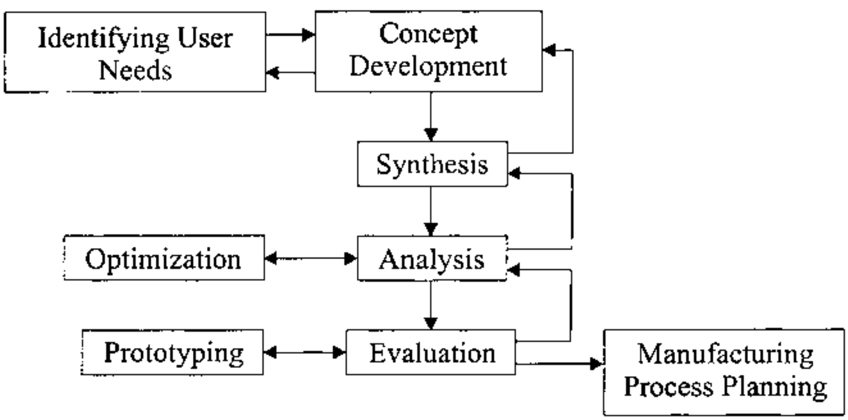
Part I

Engineering Design

The Accreditation Board for Engineering and Technology (ABET)* defines engineering design as "the process of devising a system, component or process to meet desired needs." ABET emphasizes that design is an iterative decision-making process, in which natural sciences, mathematics, and applied sciences (engineering) are applied to meet a stated objective in an optimal manner. The schematic of this process is as follows:



* Accreditation Board for Engineering and Technology, Inc. http://www.abet.org. Baltimore, MD, 2001.

One can rightfully argue that design is not such a neat sequential process as is shown in the figure. Today, product development teams have multidisciplinary members, who concurrently work on several aspects of design without being totally restricted by any sequential approach. Thus our focus in this Part I will be on concurrent design and engineering analysis.

In Chap. 2, conceptual design is discussed as the first step in the engineering design process. Customer-needs evaluation, concept development (including industrial design), and identification of a viable product architecture are the three primary phases of this stage of design. Several engineering design methodologies are discussed in Chap. 3 as common techniques utilized in the synthesis stage of the design process. They include the axiomatic design methodology developed by N. Suh (M.I.T.), the Taguchi method for parameter design, as well as the group-technology (GT)-based approach, originally developed in Europe in the first half of the 20th century, for efficient engineering data management.

In Chapter 4, computer-aided solid modeling techniques such as constructive solid geometry and boundary representation methods, are presented as necessary tools for downstream engineering analysis applications. Feature-based computer-aided design is also discussed in this chapter. In Chap. 5, the focus is on the computer-aided engineering (CAE) analysis and prototyping of products in "virtual space." Finite-element analysis is highlighted in this context. Parameter optimization is also discussed for choosing the "best" design.

2

Conceptual Design

Engineering design starts with a need directly communicated by the customer or with an innovative idea developed by a research team that would lead to an incremental improvement on the state of the art, or to a totally new product. One can, naturally, claim that there have been only a very few inventions in the 20th century and that most products have been incrementally innovated. The Walkman by Sony certainly falls into this second category, while the telephone can be classified as one of the true inventions. In this chapter, the emphasis is on the first stage of the engineering design process, namely development of viable concepts.

2.1 CONCURRENT ENGINEERING

The need for accelerated product launch in the face of significantly shortened product life cycles, especially in the communications and computing industries, has forced today's manufacturing companies to assemble multidisciplinary product design teams and ask them for concurrent input into the design process. In 1987, a U.S. Defense Advanced Research Projects Agency (DARPA) working group proposed the following definition: "Concurrent Engineering (CE) is a systematic approach to the integrated (concurrent) design of products and their manufacturing and support process." The product development team must consider all elements of the product life-cycle from the outset, including safety, quality, cost, and disposal (Fig. 1). Boeing was one of the first large manufacturing companies to utilize CE in their development of the Boeing 777, widely utilizing computer-aided design and engineering (CAD/CAE) tools for this purpose.

