less important features. These decisions not only ensure product quality and performance, but also ensure manufacturability at the right price. The impact on the product development process can be huge.

Understanding Statistical Tolerance Analysis **Definition of Statistical Tolerance Analysis**

A statistical tolerance analysis is when you take the variation of a set of inputs to calculate the expected variation of an output of interest. In mechanical engineering, a product design is composed of multiple features, each with tolerance values that control the variable aspects of those features. Statistical tolerance analysis is used to understand how these tolerances contribute the various performance characteristics of the design.

1D Tolerance Stackup

The simplest form of tolerance analysis is the single direction, 1D Tolerance Stackup. A 1D Tolerance Stackup is created by creating a cross section of a model and adding the tolerance values for each feature in a straight line.The variation in each contributes to the overall output/outcome.

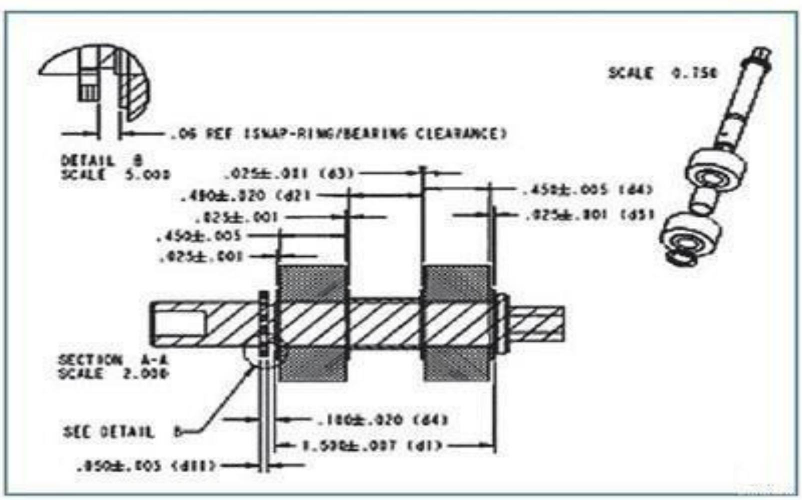


FIGURE 4.12 ID Tolerance Stackup

Worst-Case Analysis vs RSS (Root-Sum Squared) Statistical Analysis

In a Worst-Case Analysis, each dimension will have a minimum and maximum value that represents the range of acceptability for that dimension. Worst-Case answers the question, if I take the maximum range on each input, what is the maximum range for the measurement of interest or stackup? We are therefore dealing with the limits of acceptability and not probability.

RSS (Root-Sum Squared) Statistical Analysis does not focus on the extreme values, but focuses on the distribution of the variation for each dimension. Each dimension will have a unique distribution of values based on the manufacturing process. Tool wear, operator differences, changes in material and environment all contribute to variation in the dimension value. Each dimension has its own distribution curve.

When you combine the probabilities for each dimension (each separate curve) you get the probability for the total and therefore the distribution curve of the total. Statistical analysis answers the question, given the distribution of variation on each dimension what is the probability that my performance characteristic will fall within defined acceptable limits. The limitation of RSS is that it assumes all inputs are normally distributed and all performance characteristics have a linear relationship with the dimension. These assumptions do not account for the breadth of conditions that exist in typical scenarios found in manufacturing.

Second Order Tolerance Analysis

Because manufacturing methods vary for different types of parts, the distribution moments or parameters change as well. RSS only uses standard deviation and does not include the higher moments of skewness and kurtosis that better characterize the effects tool wear, form aging and other typical manufacturing scenarios. Second Order Tolerance Analysis incorporates all distribution moments:

Second Order Tolerance Analysis is also needed to determine what your output is going to be when the assembly function is not linear. In typical mechanical engineering scenarios Kinematic adjustments and other assembly behaviors result in non-linear assembly functions. Second order calculations are much more complex so hand calculations are not advisable but the computation accuracy is greatly improved and becomes viable within a tolerance analysis software package.

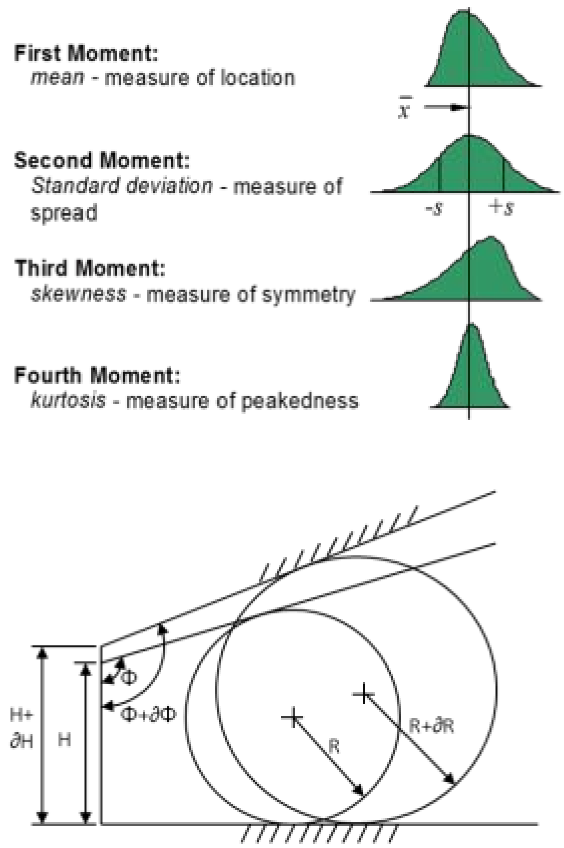


FIGURE 4.13. Summary of Statistical Tolerance Analysis for practical usage

The choice in tolerance analysis method is based on many factors, but the can be summarized as “Which method best matches the manufacturing and inspection process of the assembly”. For simple fit problems, a 1D stack-up may be sufficient. RSS is sufficient for the small number of scenarios where the inputs are normal and the assembly relationships are linear. For all other scenarios, Second Order Tolerance Analysis is required to address the real world of manufacturing.

***Tolerance Stack-Up Analysis:* Main Rules**

Start at the bottom and work up, or start at the left and work to the right. Always take the shortest route. Stay on one part until all tolerances are exhausted.

Step 1 : Identify the requirement that is to be analyzed.

Step 2 : Identify all dimensions and tolerances that contribute to the gap.

Step 3 : Assign each dimension a positive or negative value:

Up is positive Down is negative Right is positive Left is negative

Step 4 : Only one set of mating features creates the worst-case gap.

Step 5 : The analyst must deduce which geometric tolerance, location or orientation if either, contributes to the gap.

Step 6 : If your assumptions are wrong, your answer is wrong.

Assembly Limits **General Aspects**

In the design and manufacture of engineering products a great deal of attention has to be paid to the mating, assembly and fitting of various components. In the early days of mechanical engineering during the nineteenth century, the majority of such components were actually mated together, their dimensions being adjusted until the required type of fit was obtained. These methods demanded craftsmanship of a high order and a great deal of very fine work was produced.

Present day standards of quantity production, interchangeability, and continuous assembly of many complex compounds, could not exist under such a system, neither could many of the exacting design requirements of modern machines be fulfilled without the knowledge that certain dimensions can be reproduced with precision on any number of components.

Modern mechanical production engineering is based on a system of limits and fits, which while not only itself ensuring the necessary accuracies of manufacture, forms a schedule or specifications to which manufacturers can adhere. In order that a system of limits and fitsmay be successful, following conditions must be fulfilled:

1. The range of sizes covered by the system must be sufficient for most purposes.

2. It must be based on some standards; so that everybody understands alike and a given dimension has the same meaning at all places.

3. For any basic size it must be possible to select from a carefully designed range of fit the most suitable one for a given application.

4. Each basic size of hole and shaft must have a range of tolerance values for each of the different fits.

5. The system must provide for both unilateral and bilateral methods of applying the tolerance.

6. It must be possible for a manufacturer to use the system to apply either a hole-based or a shaft-based system as his manufacturing requirements may need.

7. The system should cover work from high class tool and gauge work where very wide limits of sizes are permissible.

Nominal Size and Basic Dimensions

Nominal Size: A 'nominal size' is the size which is used for purpose of general identification. Thus the nominal size of a hole and shaft assembly is 60 mm, even though the basic size of the hole may be 60 mm and the basic size of the shaft 59.5 mm.

Basic Dimension: A 'basic dimension' is the dimension, as worked out by purely design considerations. Since the ideal conditions of producing basic dimension, do not exist, the basic dimensions can be treated as the theoretical or nominal size, and it has only to be approximated. A study of function of machine part would reveal that it is unnecessary to attain perfection because some variations in dimension, however small, can be tolerated size of various parts. It is, thus, general practice to specify a basic dimension and indicate by tolerances as to how much variation in the basic dimension can be tolerated without affecting the functioning of the assembly into which this part will be used.

Definitions

The definitions given below are based on those given in IS: 919

Shaft: The term shaft refers not only to diameter of a circular shaft to any external dimension on a component.

Hole: This term refers not only to the diameter of a circular hole but to any internal dimension on a component.

Basics of Fit

A fit or limit system consists of a series of tolerances arranged to suit a specific range of sizes and functions, so that limits of size may. Be selected and given to mating components to ensure specific classes of fit. This system may be arranged on the following basis:

1. Hole basis system
2. Shaft basis system.

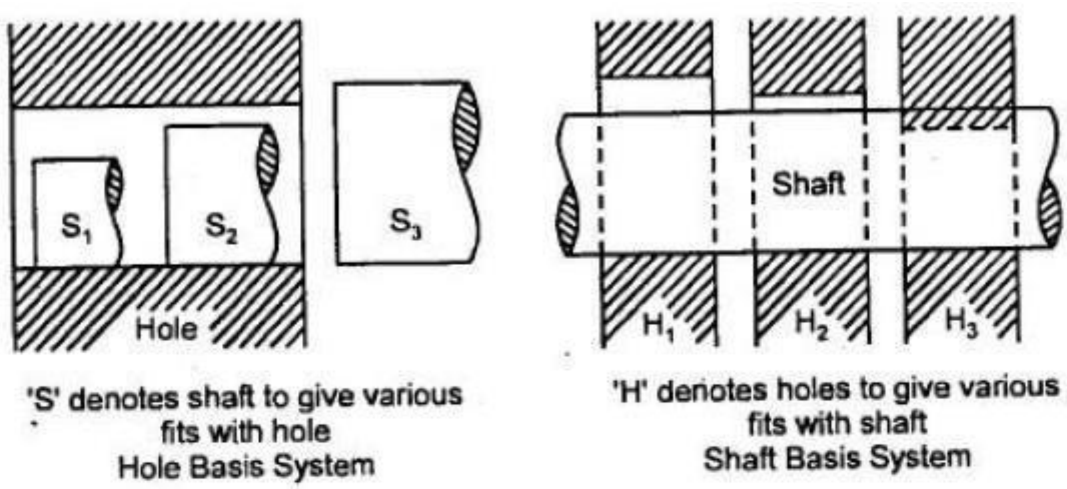


FIGURE 4.14 : Nominal and Basic Dimensions

***Hole basis system**:*

'Hole basis system' is one in which the limits on the hole are kept constant and the variations necessary to obtain the classes of fit are arranged by varying those on the shaft.

***Shaft basis system**:*

'Shaft basis system' is one in which the limits on the shaft are kept constant and the variations necessaryto obtain the classes of fit are arranged by varying the limits on the holes. In present day industrial practice hole basis system is used because a great many holes are produced by standard tooling, for example, reamers drills, etc., whose size is not adjustable. Subsequently the shaft sizes are more readily variable about the basic size by means of turning or grinding operations. Thus the hole basis system results in considerable reduction in reamers and other precision tools as compared to a shaft basis system because in shaft basis system due to nonadjustable nature of reamers, drills etc. great variety (of sizes) of these tools are required for producing different classes of holes for one class of shaft for obtaining different fits.

Systems of Specifying Tolerances The tolerance or the error permitted in manufacturing a particular dimension may be allowed to vary either on one side of the basic size or on either side of the basic size. Accordingly two systems of specifying tolerances exit.

1. Unilateral system

2. Bilateral system.

In the unilateral system, tolerance is applied only in one direction.

Examples: $_{+0.02}40.0^{+0.04}$

$-0.04\,40.0^{-0.02}$

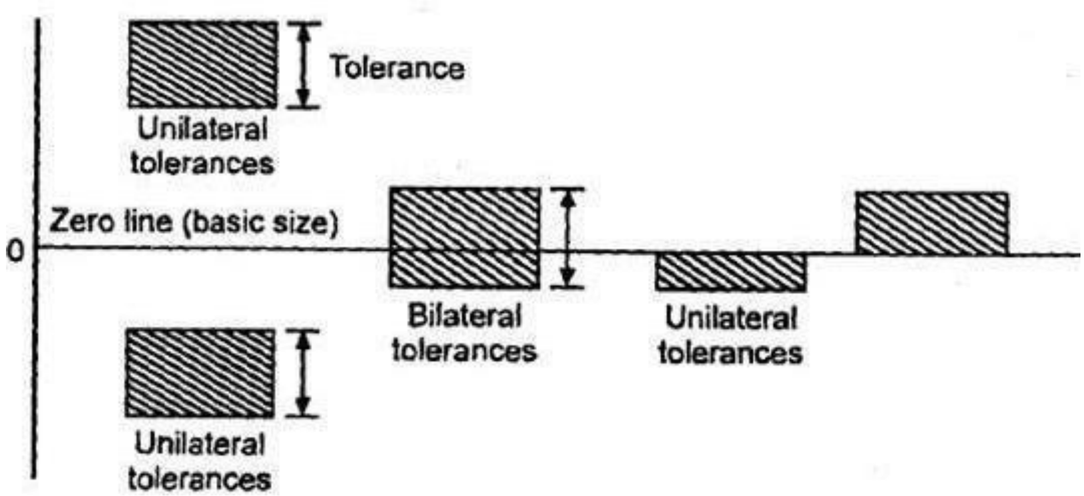


FIGURE 4.15: Types of Tolerances

In the bilateral system of writing tolerances, a dimension is permitted to vary in two directions.

Example: $_{-0.04}40.0^{+0.02}$

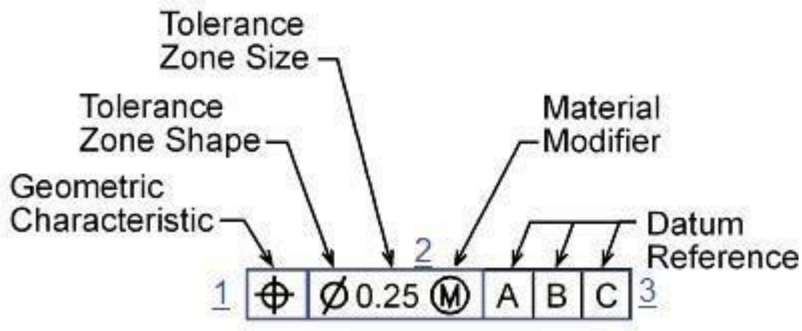
Feature Tolerances

Feature Control Frame

The Feature Control Frame is potentially the most useful tool in any geometric tolerancing system because it allows you to effectively use all of the geometric tolerancing symbols available to you.

A Feature Control Frame is a GD&T Tool that combines a Geometric Characteristic, the tolerance allowed (Tolerance Zone shape & Tolerance Zone Size), any material modifiers, and the datum feature references to create a geometric tolerance.

Feature Control Frames are a effective & compact method for providing clear & concise requirements for the many different features of your design. The Feature Control Frame can be broken down into three sections, shown here in blue.



The first box or section can contain any of the 14 different standard geometric tolerance symbols found above. In this example, the feature control frame includes a True Position Tolerance.

The next section contains the actual tolerance for the specific feature being Toleranced. In this example, the true position tolerance is 0.25 with an additional diameter symbol to indicate a circular tolerance zone at maximum material condition (M)

The third and final section indicates the datum references associated with the tolerance. In this example Datum A is the primary datum, Datum B is the secondary datum, and Datum C is the tertiary datum. This datum order is important because it standardizes the way the part is fixtured during inspection.

DESIGN FOR MANUFACTURING & ECONOMICS

A product development team working for a manufacturer of kitchen appliances was in the midst of developing a new coffee maker, referred to by the project name AB-100. The new coffee maker would provide high-quality coffee using an existing capsule system and would compete in the market against products by Nespresso, Illy, Keurig, and others. Exhibit 4.16 shows a coffee maker and coffee capsule by Nespresso.

During the AB-100 development, the product development team was faced with sev- eral decisions that it knew could have a significant impact on the product's profitability. For example:

- Should the team increase development spending and production cost to add an addi- tional feature that could lead to greater sales volume?
- Would the project be profitable if the retail price is reduced by 10% due to competitive pricing pressure?

The team used the financial analysis tools presented in this chapter to help answer these and other questions relating to the project's ability to generate profit for the manu- facturer. The emphasis in this chapter is on fairly quick, approximate methods for supporting decision making within the project team. This analysis is generally referred to as product development economics, financial modeling, or break-even analysis. It is essentially a prediction of the expected payback and profitability deriving from a specific project, in this case the development and production of a new product.

FIGURE 4-16. A home coffee maker using single-serving capsules.

Elements of Economic Analysis

This chapter describes a method consisting of two types of analysis, quantitative and qualitative. We will see in this chapter that this analysis supports a wide variety of project decisions in the product development context.

Quantitative Analysis

There are several basic cash inflows (revenues) and cash outflows (costs) over the life cycle of a successful new product. Cash inflows come from sales of the product and related goods and services. Cash outflows include spending on product and process development; costs of production ramp-up such as equipment purchases and tooling; costs of marketing and supporting the product; and ongoing production costs such as raw materials, components, and labor. The cumulative cash inflows and outflows over the life cycle of a typical successful product are presented schematically in Exhibit 4-17.

Economically successful products are profitable; that is, they generate more cumula- tive inflows than cumulative outflows. A measure of the degree to which inflows are greater than outflows is the net present value (NPV) of the project, or the value in today's dollars of all of the expected future cash flows. The quantitative part of the economic analysis method described in this chapter estimates the NPV of a project's expected cash flows. The method uses NPV techniques because they are easily understood and used widely in business. (Appendix A at the end of this chapter provides a brief tutorial on NPV.) The purpose of quantitative analysis is not only to provide objective evaluations of projects and alternatives but also to bring a measure of structure and discipline to the assessment of product development projects.

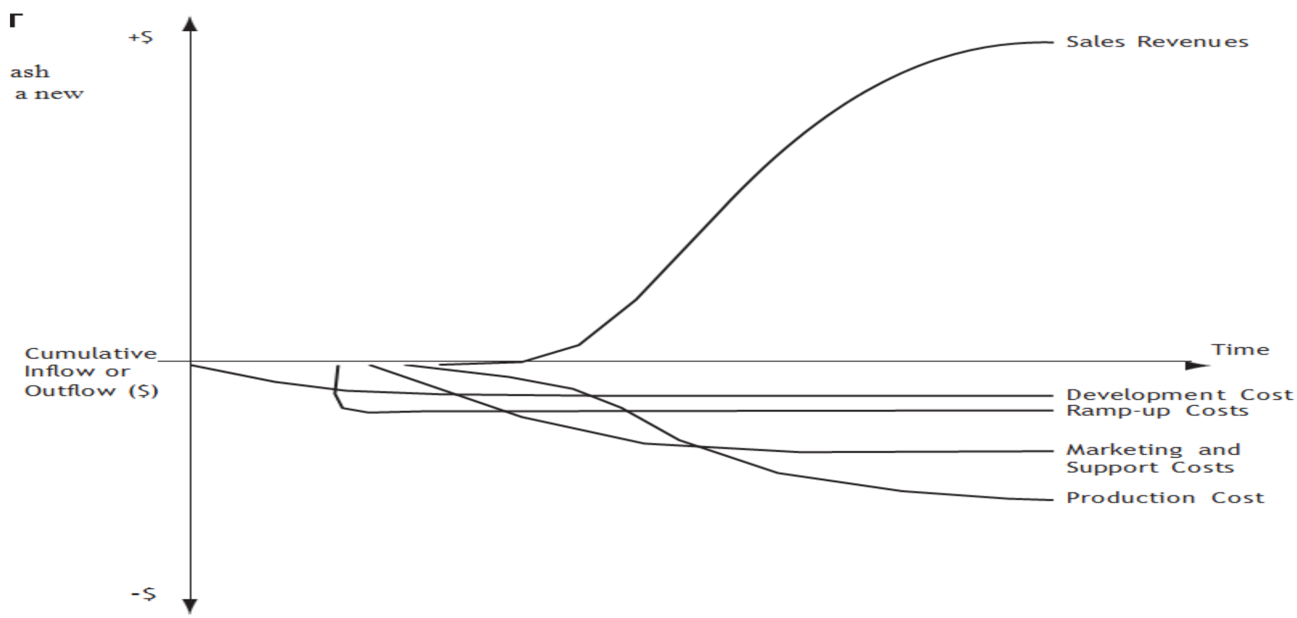


FIGURE 4.17. Typical cash flows for a new product

Qualitative Analysis

Quantitative analysis can capture only those factors that are measurable, yet projects often have both positive and negative implications that are difficult to quantify. Also, quantitative analysis rarely captures the characteristics of a dynamic and competitive environment. In fact, a product development project with negative NPV may be a worth- while investment in certain circumstances; for example, where the expenditure (loss) on one project enables valuable learning that can lead to profitable future products. The method in this chapter uses qualitative analysis to capture some of these issues. Our approach to qualitative analysis is to consider specifically the interactions between the project and (1) the firm, (2) the market, and (3) the macroeconomic environment.