It has been advocated that CE could benefit from moving away from a function-based manufacturing structure toward a team-based approach. Lately, however, companies have been adopting a hybrid approach: they maintain product-based business units as well as function units that comprise highly skilled people who work (and help) across product business units. In this context, CE-based companies (1) use CAD/CAE tools for analysis of design concepts and their effective communication to others, (2) employ people with specialties but who can work in team environments, (3) allow teams to have wide memberships but also a high degree of autonomy, (4) encourage their teams to follow structured and disciplined (but parallel) design processes, and finally (5) review the progress of designs via milestones, deliverables, and cost.

The following partial list of concurrent design guidelines will be addressed in more detail in Chap. 3, where different product design methodologies are presented.

> The conceptual design phase should receive input from individuals with diverse (but complementary) backgrounds.

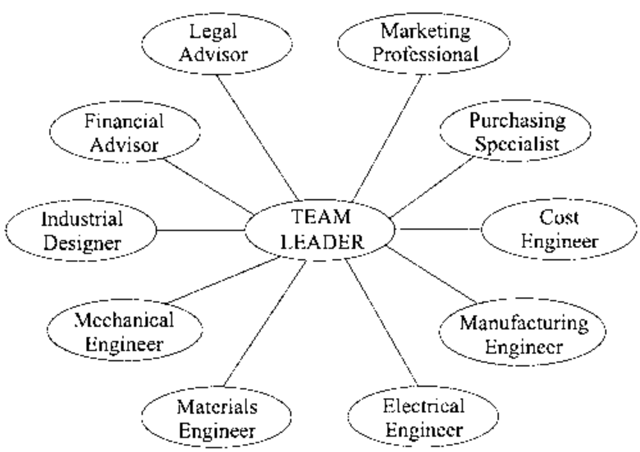


FIGURE 1 Example of structure of product development team.

Irreversible decisions should be delayed as much as possible, if they cannot altogether be avoided.

Designs should allow "continuous improvement" based on potential future feedback.

Product features should be analyzed with respect to manufacturability, assembly, and human factors.

Product modularity, standardization, and interchangeability should be maximized where profitable.

Product parameters should be designed in anticipation of imperfect use—"design for robustness."

Production processes should be finalized concurrently with product design selection.

Production plans and capacities should be in sync with marketing efforts and aim for short lead times (for delivery).

2.2 CONCEPT DEVELOPMENT PROCESS

Conceptual design encompasses many activities carried out by people with a variety of backgrounds with the ultimate objective of a profitable product launch. Industrial designers and human-factor engineers are normally involved at this stage of (conceptual) design and preliminary prototyping in order to provide timely input to the product design team. The first step in this process is customer-need identification and the second is concept generation and selection.

The process of customer-need identification must be carried without attempting to develop product specifications. The latter can only be decided upon once a concept is chosen and preliminarily tested to be technologically feasible and economically viable. Gathering useful data from the customer may include interviews with a select (representative) group in order to identify all their requirements, preferably in a ranked order. Naturally, need identification is an iterative process that involves returning to the "focus group" with more questions following the analysis of earlier collected data.

Concept generation follows the step of customer-need identification and development of some functional (target) specifications based on the experience and know-how of the product design team members. As will be discussed in Chap. 3, it is expected that the team will follow one (or a mixture) of the design methodologies developed in the past three decades in order to decompose the problem into its manageable parts and provide decoupled solutions. Assuming that the product design problem at hand is an incremental-innovation type, the team members are expected to search through existing similar products, technologies, and tools for "clues." At this stage, it is natural to develop (in an unrestricted way) as many concepts as possible and not dismiss any ideas—"brainstorming." This stage can be concluded, however, with a methodical review of all data/ideas/proposals in order to narrow the field of options to a few conceptual design alternatives. Figure 2 shows two alternative scooter designs patented in the U.S.A., Patents US D438,911 S and US D433,718.