When Should Economic Analysis Be Performed?

Economic analysis, including both quantitative and qualitative approaches, is useful in at least two different circumstances:

- Go/no-go milestones: Go/no-go decisions are typically made at the end of each phase of development. These decisions may involve questions such as: Should we try to develop a product to address this market opportunity? Should we proceed with the implementation of the selected concept? Should we launch the product we have developed?
- Operational design and development decisions: Operational decisions involve ques- tions such as: Should we spend $100,000 to hire an outside firm to develop this com- ponent to save two months of development time? Should we launch the product in one year at a unit price of $260 or wait another quarter when we can reduce the price to $240?

The financial modeling done at the beginning of a project can usually be updated with current information so that it does not have to be re-created in its entirety each time. Used in this way, the analysis becomes one of the information systems the team uses to manage the development project. Economic analysis can be carried out by any member of the development team. In small companies, the project leader or one of the members of the core project team will implement the details of the analysis. In larger companies, a representative from a finance or planning group may be appointed to assist the development team in performing the analysis. We emphasize that even when someone with formal training in financial modeling takes responsibility for this analysis, the core team should fully understand the analysis and be involved in its formulation and use.

Economic Analysis Process

We recommend the following four-step method for the economic analysis of a product development project. The balance of this chapter is organized around these four steps.

1. Build a base-case financial model to compute expected profit.
2. Perform sensitivity analysis to understand the key assumptions of the model.
3. Use sensitivity analysis to understand project trade-offs.
4. Consider the influence of qualitative factors on project success.

Step 1: Build a Base-Case Financial Model

Constructing the base-case model consists of estimating the future cash flows and then computing the NPV of those cash flows.

Estimate the Timing and Magnitude of Future Cash Inflows and Outflows

The timing and magnitude of the cash flows is estimated by merging the project schedule with the project budget and estimates of ongoing revenues and expenses. The level of detail of cash flows should be coarse enough to be convenient to work with, yet it should contain enough resolution to facilitate effective decision making. The most basic categories of cash flow for a typical new product development project are:

- Sales revenues
- Development and testing cost
- Equipment and tooling cost
- Production and distribution ramp-up cost
- Market launch, ongoing marketing, and product support costs
- Production direct and indirect costs

Depending on the types of decisions the model will support, greater levels of detail for one or more areas may be required. More detailed modeling may consider these same types of cash flows in greater detail, or it may consider other flows. Typical refinements include:

- Breakdown of seasonal sales by quarter
- Inclusion of growth or decline of sales volume and/or pricing
- Breakdown of development cost into design, testing, and refinement costs
- Breakdown of production costs into direct costs and indirect costs (overhead)
- Breakdown of marketing and support costs into launch costs, promotion costs, direct sales costs, and service costs
- Inclusion of tax effects, including depreciation and investment tax credits
- Inclusion of cannibalization (the impact of the new product on existing product sales), salvage costs, and opportunity costs
- Inclusion of working capital cash flows and interest on accounts

The financial model we use in this chapter is simplified to include only the major cash flows that are typically considered in practice, but conceptually it is identical to more complex models. The numerical values of the cash flows generally come from bud- gets and other estimates made by the development team, the manufacturing organization, and the marketing organization. Note that all revenues and expenses to date are sunk costs and are irrelevant to NPV calculations. (The concept of sunk costs is reviewed in Appendix A.) Exhibit 1.1 shows the relevant financial estimates for the new coffee maker AB-100.

To complete the model, the financial estimates must be merged with timing information. This can be done by considering the project schedule and sales plan. (For most projects, quarter-year time increments are used.) 4.18 shows the AB-100 project timing information in Gantt chart form. The remaining time to market is estimated to be four quarters, and product sales are anticipated to last 12 quarters.

TABLE 4.3. To create the base model for AB Model

Model Parameter	**Base-Case Value**
Product development	$5M over 1 year
Equipment and tooling	$4M over 1/2 year
Production ramp-up	$2M over 1/2 year
Market launch	$10M over 1/2 year
Marketing and support	$5M/year after launch
Production direct cost	$55/unit
Production overhead	$1M/year
Initial sales and production volume	200,000 units/year
Quarterly sales profile	Q1 20%, Q2 25%, Q3 25%, Q4 30%
Sales volume growth	15%/year after first year
Initial retail sale price	$260/unit
Retail price growth	210%/year after first year
Distributor and retail margin	40% combined
Discount rate	7%/year

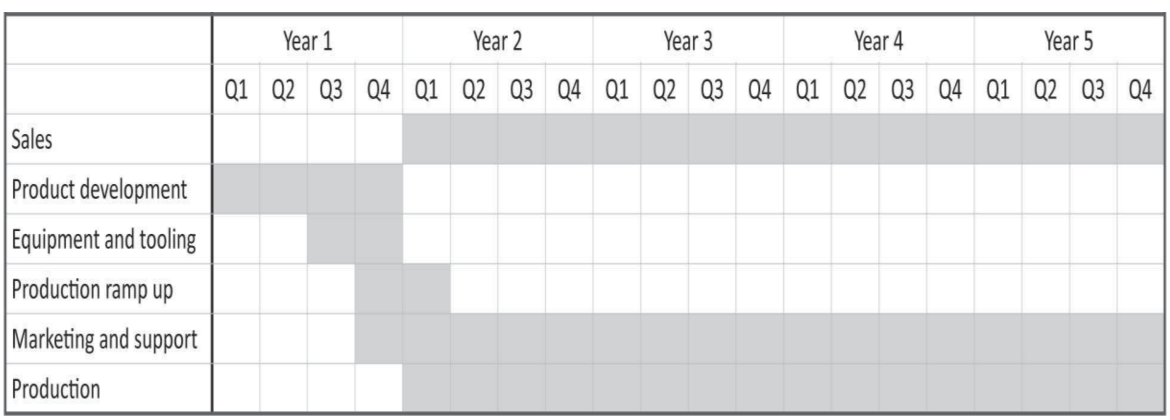


FIGURE 4.18 AB-100 project schedule from inception through production and sales.

Limitations of Quantitative Analysis

Base-case financial modeling and sensitivity analysis are powerful tools for supporting product development decisions, but these techniques have important limitations. One school of thought believes that rigorous financial analyses are required to bring discipline and control to the product development process; however, detractors argue that quantitative analysis suffers from some of the following problems:

- Analysis focuses only on measurable quantities. Quantitative techniques like NPV emphasize and rely on that which is measurable; however, many critical factors impacting product development projects are difficult to measure accurately. In effect, quantitative techniques encourage investment in measurable assets and discourage investment in intangible assets.
- Analysis depends on validity of assumptions and data. Product development teams may be given a false sense of security by the seemingly precise result of an NPV calculation; however, such precision in no way implies accuracy. We can develop a highly sophisticated financial model of a product development project that computes project NPV to the fifth decimal place, yet if the assumptions and data of our model are not correct, the value calculated will not be correct. Consider the AB-100 development time sensitivity example's assumption of a fixed product sales window. This assumption was useful, but its integrity can easily be questioned. Indeed, a different assumption could give dramatically different results.
- Teams can easily game the analysis. It has been said that one can achieve any NVP they like by tweaking the model values. This is certainly true. In the AB-100 example, changing the entire model parameters to the best-case or worst-case values would either triple the NPV or make it negative, respectively. This illustrates the necessity for both the team and its managers to understand the model in sufficient depth to challenge the underlying assumptions.

These concerns are generally quite valid; however, in our opinion, they are largely associated with naive application of the methods of the quantitative analysis or arise from the use of financial analysis within a poorly managed product development process. We reject the notion that quantitative analysis should not be done just because problems can arise from the blind application of the results. Rather, development teams should under- stand the strengths and limitations of the techniques and should be fully aware of how the models work and on what assumptions they are based. Furthermore, qualitative analysis, as discussed in the next section, can remedy some of the inherent weaknesses in the quantitative techniques.

No.	PART - A
1	Define DFM
2	List the steps in DFM process.
3	Give the main categories involved in DFM.
4	List the steps to reduce manufacturing cost.
5	Explain assembly cost briefly.
6	Define component cost.
7	List out the impact of overhead cost
8	Define fixed cost.
9	List the steps involved in reducing assembly cost.
10	Assess the different types of economic analysis.
11.	Interpret the steps involved in prototype design.
No.	PART - B
1	Explain the following, (i) Basic Principles used in prototype design. (ii) Prototyping technologies
2	Explain the steps in estimation of manufacturing cost.
3	Describe in detail the DFM process, with suitable example.
4	Explain the steps to reduce component and assembly cost.

SCHOOL OF MECHANICAL ENGINEERING

DEPARTMENT OF MECHANICAL ENGINEERING

UNIT – 5 – SMEA3009 – INDUSTRIAL DESIGN

NEED FOR INDUSTRIAL DESIGN

Industrial design is a process of design applied to products that are to be manufactured through techniques of mass production. Industrial design is also to create and execute design solution for problems of form, function, usability, physical ergonomics, marketing, brand development, and sales.

But why is industrial design important in today's era?

Everyone has his or her requirement and for the requirement to be satisfied, an Industrial Designer makes his way in. Industrial designers develop products guided by the special requirements of their client and manufacturer. They prepare clear and concise recommendations through drawings, models and descriptions. Industrial designers improve as well as create, and they often work within multi-disciplinary groups that include management, marketing, engineering and manufacturing specialists.

The market is flooded with similar products, and the only thing that differentiates one brand of a particular good from another is its design. While products have always served a function, they are more and more carrying meaning. It is the role of good product design to effectively communicate that meaning to the consumer. It is vital for businesses that want to do well to listen to and respond to the needs and desires of consumers, providing creative and innovative product design.

Growing Urbanization is another reason why Industrial Design is important. As the society develops, a need for products in a more fashionable way according to the current trends arises and Industrial Designing helps fulfill those needs. India is one of the countries where industrial designing is developing rapidly. Many design schools offer courses on industrial designing in India.

Industrial Design is a fast growing field in designing and holds a very important place in the industry.

Impact in design process

The design process has a number of elements to it and each must be followed in order to get a design which is both aesthetically pleasing to the client and practical in its use.

- On-site visit
- Client consultation (design brief)

- Concept design drawings
- Client amendments
- Full working drawings completed

The on-site visit is essential for large projects for the designer to get an accurate feel for the project. At this time aspects of the land are taken into account and noted, for example, any views that can be exploited, the slope of the block and the orientation of the site.

All these factors can have a major influence on the design of the project and need to be carefully considered during the planning stage. At this stage it is a good idea to organise a site survey (contour survey) and soil test, as these can take time to complete.

The client consultation is greatly focussed on the client design brief (and this forms part of the contract). Now, a design brief can be a detailed document or as simple as a couple of notes.

This all depends on the complexity and scope of the project. For example, the level of detail of a design brief for a deck is going to be quite considerably less than that of a new home. For the purpose of this article we will be focussing on the process for a new home.

The first process to go through when developing a design brief is to identify all family members who are going to reside in the residence and analyse their specific requirements both socially and physically. This pertains to their relative stage in life and what needs they may have now and in the future. Once this has been determined it is than possible to work out the spaces that are required:

Number of bedrooms and the relationship between them

What type of living spaces are needed (informal, formal, media room, kids retreat, etc.)

How the kitchen is going to link the living spaces

The number of wet areas (bathroom, ensuite, powder room, laundry)

The houses entry and exit points and how they relate to the rest of the house Size of garage and workshop (must accommodate cars, boats, toys)

The inclusion of storage (linen, store, attic)

The consideration of budget should also be a part of the design brief and a solid ‘ball park' figure should be determined by the client before any particulars of the design are discussed. There is nothing worse than getting your heart set on a particular aspect of the design and then finding out it exceeds your budget. A visit to your local bank is usually a good place to start when determining your budget limitations.

With a detailed design brief a concept drawing can be produced incorporating all the necessary elements and needs of the clients. The concept plan consists of a floor plan to scale, a basic site plan positioning the building and a front elevation showcasing the proposed front façade. It is at this stage the client has the opportunity to amend the plans and change certain aspects of the design.

The concept drawings are then amended and presented to the client for one more review. This time the design and layout of the residence is finalised and the process proceeds to the final stage of documentation.

Documentation

In the documentation phase the working drawings are completed by Impact Design and Drafting this includes; site plan, floor plan, elevations, section, bracing, tie-down and timber schedule. These plans are sufficient for council submission. However, additional plans which are available include; construction details, internal elevations, electrical plan, slab plan and details of design features. Depending what service level was chosen by the client these additional plans may be included in the package.

Once all the plans have been completed it is than time to look at sourcing some external consultants that will be required to successfully achieve a building approval. Some of these consultants include engineers, private certifiers, town planners and interior designers (not required for council approval). Once again depending on what service level the client has chosen we at Impact Design and Drafting can organise the consultants and obtain a building approval from your respective council.

At Impact Design and Drafting we have extensive knowledge and experience in developing client's ideas into a completed project and we enjoy the design process. Some clients come to us with their own designs and we are happy to tweak the designs and finish the project for them as well. Just remember designing your new home, renovation or addition is meant to be fun and enjoyable so let your creativity flow.

investigation of customer needs

An innovative product doesn't come from a law passed by the government. It also doesn't come from venture capitalists looking for a higher return on an investment.

Innovation comes from identifying customers' needs and providing solutions that meet those needs.

Companies like Uber, Airbnb, and Intuit understand this. Uber's success, for example, has come not from building new, better taxis, but from seeing — and then solving
— people's transportation problems.

Although you might not be working on the next Airbnb, Uber, or even a product you think is exciting, like business software, or temperature controls, understanding and identifying customer needs may lead to a revolutionary innovation. After all, Nest revolutionized the rather mundane industry of thermostats and changed how everyone heats and cools houses.

STARTING WITH EXISTING DATA

You most likely have existing data at your fingertips. Review past surveys, customer interviews, and customer-support call logs. There's no point in funding an extensive and expensive research campaign if the data you need is already collected.

Save the budget for data you don't have and more advanced questions you need answered.

INTERVIEWING STAKEHOLDERS

Why not begin with the data you don't have to pay for: the collective knowledge stakeholders have. Start with sales and support teams. They know the product and the customer. They often have a list of feature requests, bug reports, and enhancements straight from the customer's mouth.

Combine these to generate a preliminary list of requirements. Look for patterns, but don't automatically dismiss one-offs look to corroborate them with findings from other methods.

MAPPING THE CUSTOMER PROCESS

If you know your customer's process, map it out.

For example, before Uber, to get a ride you called a taxi company, waited to reach a dispatcher, waited for a car to be dispatched, hoped the driver would find you, and hoped you had enough cash when you reached your destination.

With Uber, you open your smartphone and summon the nearest car with one tap; you already know how far away the car is because you can see it in real time on a map.

The driver also sees your location so he or she can come right to you. The figure shows a simple process map comparing these experiences.

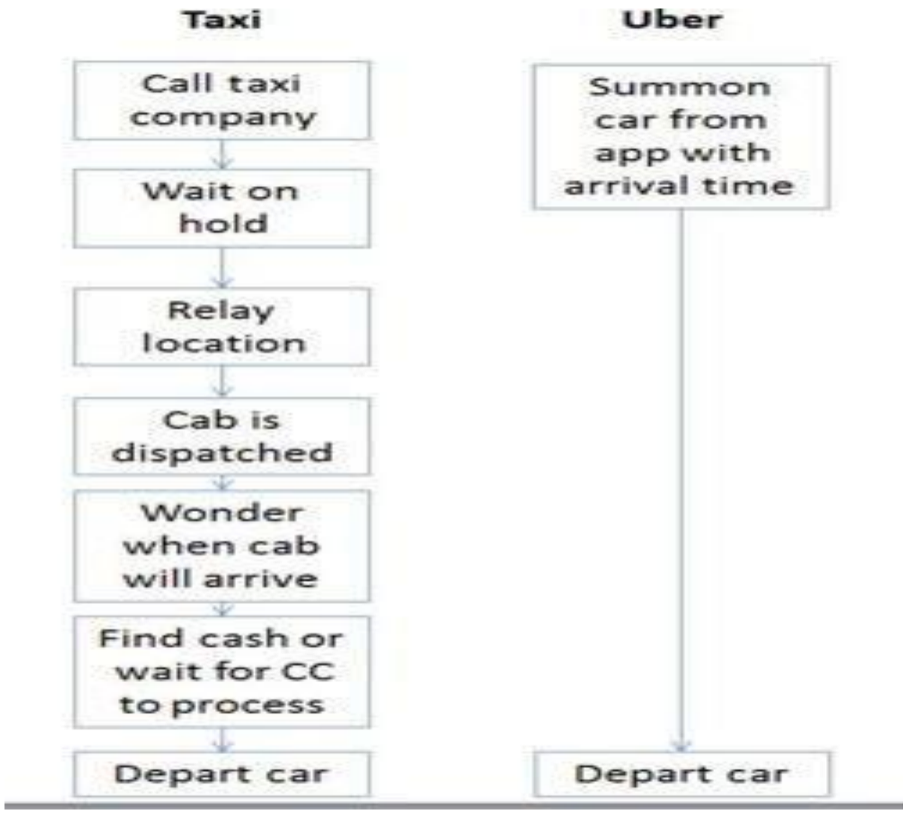


FIGURE 5.1. Process Map

MAPPING THE CUSTOMER JOURNEY

A customer journey map is a visualization of the process a customer goes through when engaging with a product or service. It takes process mapping to a new level by including multiple phases and touch points a person goes through from prospect to loyal customer. It's a document meant to unify fragmented efforts and identify points of friction and opportunities for improvement.

Finding and fixing the pain points in a customer's journey isn't just about damage control: It's also about the innovation that comes from fixing the pain.

CONDUCTING "FOLLOW ME HOME" RESEARCH

"Follow me home" research relies on observation by literally following a customer home or to work. You follow a customer to her workplace, spending the day watching her do her job. You observe process pain points and then look for opportunities for improvement.

For example, during a "follow me home" exercise, a team of researchers at Intuit noticed that retail customers were exporting their transactions from their point-of-sale cash registers into QuickBooks to manage their books. This step took time and sometimes led to failure and frustration. The innovative solution? Developers integrated QuickBooks into acash register and eliminated the export step for customers and created a new version called QuickBooks Point of Sale (POS).

INTERVIEWING CUSTOMERS

Go right to the source: Ask customers what problems they have and what features they want. Even when customers can't articulate their needs clearly, you can often gain insights that lead to successful innovations.

Use the "Five Whys" technique to help you discover what needs people don't even know they have, needs that no one has recognized before: Keep asking why until you get at the root cause of the problem and not a symptom. (It's called "Five Whys" because you often have to go through five levels before you get to the point where you can make a change that addresses the problem.)

CONDUCTING VOICE OF CUSTOMER SURVEYS

Voice of Customer surveys collect data, from email or from a pop-up on a website, about the attitudes and expectations of existing or prospective customers. Use a mix of open- and closed-ended questions to see what produces the most useful data.

Although customers aren't necessarily good at identifying their needs, this type of survey often yields data from which you can discern customer goals, challenges, problems, and attitudes, and then recommend opportunities for improvement.

ANALYZING YOUR COMPETITION

Consider using research firms that might present a more objective face to customers who engage with your organization and its competition. Consider using the SWOT rule: Identify your competitors' strengths, weaknesses, opportunities, and threats. You can use a SWOT for a brand, product, or even an experience.