The final "winning" concept selection process is a critical stage in product design and does not necessarily imply the rejection of all in favor of one. This stage seeks a wider input from manufacturing engineers and (future) product-support group members in order to rank all proposals (or even subsystems within each proposal). Preliminary prototyping (physical or virtual) may be necessary in order to consult with potential customers and evaluate usability (or even quality) of the selected product design concept.

As discussed in Chap. 1, the multinational manufacturing company of the future will need to develop and design products for global markets. Several key issues will have to be addressed in this respect: industrial designs for different domestic markets and cultures, ergonomic designs for different populations and segments of these populations, and utilization of modular design concepts for remaining competitive in several domestic markets.

2.3 INDUSTRIAL DESIGN

The Industrial Designers Society of America (IDSA) defines industrial design as "the professional service of creating and developing concepts and specifications that optimize the function, value and appearance of products and systems for the mutual benefit of both user and manufacturer." The following objectives have been commonly accepted by the industrial design community:

Appearance: The form, styling and colors of the product must convey a pleasing feeling to the user.

Human factors: The ergonomic and human-interface design of the product should facilitate its utilization in a safe manner.

Maintenance: Design features should not hinder maintenance and repair.

Other important factors include minimization of manufacturing costs through the utilization of appropriate materials and easy-to-produce form features. Most companies would also prefer to convey a corporate identity that is easily recognizable by the customer, through the product's design.

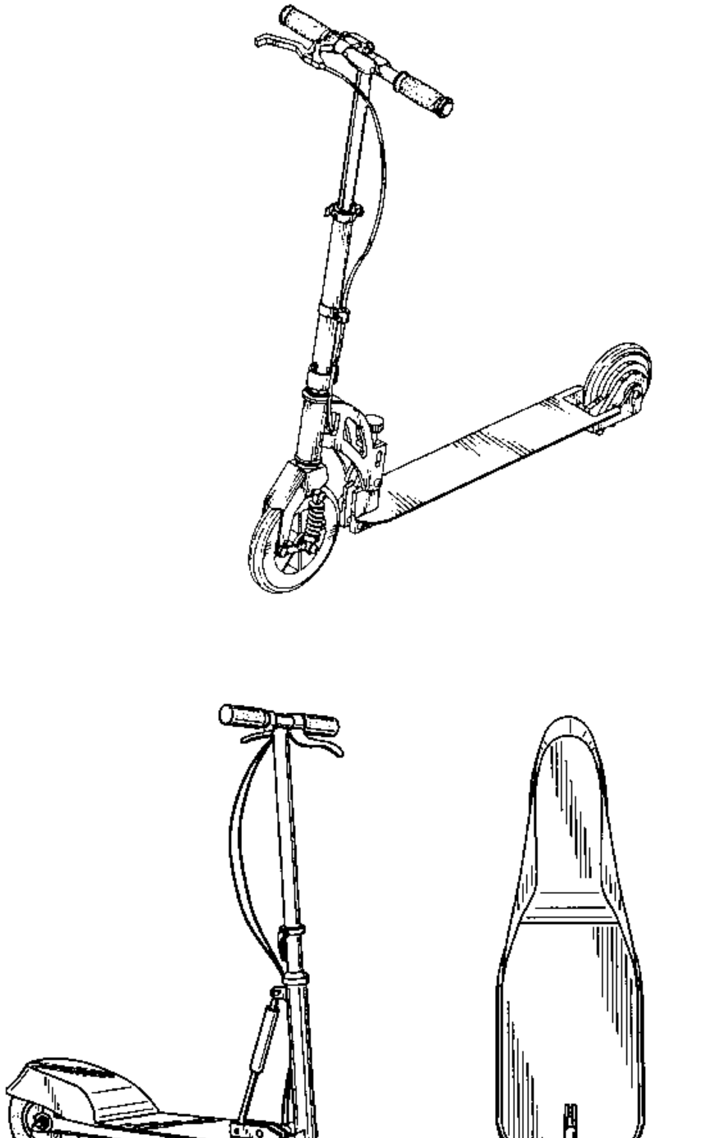


FIGURE 2 Scooter designs.