Define the competition both narrowly and broadly. Don't just look at your competition in the same industry, but other industries as well.

ANALYZING CAUSE-AND-EFFECT RELATIONSHIPS

No one will disagree that it's usually good to think positively, but sometimes, negative thinking can solve problems more effectively. Through observations, surveys, and other data sources, you may find problems that are actually just symptoms of other root cause problems.

Task failures, errors, and long task times are usually the symptoms of multiple underlying problems. These can be problems in the interface or a disconnection with the user’s goals. Through the process of asking “Why?” multiple times and segmenting different causes, you can help identify and address root problems in the user experience.

RECORDING EXPERIENCES THROUGH DIARY STUDIES

Sometimes opportunities reveal themselves over time. One cost-effective longitudinal method is a diary study. Ask participants to record problems, frustrations, positive experiences, or thoughts at intervals throughout a day, week, or even a year. This can be low tech, with customers writing their experiences and thoughts down on paper and mailing it in, or high tech, in which you send text messages or emailed surveys to customers at particular intervals.

Because you’re asking your customer to do the data collection for you, be sure you have targeted questions and clear hypotheses you want to test with all the data that gets collected.

Expect a good percentage of customers to drop out or not be 100% diligent about filling out their diaries. Still, any information you can garner is better than no information at all. After all, you can’t fix what you don’t know about.

MANAGEMENT OF THE INDUSTRIAL DESIGN PROCESS

When launching new products, it is essential to progress through the product development stages quickly and efficiently, from initial concept through to finished product.

In this specialization, you will learn to effectively manage the product creation process and to communicate with a variety of target groups, both internal and external (i.e. clients and suppliers).

While the product development manager is not always directly involved in a product's design, he or she needs to be aware of various design techniques in order to successfully lead multi-disciplinary design teams. This may include generating a product development plan, drafting recommendations for the organization of a product’s development, organizing a feasibility study and optimizing a product’s life cycle.

TECHNOLOGY DRIVEN PRODUCTS

As innovation can take an infinite variety of forms, so its underlying insights can be derived from a great many different sources. Technology-driven innovation usually originates in scientific discoveries and in hundreds of years of accumulated technical know- how. These combined forces of science and technology drive ever greater specialization in the spheres of knowledge. When new technologies make the transition from the scientific domain to realization in technology, inventors and corporate R&D groups, companies compete to develop commercial applications.

In the early decades of industrialization the development of new technology was itself often a key source of competitive advantage. Consequently, companies invested heavily in R&D projects that produced new products in every sector of the economy. In some areas, this remains true today; pharmaceutical and bio-tech companies actively search for new genes, molecules and delivery systems; computer chip manufacturers are constantly refining the processes of design and manufacture in the endless pursuit of greater performance and smaller size; materials scientists in many fields are searching for higher performance and lower price, the twin hallmarks of innovation. Similar efforts characterize every other high-tech field.

Critical Success Factor

For companies that do not compete in the high tech sector, the development and deployment of technology is also a critical success factor, but here the role of technology is largely in operations, because technology is critical to every aspect of coordination, communication and management in today’s markets. For these companies (the vast majority), technology is completely embedded in how people work and improvements in technology applications can be a significant source of differentiation.

For example, FedEx relies on one of the largest and most sophisticated information technology operations in the U.S. to get packages to their destinations overnight, while allowing customers to track a shipment’s every step along the way. Similarly, supply chain management and automation at Wal-Mart was one of the company’s early competitive strengths and they remain so today. At major banks, millions of credit card transactions are processed each day; the pattern recognition software systems that search for fraud are run on massive computers that analyze terabyte-sized data files.

Technology Providers and Appliers

For companies that are heavy users of technologies that are not their end product, technology itself has nevertheless become a significant domain for innovation; technology- driven innovation, therefore, is central to their competitive position just as it is in high tech manufacturing. In this context, technology-driven innovation refers to the interplay between technology providers and technology appliers, and addresses the complex innovation dynamics that emerge when they work together to bring new capabilities into reality.

Discovering and deploying useful new technologies is a serious commitment for technology-driven innovation companies because of the competitive advantages that can be achieved. Managing the supply chain, managing millions of customer relationships or financial transactions, managing massively complex manufacturing sites are all critical functions that absolutely depend on technology. As technology advances new modes of operation have to be worked out, which calls forth a collaborative process of innovation between suppliers and users.

There is an ironic aspect to this – because technology is so pervasive, because access to it hardly varies from continent to continent and because its root purpose is almost always to increase efficiency, the acquisition and deployment of technology has itself become a force of commoditization. Commonly-available technology (including computers, communications gear, new materials and new methods) are all being applied globally to improve operations, to lower costs and lower prices, and to drive the process of commoditization deeper into all aspects of economic activity.

Generally, therefore, today's technologies drive commoditization in nearly every sector of the economy – unlike in the 19th and 20th centuries, when innovation in technology was a source of competitive differentiation.

There is one exception to this trend, and that is in the creation of knowledge and the use of knowledge in services, which is often a source of differentiation through forces such as personalization, customization, and the aggregation and re-purposing of data, information and knowledge. It is for this reason that many of the most innovative companies of the last two decades are business model innovators, companies that do not innovate in the development of technology, but rather in its application in services and distribution, companies like FedEx and Wal-Mart as well as Starbucks, Home Depot, Zara, Amazon and even Nike.

User driven products

What is user driven content?

User driven content is information that has been heavily influenced by the opinions, thoughts and ideas of individuals. The notion is that customers are no longer spectators but collaborative partners in business development. Today, customers are more empowered then ever as they actively initiate conversations, shape and manage the flow of data related to products and services across a wide range of communication channels. Gone are the days when the expert team of brand managers, marketers and product designers spend countless hours around the conference room table discussing ways to get inside the customer's head.

User driven content: Implications for business strategy. Customer-centric companies understand that the only way to develop good products is to incorporate customer feedback into every critical phase of the design and delivery process. Their design teams take advantage of early customer input or feedback to develop and test products faster and correct design flaws more efficiently. They also recognize that collecting quality user driven data, especially during the early phases, can increase sales, customer retention and brand loyalty. Finally, user driven product development increases bottom-line results by eliminating costly product redesigns and re- launches.

Create user driven products with OneDesk

OneDesk understands that only a well-structured cross-functional collaboration between departments will produce high value products. That is why includes easily customizable project management tools that put your entire company on the same page, so you can get organized and get the job done efficiently.

Equip your team with the right tools to gather useful data, listen to the ideas and concerns, and incorporate product suggestions from your customers. This will give your team a positive direction and empower them to produce products that will surprise and delight your customers.

INTEGRATING CAE, CAD, CAM TOOLS

Before we go on to the any of those activities, I first want to briefly describe what is normally referred to as computer aided design. In computer aided design we basically talk of integrating computer science techniques with or integrating computer science techniques for engineering design. What that means is any kind of use of computers in the design activity is referred to as computer aided design. This includes a wide variety of usage, this includes a wide variety of techniques that are used some are computer graphics techniques, some are simply using computer as programming tools. We will see what are the different activities that can come under these or what are the different computer science techniques or computer techniques which have been used under the design domain.

This use would include use of both hardware as well as software. When you are talking of hardware different kinds of hardware have been used in terms of the screens that you have, the input devices like I think you all familiar with the mouse. The other input devices maybe a ball or maybe a light pen, there are other output devices like plotters. So different kinds of hardware are relevant which are specifically meant for CAD activities. Different kinds of software which have been developed which are different kinds of modelling software we will be talking of that in detail.

Then if you talk of different numerical techniques, numerical methods, when I talk of numerical methods I include optimization, I even include the normal programming or instead of talking of automation we just program a particular activity where we are using the computer as a number crunching machine.

All those activities are what I include under numerical methods. They can include matrix multiplication or where very large matrices are involved, they can include solution of partial differential equations, they can include optimization techniques all these are what I cover under numerical methods.

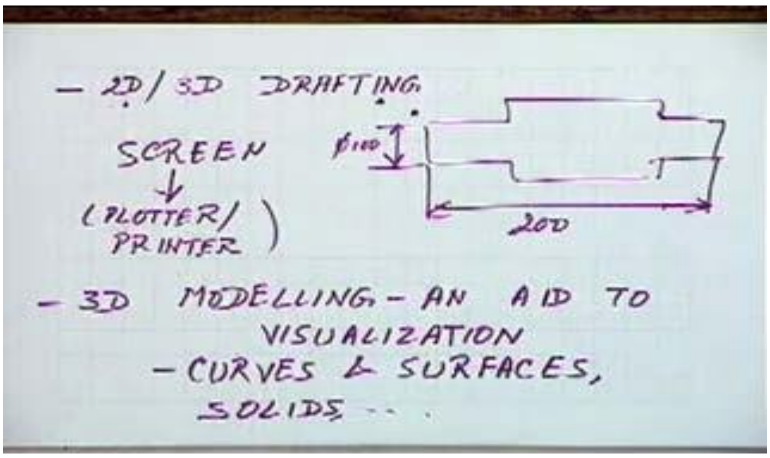


FIGURE 5.2 .Drafting

When you talk of CAD after numerical methods, the next thing that is normally including under CAD is what is referred to as drafting which is either 2 D or 3 D drafting.

When we say drafting

what we mean is the normal drawing work that is done. You have all done a course on engineering drawing. Whatever drawing you do on a drawing board, the same instead of doing it on the drawing board you do it on a computer that means if you have to draw lets take a very simple example if I want to draw the shaft and I want to give it a dimension something like this and maybe some length over here which is let’s say, if I want to give it a set of dimensions like this I can make a engineering drawing out of this on the drawing board. Instead of using the drawing board I can do the same thing on the computer using Auto CAD or using some other drafting package. This drawing consists of a set of lines that have been draw here, the set of arrow heads, the set of text that has been written and so on. In this each entity is a line or an arc if you are drawing or if you have an arc over here that will be an arc, so each entity is a line or an arc.

An entity is a not the complete shaft, we don’t have the concept of a shaft right now, we have just drawn a set of line in a set of arcs. This is what we mean by drafting. These lines can be 2 dimensional lines or they can be 3 dimensional lines but they are essentially lines and arcs. And we use these lines and arcs to make a complete figure on the computer. Once we make a complete figure on the screen, from the screen I can take a printout using maybe a plotter or a printer. So that is where CAD specific hardware comes into picture. We have specific hardware meant for plotting, we have specific hardware meant for printing. The screen will normally be a high resolution screen like a VGA monitor or something like that and the basic application is the drafting application that we were talking about. So this is 2 D or 3 D drafting.