2.3.1 Industrial Design History

The beginnings of industrial design can be traced to the start of the mass production of household items (especially automobiles) in the early 1900s. While most European designers of the time were drawn from the ranks of engineers, their U.S. counterparts were primarily individuals with arts backgrounds, including marketing people. The latter group advocated utilization of nonfunctional features on the exterior of the product for maximum appeal with little emphasis on the interior of the product. Thus, while the European products were simple, precise, and economical, the American products were colorful and fancy looking (aerodynamically designed, even when the aerodynamic features were totally nonfunctional, for example, on furniture and refrigerators) (Figure 3).

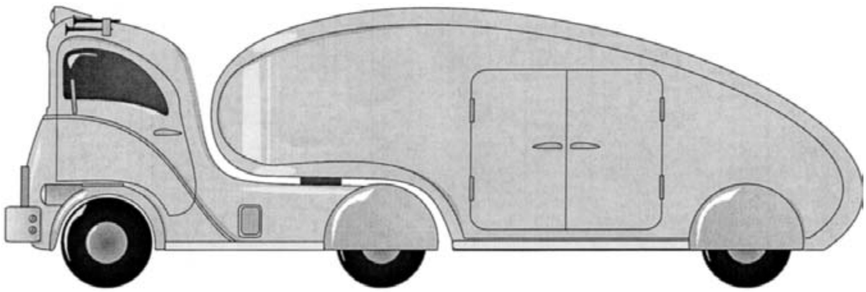
In the U.S.A., the use of industrial design in the automotive industry started in around 1924 or 1925 and was due to the personal efforts of GM's manager A. P. Sloan. Sloan insisted on styling and color variations in GM cars, which were competing at the time with the single model of Ford. For a period of time, color was the answer to the demand of beauty by the U.S. public. Around 1926, the market was flooded with colorful products (automotive and other household and office products), including the successful Corona typewriters.

In the late 1920s, large manufacturers started to hire designers and create appropriate departments within their corporations, though in parallel many designers formed consulting firms and maintained their independence. The latter group, however, spent most of their efforts on package design. The early 1930s witnessed the birth of streamlining, which employed sweeping horizontal lines, rounded corners and projected frictionless motion, for the design of many different products (chairs, refrigerators, cars, etc.). The number of industrial designers in the U.S.A. rose from 5,500 in 1931 to 9,500 in 1936 as industrial design became an (accepted) standard practice among manufacturers.

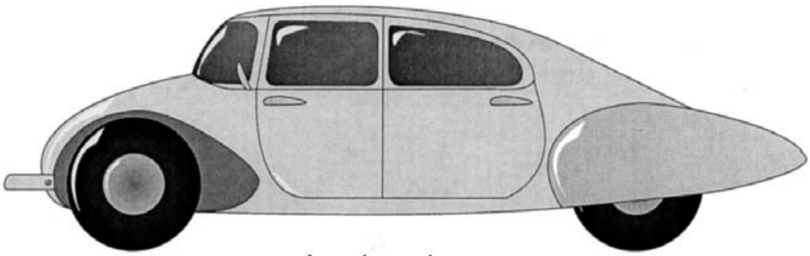
Naturally, industrial design trends were quickly brought into line with engineering, as most designers became internal members of larger design teams in manufacturing enterprises. Consequently, today, industrial designers actively participate in the conceptual design stage of the product as opposed to simply being consulted for marketing purposes once the product has reached the premanufacturing stage.

2.3.2 Industrial Design Process

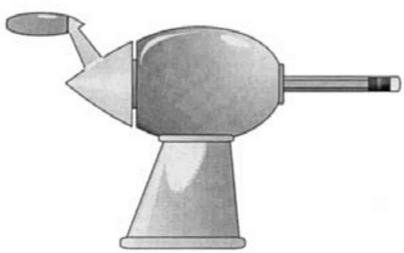
The intensity of industrial design in the development of a product is a direct function of its future utilization, namely, the characteristics of the customer.



Aerodynamic truck



Aerodynamic car



Aerodynamic pencil sharpener

FIGURE 3 Aerodynamic design.

An ink-jet printer, an office photocopier, and a lathe all require different emphases on the importance of certain design features. An office photocopier must allow users to understand its operational features with minimum mental effort but must also be designed for ease of maintenance by the service people. Users of a lathe, however, are expected to be well qualified to use the machinery, whose paramount concern is safety and of course ease of daily maintenance tasks. Household appliances would require to have aesthetic appeal and convey some brand-name identity.

As a vital member of the overall product design team, an industrial designer's first task is the evaluation of customer needs during the concept development phase. Industrial designers are expected to have the skills necessary to interview customers and research the market for identifying the needs clearly and communicate them to the engineers. At the concept generation phase, they concentrate on the form and human interfaces of the product, while engineers are mostly pre-occupied with addressing the functional requirements. Having an artistic background, industrial designers can also take a hands-on approach in generating alternative prototype models for conveying form and aesthetic requirements.

Once the field of design alternatives has been narrowed down, industrial designers return to their interactions with customers for collecting vital information on the customers' views and preferences regarding the individual concepts. At the final stages of the industrial design process, the role of the design engineers can vary from actually selecting the winning design and dictating the terms of manufacturing (mostly for consumer products, such as phones, wrist watches, and furniture) to simply participating in the marketing effort (mostly for products used by manufacturers, such as lathes, presses, and robots).

2.4 HUMAN FACTORS IN DESIGN

Interactions between people and products can be classified into three categories: occupying common space, acting as a source of input power, and acting as a supervisory controller. Human factors must be considered for every possible interaction, whether it being simply the operation of the product or its manufacture. Designers must analyze their products for evaluation of hazards, preferably for their subsequent elimination, and when impossible, for their avoidance. The following hazards could be noted in most mechanical systems: kinematic (moving parts), electrical, energy (potential, kinematic, and thermal), ergonomic/human factors (human–machine interface) and environmental (noise, chemicals, and radiation).

Safety of the person and quality of the product are the two paramount concerns. As noted above, if a hazard cannot be eliminated through design, the human users of the product should be provided with sufficient defense for hazard avoidance and with clear feedback, via signs, instruction, or warning sensors, to indicate the potential for a future hazard.

Of the three mentioned above, for interactions of the first type (i.e., occupying the same place), designers must carefully analyze available statistical data on the human metrics (anthropometric data) in order to determine the optimal product dimensions and to decide where to introduce reconfigurability (for example, different car-seat positions). The multinational company that aims to compete in different domestic markets must allow for this parametric variability in their design.

People often interact with their environment through touch: they have to apply force in opening a car door, twisting a bottle cap, or carrying boxes or parts on the shop floor. As with available human metrics for height, weight, reach, etc., there also exist empirical data on the capability of people in applying forces while they have different postures. Safety is also a major concern here. Products and processes must be designed ergonomically in order to prevent unnecessary injuries to the human body, especially in the case of operators who carry out repetitive tasks.

Supervisory control of machines and systems is the most common human/machine interaction. In such environments, people monitor ongoing machine activities through their senses and exercise supervisory control (when necessary) based on their decisions. (It has been estimated that 80% of human interactions with the environment is visual. Hearing is the next most important sense for information gathering.) The issues of sensing and control, thus, should be first individually examined. (With significant advances in artificial sensing and computing technologies, today, many supervisory control activities are carried out by computer controlled mechanical systems when economically viable, or when people cannot perform these tasks effectively, for example, automatic landing of aircraft.)

The following are only some representative issues that a designer must consider in designing human/machine interfaces (Fig. 4).