The other kind of activities that are normally included in CAD is what we call as 3 D or even 2 D modelling. When you are taking of 3 D modelling, we essentially talk of representing this object. Now if we are talking of shaft over here, we are talking of representing this object as a three dimensional object. If we have it as a three dimensional object let’s take this pen, I took this example yesterday also. If I talk of this pen and I represent it as a three dimensional object on the computer, I can take views from any angle. If you are taking a front view you can take a front view like this, if you want to take a topview you can take a top view. If you want to take an isometric that is a view roughly at this angle or something like this, you can also get an isometric view. If you want to take sections, you can take sections. So you represent it as a 3 D model and then take different sections, different views, get the different views and then dimension them accordingly so this is what you mean by 3 D modelling. I will just show you some of the slides from these texts. Can you see it on the monitor?

FIGURE 5.3. 3 D model

Now in this you will find a complete scene which has been modeled on the computer. You see a dining table which has been set, different objects which have been placed. Now each of these objects has been modeled using some of these techniques. We were able to use this model to visualize what the table would look like. Here it's a flight simulator, we are able to use this model to see what the scene is like, what are the different objects there and so on, to see it from different angles and to get a feel of the actual situation. We can have some more examples.

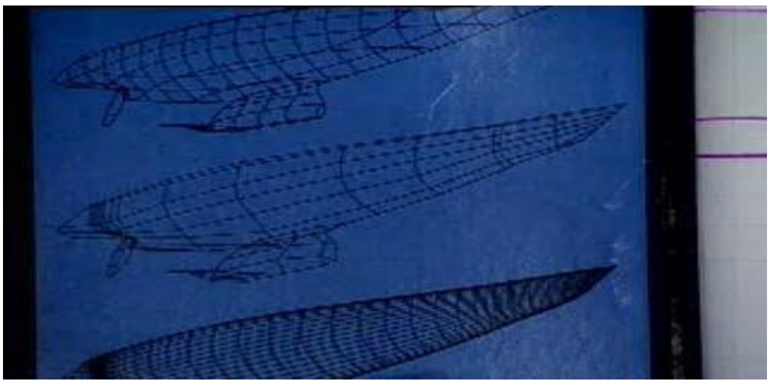


FIGURE 5.4 . Modeled using different techniques

These are objects of different shapes but modeled using different techniques. This model looks very different from the model that you have just saw. In this the surfaces have been modeled by a mesh of wires, it's a wire mesh kind of model, wire mesh kind of display that is being used but this is also a 3 D model, it's a 3 D modelling technique which has been used here. So the other CAD activity is 3 D modelling and this is a major part of what we mean by computer aided design. Often people refer to this as drafting as computer aided design

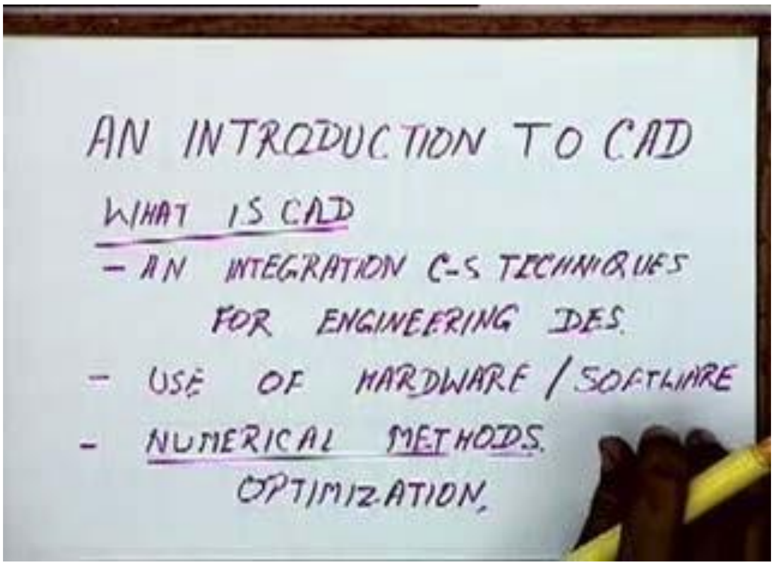


FIGURE 5.5.CAD

Some people even refer to just numerical methods also being computer aided design because even in numerical methods you are using the computer as an aid for designing but the major part this activity of computer aided design comes under this realm of 3 d modelling. When you are talking of modelling, it is an essentially an aid to visualization. You want to visualize the object from different angles see different corners, see whether different parts are interfering or not that is what we mean by an aid to visualization. So modelling, we use as an aid to visualization then when you talking of modelling, we are trying to model the different curves and surfaces.

If you are modelling a complete solid, you also have to model the curves and surfaces that come on it. For example in this object you are seeing the surfaces which form this solid. If you want to represent this solid, we also have to represent the curves and surfaces which from a part of the solid. So when we talking of 3 D modelling it is not just representing the solid as such, you also have to represent the curves and surfaces which constitute that solid or which define that solid. So under 3 D modeling, we represent curves, surfaces, solids and so on, all this comes under 3 D modeling.

Now once we have represented a 3 D model, the next question that comes up is that what do we do with the 3 model. one we have already said we will use it for visualization, you want to visualize the object on the screen, it will help us give a feel of the situation and we will able to see whether different parts are interfering, whether the particular part in motion is interfering with something else or not and such things. So one use is visualization but another very important use of these CAD models is in analysis. Once we have the model of a particular object, we should be able to analyze it for the different forces that are acting on it the different forces, the different displacements that the object will be going through and so on.

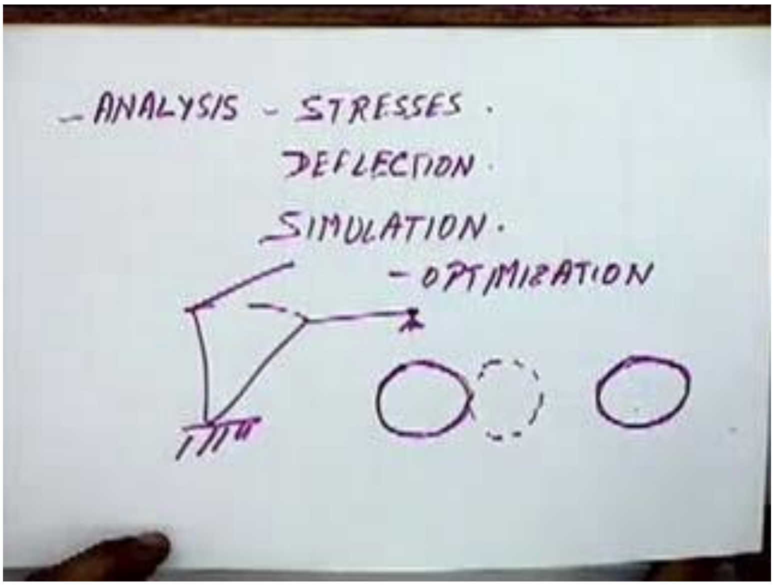


FIGURE.5.6. analysis for stresses

Now this analysis can be analysis for stresses, you can analyze it for deflections. We can also when we are talking of analysis we can actually simulate the objects in actual use that means by simulation what we mean is let's say if we have a simple mechanism like this maybe it's a part of a robot arm or something like that with some maybe gripper attached to here. Now this roboarm is moving in space, from this position maybe it goes to some position like this, the path that I take this link rotates like this along with that this link is also rotating simultaneously. We want to be able to visualize how this object, how this mechanism would move in actual space. So we want to simulate its motion and then actually animate it on the screen and see how the motion will take place. So that is what we mean by simulation, we want to simulate the motion of an object. In very important application of this kind of analysis is let's say if we have one object, this object can be very complex object maybe car or a bus and we have another object which is maybe another car or maybe a two wheeler or something like that, they meet in a head on collision.

Once they will collide there will be some deformations, there will some forces on the passengers, there will be some stresses on them, stresses on the different parts of the body so we want to estimate, we want to see what will happen in the crash that is crash simulation that is also another type of analysis. All that can be done if we have a model of each of these objects, if we have some representation for this object, some representation for this object, if we have some representation for this set of links for this robo and so on. So all this comes under computer aided design.

We are using the computer as a tool for designing each of these objects and we essentially modelling these objects first then using it for analysis using special tools for each of these kinds of analysis. And of course in another analysis, we have already mentioned optimization. If we have the model of an object, we can use it for optimization, we can use it for optimizing the size or weight and so on for different criteria. So the model that is created that model can be used for any of these activities.Other than analysis an important application of these CAD models is applications of CAD models are in the areas of what we call as CAD CAM integration. In CAD CAM integration essentially we are talking of let's say this is an initial stage what we call as CAD where we are developing the model, we are analyzing the model and finally designing a particular object then we have the manufacturing stage. Within the manufacturing stage let's say we have a set of CNC machines, this object has to be manufactured on the CNC machine.For manufacturing this object on the CNC machine, for this CNC the CNC code has to be generated, has to be written down. This code will depend on the object that has been modeled; it will depend on the set of manufacturing steps that have to be carried on. If we have the model for an object, we can use that model to generate this code and to get an interface, to have automatic interface between CAD and CAM that means directly by a CAD model let's say if we are talking of a shaft, if this shaft is represented internally in a proper manner then from this representation of this shaft, from the model of this shaft we can directly get the NC code that will be required to make it. We will be able to generate a process plan, between CAD and CAM we will have a stage called what is to referred to as computer aided process planning. For making a process plan for this, the CAD model that has been made that will form the input for that. So CAD models will form an input for computer aided process plan and will also be used for generating the NC code.In case if we are talking of an integrated manufacturing environment, in the integrated manufacturing environment, this CAD CAM integration plays a very vital role. So under the applications this CAD CAM interface and of course computer aided process plan, these form a very major application for the CAD models. In fact there is a whole area which is normally referred to as CIM computer integrated manufacturing. It refers to CAD, it refers to the process plan that is being generated and it refers to the manufacturing stage. This complete stage, this complete cycle comes as a part of CIM computer integrated manufacturing. There are other aspects also to CIM, we won’t get into that but the CAD model that has been created forms the basic links for each of these stages in CIM. If you talking of an integrated manufacturing environment, the CAD model is the starting point.

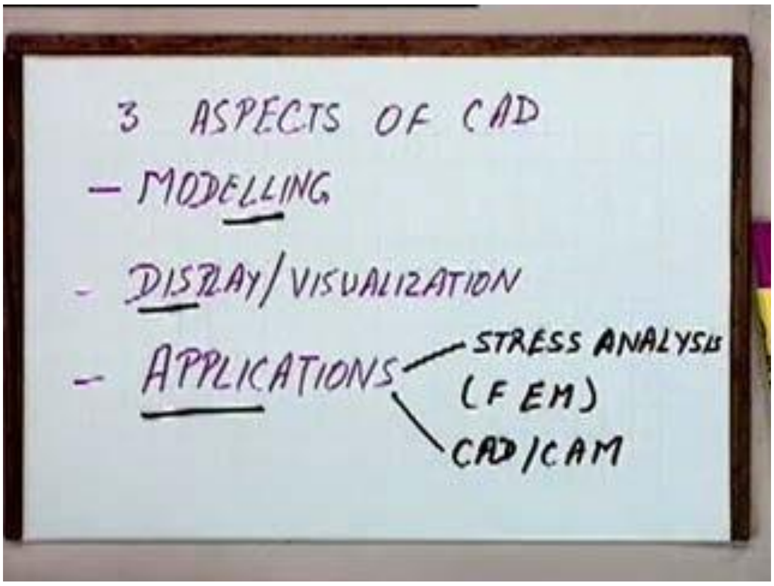


FIGURE 5.7. Three aspects of CAD

So if we summarize from this the three important aspects, the first important aspect is what we refer to as modelling. The second is what we refer to as the display or visualization. You have modelled an object, you want to display it, we want visualize it and the third is what we refer to as applications.

The applications would be CAD CAM applications, stress analysis applications, CAD simulation applications and so on. In addition to these we have also mentioned numerical methods as an important part of CAD. Quite often CAD is referred to as numerical methods and optimization but as a part of this course, we will not be touching upon this part. In this course we will essentially be talking of computer aided design as starting from a CAD model, we will be talking of modelling and its applications. We will not be going into numerical methods optimization and other such techniques. This course is going to talk mainly of computer aided design as consisting of modeling, as consisting of its use and display and applications. The applications or the main application that will be talking of would be stress analysis and we will be talking of the finite element method and the other application would be CAD CAM integration which we might touch upon. So these are the three different aspects of CAD which we will be touching upon as a part of this course. We will briefly see what are the different activities that come under each of these three.

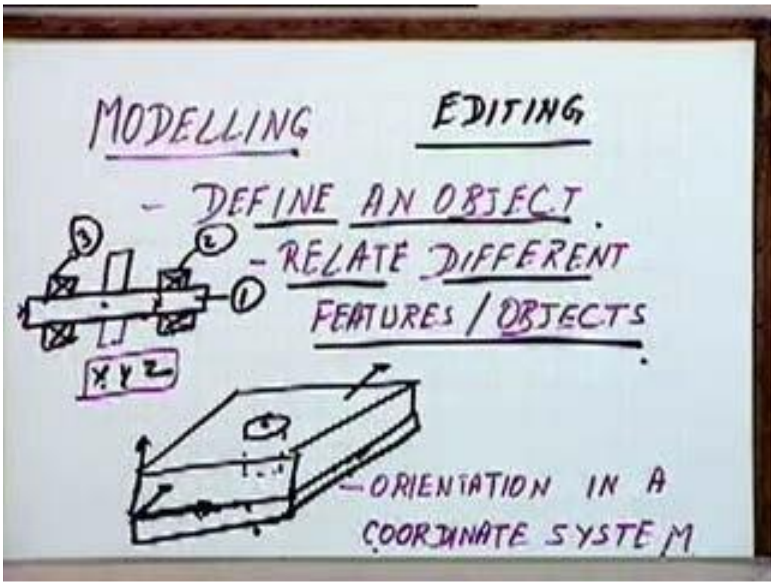


FIGURE 5.8.Modelling

So when we are talking of modelling, under modelling the first thing that we want to do is to define an object. We take a simple object, we want to define it on the computer, we want to define it using some modelling techniques. The first thing that modelling deals with is how to define an object, that is going to be the first important part of modelling. When we are talking of defining an object, we were essentially saying that we want to relate the different features; I will just the different features of an object relate different features or relate different objects.

For instance if you consider this shaft, now this shaft is supported on a set of bearings. When you want to model this complete system, we have to define this shaft as one object, this bearing as the second object and this bearing maybe as a third object and in addition to that there might be some mountings on it maybe there is a gear here or a chain and sprocket here or something like that and something else connected on the other end, so there might be different objects connected on them. When we you are modelling this complete scenario, each of these objects would first be defined.

Then we have to define the relationship between these objects that means this shaft is next to this bearing and is touching it on this surface. So let's say if for this object we are defining this as an origin and for this bearing maybe we are taking this as the origin for this bearing. We will like to define that this bearing is located at a particular xyz value with respect to this origin so that defines a relationship between this bearing and this shaft. This relationship is a geometric relationship with respect to adjacency, with respect to which object is next to the other object and so on. It defines the geometric location of the two objects with respect to one another.

Similarly if you are talking of this mounting which can be a let's say chain and sprocket or a gear, we will have to define this sprocket whose origin is here is at a certain location with respect to this point. This is what we mean by we have to relate different objects; we have to relate them with respect to one another. Relate different features let's say if you are talking of a simple block like this, on this block let's say we have a through hole, this hole is a feature on this block. We will have to relate that this block let's say whose origin is at this location, this is the origin this hole this feature is at a particular orientation with respect to this origin at a particular distance.

This hole is at let's say this face, on the top face. This hole is a vertical hole and is a through hole. All this information has to be available when you are talking of defining this objects that is what you mean when you say relate different features. This hole is one feature, this top face of this object is the second feature, you have to relate the two together saying that this face is next to this hole.

The basic idea that I want to convey right now is that when you are trying to relate the different feature and objects, a lot of information has to be stored in that model. So when you are talking of modelling that includes a lot of information, is not just defining this object as maybe a block, a lot of information goes into it. So unless we are able to relate these features, we will not be able to use this object in any situation.

Unless I know that this hole is at the so and so location is a vertical whole and is a through hole, unless I known all this I cannot get the manufacturing sequence for it. For finding of the manufacturing sequence for making a hole, I need to know the location I need to know the direction of the hole and I need to know how deep it is. So unless all that is known to me, I will not be able to use this model for any realistic propose that is why we say that when we are talking of defining an object, we have to relate different features of the

object. And another thing related to this that I have already mentioned is that we have to talk of orientation in a coordinate system.

We define a coordinate system that let's say this is the origin for the shaft, this is the origin for the bearing, the two are or this origin is at a location xyz with respect to this origin, all that is with respect to a particular coordinate system. So whenever we are talking of modelling you are doing that with respect to a particular coordinate system, you have to define a coordinate system and give all our dimensions with respect to that system. And then once a model has been made in any say design situation, the model will never be static, meaning that the model will change from time to time.

I have made this model but then I find you know the thickness of this plate is too small, so now I want to increase the thickness so I want to go and make a change. The moment I want to make any change that means let's say I want to change the thickness. In this figure I will have to increase this size, this size, make this change, this change and rub out all these. If I am doing on the drawing board I will have to make all these changes.

So when I am talking of making these changes, we refer to this process as a process of editing, editing an existing model or making changes in an existing model.

So once a model is available then we talk of what I refer to as display or visualization aids. When you are talking of display, we are talking of displaying model

objects. When you are talking of displaying the model objects what we basically want to do, if this object we want to map it onto screen coordinates. That means if you have a simple block like this the block let's say for this block I am taking this as the origin, the width is maybe 500, height is 400 and the depth is maybe 300.

If I am taking a particular view in which maybe let's say an isometric view something like this. Now this view has to be drawn on the screen. So, on the screen the orientation of the location of each of these points has to be defined. So on this screen if I am taking this as my 0 0, I have to decide this 0 0 0 over here has to map to which point on this screen. That means every point of this block has to be mapped down to a screen location that is what we mean by mapping onto screen coordinates.

If I am able to map every point on this block then I can draw the object on the screen. So when we are talking of displaying a visualization of that object, we are basically talking of taking the model object, for each and every point we find a corresponding point under screen coordinates that is what you mean by display. In this display if we have surfaces then these surface might have to be shaded.

If I have a simple cylinder like this, for an engineering view of this cylinder I need not bother, I can just take a front view and a top view and make my three orthographic views but for visualization I might like to get a shaded view. If I am taking a shaded view it will look something like this depending on where the light is placed. So when you are talking of displaying I should be able to take any object and display it on the screen, show it on the screen depending on what is the location of my light source, what is the nature of the surface whether it reflects a lot of light or whether it is a diffusing kind of surface and so on.

So when you are displaying surfaces, we will talk of issues like shading and we will talk of what is referred to as hidden surface removal.

If I am trying to make a view of a simple block, I am displaying all the surfaces this is what the view would look like. And it is easy to see that this view is confusing, it is not easy to make out which surface is in the front which surface is at the back. I can't make out whether this surface is in front or whether this surface is in front. So normally we like to remove the hidden surfaces, the surfaces at the back which are not visible, the edges which are not visible we like to remove those lines and edges. So instead of drawing it like this, we like to draw it just like this. This should improve the clarity of the presentation, it will help in visualization.

So when we are talking of display, we like to remove hidden lines. This is normally referred to as hidden line removal or hidden surface removal. Then when we are talking of display, we will also like to talk of projections. If I take an orthographic view or a front view, simple front view of this object, I will get a rectangle. If I take an isometric view, I will get a view which would be something like this. If I take maybe perspective view, I will get a view which would be something like this.

If I have modelled this object that is if I have given the geometric description of each of the surfaces and each of the edges, if all that information is available with the computer I should be able to generate any of these views depending on the direction from which I am looking, depending on my specifications given. I should be able to do these projections. We will be seeing methods for each of these tasks. We will see how projections can be obtained, we will see how hidden surfaces can be removed, we will see how simple display of lines and curves can be done. We will also see how the shading can be done, all these techniques we will be covering as the part of this course.