Clear and unambiguous display of sensory data: Displays should be clear, visible, and large. Analog displays are easier for quick analysis of a phenomenon, whereas digital displays provide precise information. Additionally, we must note that (1) the number of colors easily distinguishable by the human eye is less than ten, (2) the visual field extends 130° vertically and about 200° horizontally, (3) it takes about half a second to change focus, (4) a moving object's velocity and acceleration greatly reduce its accurate positioning, (5) the hearing range is between 20 and 20,000 Hz, and (6) noise above 120 dB (for example, generated by a jet

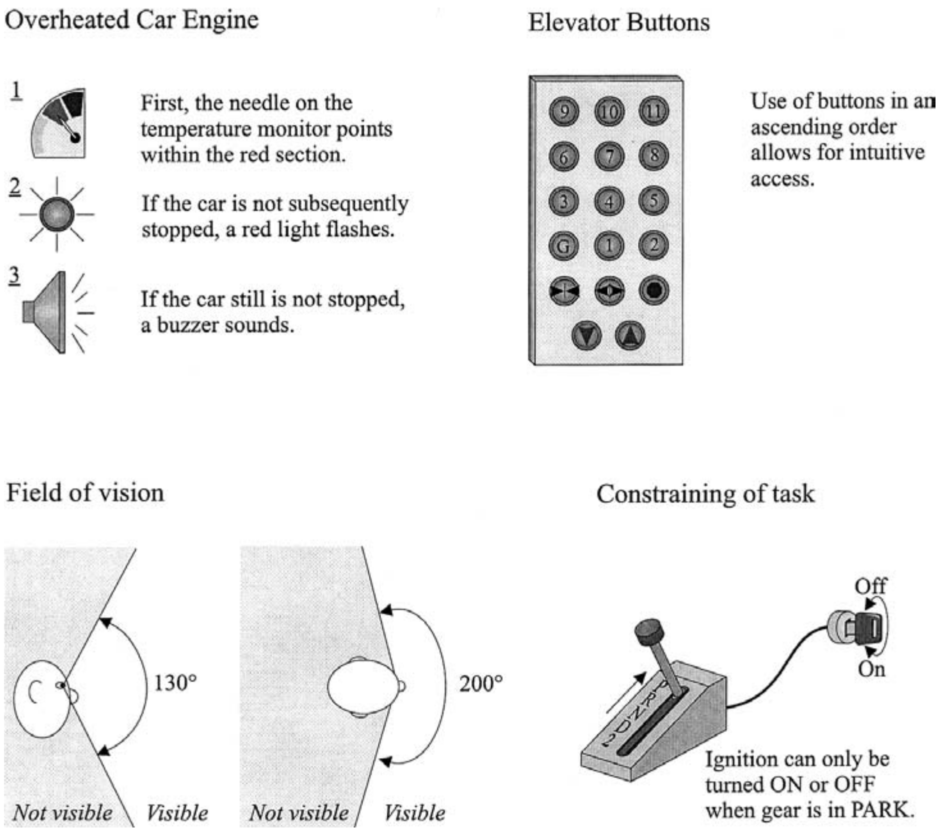


FIGURE 4 Human factors issues.

airplane) would cause discomfort if listened to by more than a few minutes.

Simplification and constraining of tasks: Control operations must involve a minimum number of actions. Where the possibility of incorrect actions exists, they should be prevented by clever design.

Suitable placement of input devices: Control devices, such as levers and buttons, should be placed for intuitive access and be easy to notice and to differentiate.

Providing feedback of control actions: The operator should be provided with a clear feedback (light or sound) in response to a control action undertaken, especially in anticipation of unwanted actions (where these cannot be physically prevented).

In order to cope with emergencies, we must also be aware of the information-processing limitations of human operators. As expected, people's information processing efficiency is significantly degraded when performing repetitive, boring tasks. General tiredness and personal stress further degrades this efficiency. The human operator is restricted in recalling from memory a task to be done within the next very short period of time. This phenomenon is further complicated if the necessary operation requires multiple subtasks. Thus, at emergencies, people react according to expected stereotypical actions. For example, they expect an increased reading with a clockwise dial display, push a switch upward for "on," and press down a brake pedal for stopping.

2.5 CONCEPTUAL DESIGN

Design projects can be classified broadly as (1) varying a product by modifying one or more of its parameters, but maintaining its overall functionality and performance, (2) redesigning a product by improving upon its performance, a large number of its characteristics, and/or its quality, (3) development of a new product, whose development process (design and materials) is affected by the expected production level (batch versus large volume), and (4) made-to-order design of a product. No matter what category the project falls into, however, the first step in the conceptual design process is problem formulation, followed by concept generation and concept evaluation phases.

2.5.1 Problem Formulation

Problem formulation must not be treated as an intuitive and trivial step of the engineering design process. One can never overemphasize this stage of identifying a customer's needs, which should be carried out with great care. Since design must yield an optimal solution to the problem at hand, the objective and constraints of the problem must be defined (preferably in a tangible manner). Let us, for example, consider the development of Sony's (portable) Walkman, where the overall goal could have been stated as "Provide individuals with a device capable of replaying tape/CD-recorded music, while they are mobile, with a carry-on power source and in a private listening mode." From an engineering perspective, there would exist several objectives (that could be interrelated) to satisfy this overall goal. The unit must have its own (preferably integral) power source, provide earphone connection, and of course be affordable. Typical constraints for this example product would be size, weight, and durability. (Naturally, some objectives can be formulated as equality, i.e., "must-have," constraints).

The technical literature provides us with numerous empirical and heuristic techniques for analyzing the problem at hand (as defined by the customer) and relate the customer requirements to engineering design parameters. Quality function development (QFD) is such a technique, first developed in Japan, that utilizes a chart representation of these relationships (Fig. 5). The primary elements of the QFD chart are

Customer requirements: A list of the characteristics of the design as explained by the customer.

Engineering requirements: A list that is generated by the engineers in response to the customer requirements. The list should be as comprehensive as possible.

Benchmarking: A comparison process to competitors' similar products.

Engineering targets: A set of target values for engineering requirements.

Customer needs are normally expressed qualitatively or in fuzzy terms, whereas engineering characteristics are usually quantitative. Engineers are required to determine the functional requirements of the product that influence the needs expressed by the customer. These requirements can be qualitative (an acceptable form at the conceptual design phase) or expressed

	Engineering requirements							
Customer requirements	Self-powered	Size	Weight	Shape	Ease of operation	Ruggedness	Cost	Benchmark (Competitor A)
Portable	X	X	X	X				W
Reliable					X	X		M
Appealing		X		X	X			W
Inexpensive	X					X	X	S
Engineering targets	6 V		100 g				$30	

FIGURE 5 An exemplary QFD chart for Sony's Walkman.

as ranges (with possible extreme limits), for example, "the cost should be between $35 and $45."

Functional requirements can express goals and constraints in the following categories: performance, (geometrical) form, and aesthetics, environmental and life cycle, and manufacturability. Performance requirements would include goals on output (rate, accuracy, reliability, etc.), product life, maintenance, and safety. Form requirements refer to physical space and weight and industrial-design issues. Manufacturability requirements refer to the determination of fabrication and assembly methods that need to be employed for a profitable product line.

In the QFD chart shown in Fig. 5, the "X" mark indicates the existence of a relationship between the corresponding customer and engineering requirements. In the benchmarking column, "S" refers to a strong competitive position, whereas "M" and "W" refer to moderate and weak competitive positions, respectively.