So from all this we can conclude that if we are talking of modelling, modelling has different requirements. The first is that solids are modelled or have to be modelled by storing information of constituent surfaces. If I have any solid, I cannot represent the solid unless I am able to represent the surfaces because my different features will be on the surfaces. If I have a hole or if I have slot, if I have glove they will all be on the surfaces. So all my surfaces will play an important role in defining the solids, so we say that solids are modelled by storing information of constituent surfaces.

Similarly when we are talking of displaying surfaces, we will also have to talk of curves. If I have surface like this, I cannot represent this surface unless I am able to represent the edges of this surface. So if I am talking of surfaces, curves are also equally important. Then if I am representing or if I am storing information of with respect to surfaces and curves this would help us in firstly displaying these surfaces. Now this would help in displaying surfaces that means if I have to display any object, how do I display a solid? The only I can display the solid is by displaying all the boundary surfaces. In the simple example when I am trying to display this solid, what I am basically doing is I am displaying each of these surfaces one after another, so I cannot display a solid unless I am able to display the surfaces. So storing information of constituent surfaces is going to help us in displaying the surfaces. It will also help us in computing solid properties.What we mean by solid properties? For this object, if I want to find out the weight of this object or if I want to find out the volume of this object, the moment of inertia of this object I should be able to do that. I cannot do that unless I know what are the bounding surfaces. If I know the bounding surfaces I can find out the weight, I can find the moment of inertia and so on. So this information is going to be important in computing the solid properties. Then I have already mentioned that solids are modelled by storing information surfaces and surfaces will be modelled by storing the information on the curves. So this relationship between solids and curves is well represented by this diagram.

Essentially what it says is if you want to represent any volume, a volume is delimited by or is bounded by a set of surfaces. Surfaces can be either plane surfaces that is planes or they can be warped surfaces, warped surfaces or curved surfaces. Whether they are plane surfaces or whether they are warped surfaces, their boundary will be different kinds of curves. So if you have a curve can be a boundary for a warped surface or it can be a boundary of a plane surface. We can also have a family of curves which define a surface, a network of curves or a set of curves which define a surface.For instance if we take a set of curves like this, we say this is an family of curves. One set of maybe cubic curves in one direction, another set of cubic curves in the second direction and this defines a surface patch. So we can have a network of curves or we can have patches which can define a warped surface or which can define a three dimensional surface. A curve can consist of a set of curve segments. What you mean by a set of curve segments? We have a curve from one point to a second point then we have a different kind of curve from this point to the next point and in another kind of curve from here to here and so on. So a curve can consist of a set of curve segments like this, so curves can consist of a set of curve segments and curve segments would be defined by end points, end points or the geometric properties.

So if you want to represent a solid or volume, this solid or volume will be represented by surfaces which are represented by curves which are in turn represented by curve segments which consist of points. If we have to describe solid modelling techniques, we cannot describe them unless you have some idea of how to represent curves and surfaces. The basic method of representing any solid is always going to have methods of representing curves and surfaces embedded in it. So the basic idea is that when we talk of modelling surfaces or modelling solids before that we will be talking of curves and surfaces and their modelling techniques. So in this course we will first talk of different methods of, when we talk of modelling we will first be talking of different methods of representing curves, different methods of representing surfaces and then we will talk of different methods of representing solids. You defined curve segments being definedby end points. That is to say curves may essentially lines.

I am glad to you have put that question. Actually instead of end points I should have said control points that is the better way of saying that. If we have a curve starting from this point, ending at this point, here if I just specify two points, I can only have a straight line between them but if I have a set of control points, I can have a set of points here. This is the set of control points which define this curve then I can have a curve either a cubic curve or a higher degree polynomial curve depending on the modelling technique I am using. If I am using five points or if I am using ten points, I will have a curve of the corresponding degree. So the curve will be modelled not just by the end points but by a set of control points or if I am just giving the end points and also be specifying something in addition to that maybe the direction of the tangent over here or some such related information. Maybe I will specify the direction of the tangents plus I will specify that this is the second degree curve then maybe end point, just end point would be sufficient.

But the basic idea in this figure is that if I have to represent a curve segment, I cannot do that without storing the relevant points in line. The relevant points will be the set of control points including end points, including some other information in terms of tangents and so on. So here it won't just be the end point or the start point and the end point but it will be also be a set of control points which will be important for every curve.

What Is Robust Design?

We define a robust product (or process) as one that performs as intended even under non ideal conditions such as manufacturing process variations or a range of operating situations. We use the term noise to describe uncontrolled variations that may affect performance, and we say that a quality product should be robust to noise factors.

Robust design is the product development activity of improving the desired performance of the product while minimizing the effects of noise. In robust design we use experiments and data analysis to identify robust set points for the design parameters we can control. A robust set point is a combination of design parameter values for which the product performance is as desired under a range of operating conditions and manufacturing variations.

Conceptually, robust design is simple to understand. For a given performance target (safely restraining rear-seat passengers, for example), there may be many combinations of parameter values that will yield the desired result; however, some of these combinations are more sensitive to uncontrollable variation than others. Because the product will likely operate in the presence of various noise factors, we would like to choose the combination of parameter values that is least sensitive to uncontrollable variation. The robust design process uses an experimental approach to finding these robust set points. To understand the concept of robust set points, consider two hypothetical factors affecting some measure of seat belt performance, as shown. Assume that factor A has a linear effect, fA, on performance and factor B has a nonlinear effect, fB. Further consider that we can choose set points for each factor: A1 or A2 for factor A, and B1 or B2 for factor B. Assuming that the effects of fA and fB are additive, a combination of A1 and B2 will provide approximately the same level of overall performance as a combination of A2 and B1. Manu- fracturing variations will be present at any chosen set point, so that the actual value may not be exactly as specified. By choosing the value of B1 for factor B, where the sensitivity of the response to factor B is relatively small, unintended variation in factor B has a relatively small influence on overall product performance; therefore, the choice of B1 and A2 is a more robust combination of set points than the combination of B2 and A1.The robust design process can be used at several stages of the product development process. As with most product development issues, the earlier that robustness can be considered in the product development process, the better the robustness results can be. Robust design experiments can be used within the concept development phase as a way. To refine the specifications and set realistic performance targets. While it is beneficial to consider product robustness as early as the concept stage, experiments for robust design are used most frequently during the detail-design phase as a way to ensure the desired product performance under a variety of conditions. In detail design, the robust design activity is also known as parameter design, as this is a matter of choosing the right set- points for the design parameters under our control. These include the product's materials, dimensions, tolerances, manufacturing processes, and operating instructions. For many engineering design problems, equations based on fundamental physical principles can be solved for robust parameter choices; however, engineers generally cannot fully model the kinds of uncertainties, variations, and noise factors that arise under real conditions. Furthermore, the ability to develop accurate mathematical models is limited for many engineering problems. For example, consider the difficulty of accurately modeling the seat belt submarining problem under a wide variety of conditions. In such situations, empirical investigation through designed experiments is necessary. Such experiments can be used to directly support decision making and can also be used to improve the accuracy of mathematical models. In the case of the seat belt design problem, Ford's engineers wished to test a range of seat belt design parameters and collision conditions; however, crash testing is very expensive, so Ford worked with its seat belt supplier to develop a simulation model, which was calibrated using experimental crash data. Considering the hundreds of possible design parameter combinations, collision conditions, and other factors of interest, the engineers chose to explore the simulation model using a carefully planned experiment. Although simulation requires a great deal of computational effort, the simulation model still al- lowed Ford engineers to run dozens of experiments under a wide variety of conditions, which would not have been possible using physical crash testing

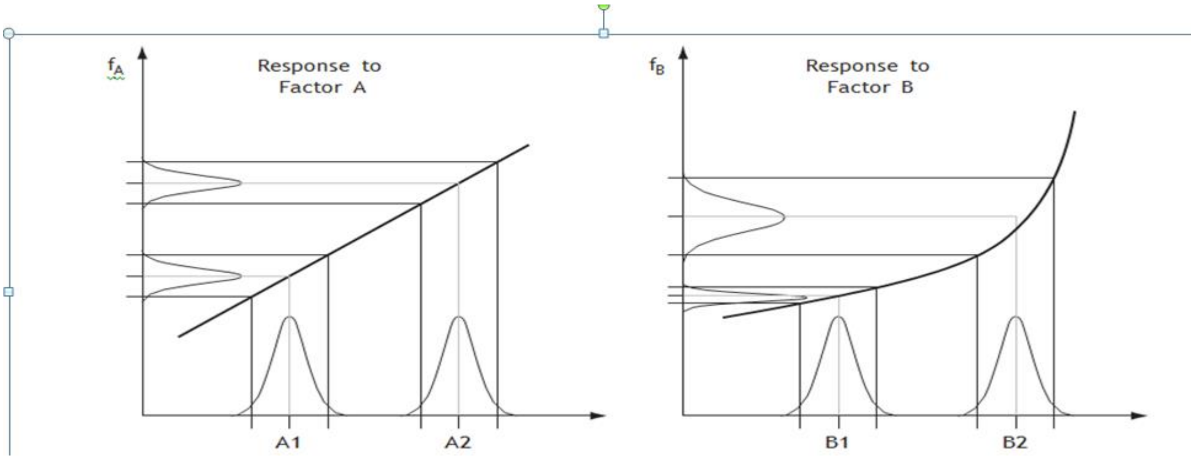


FIGURE.5.9.Robust design exploits nonlinear relationship to identify set points where the product performance is less sensitive to variations

UNIT V

INDUSTRIAL DESIGN

S.No.	PART - A
1	What is the need for Industrial design?
2	What is an investigation of customer needs?
3	Define Conceptualization in Product Design.
4	Define Refinement in Industrial Design.
5	What do you mean by technology driven products?
6	Define Computer Aided Engineering (CAE)
7	Define Computer Aided Design (CAD)
8	Define Computer Aided Manufacturing(CAM).
9	How Industrial design will provide impact in the product design process?
10	What is the management of industrial design process?

S.No.	PART - B
1	Give short notes on, (i) Robust design (ii) Simulation of product performance.
2	Explain the steps in Industrial design process.
3	Explain the Investigation of customer needs in Industrial design.
4	Compare the assessment of Industrial Design quality with continuous quality control systems.
5	Explain the need for CAE/CAD/CAM in Industrial design, using suitable illustrations.