2.5.2 Concept Generation

The conceptualization stage of design can benefit from uninhibited creative thinking combined with wide knowledge of engineering principles and of the state of the art in the specific product market. Creativity is not a (scientifically) well understood process, though it has been researched by numerous psychologists. The Creative Education Foundation model proposed in 1976 has five stages that form a sequential process: (1) fact finding, (2) problem formulation, (3) idea finding (narrowing of ideas toward feasible solutions), (4) evaluation, and (5) acceptance finding (premanufacturing stage of design).

2.5.3 Concept Evaluation

One can appreciate the difficulty a design team faces in decision making, during the concept evaluation phase, without having the engineering design specifications to compare the alternative concepts. Quantifying designs based mostly on intangible criteria is the task at hand.

Pugh's method of concept selection, for example, evaluates each concept relative to a "reference concept" and rates it (according to some criteria) as being better (+), about the same (S), or poor (−) (Table 1). The evaluation process starts by choosing the criteria based on the engineering requirements (as listed in the QFD chart), or, if these are underdeveloped, based on the customer requirements. The criteria can be ranked without attempting to assign specific weights. The next step would be choosing a reference concept (preferably the "best" perceived concept). The evaluation stage of the process, then, requires comparison of each

TABLE 1 An Exemplary Pugh Concept Comparison Table

	Ref. concept	Concept 1	Concept 2	Concept 3	Concept 4
Criterion 1	D	+	–	–	S
Criterion 2	A	S	+	–	–
Criterion 3	T	+	–	S	–
Criterion 4	U	–	S	+	–
	M				
Σ (+)		2	1	1	0
Σ (–)		1	2	2	3
Σ (S)		1	1	1	1

concept to the reference according to the criteria chosen by the product team and the assignment of the corresponding score (+, S, or –). Based on the assigned scores, one ranks all the concepts and redefines the reference concept as the best among the ranked. (For example, in Table 1, at the stage of comparison shown Concept 1 could be chosen as the next reference concept.) The procedure would then be repeated with the new reference concept as our new comparison concept and stopped, eventually, if the repeated evaluations yield the same reference concept. At that time, the design team may simply decide to proceed with one or with the top n concepts to the next product design stage.

2.6 MODULAR PRODUCT DESIGN

As defined by Ulrich and Eppinger, "product architecture is the assignment of the individual functional elements (duties/requirements) of a product to the physical building blocks (clusters) of the product." The functional elements of a product refer to the specific subtasks a product would perform (for example, feeding paper in a printer), whereas the physical building blocks are the clusters of components that allow implementation of these functions (for example, paper feed being achieved via a collection of rollers and a motor subassembly in a printer). In a modular product design, clusters implement functions in their *entirety* and independently, whereas in an integral design, a function may be implemented using more than one (physical) cluster.

Standardization has long been a cost-saving measure, normally implemented at the component level for integral designs. Modular product design elevates standardization to the level of functional elements, where they can be used in different product models to carry out the same functions, allow easy replacement, and provide expansion (add-on) capability. One can conclude that product (design) modularity is a necessary step in achieving tactical flexibility in a manufacturing environment and providing customers with economically viable variety (Sec. 1.4).

2.6.1 Modularity Levels

There exist six levels of modularity (Fig. 6):

Component sharing: This is the lowest level of standardization: the same components (e.g., motors and clutches) are used across many products (which may be modular or integral in design).

Component swapping: This is a component sharing modularity approach built around a single core product. Great numbers of variations can be presented to the customers (almost approaching a one-of-a-kind product line). The Swatch family of watches is a typical example.

Cut-to-fit: This is a parametric design variability achieved by customizing a small number of geometric features on the product. In the 1990s, Matsushita in Japan provided customers with personalized bicycles with a two-week delivery schedule once the order was received from the "fitting" store.

Mixing: The product is simply a mixture of components, in which the components lose their identity within the final product. An exemplary application area could be the mixture of chemicals according to a recipe.

Bus configuration: Similar to mixing, a mixture of components is assembled on a "mother" bus/board/platform. Typical examples include computers and automobiles. Naturally, modularity can only be achieved through a flexible design of the bus.

Sectional: This is the ultimate level of modularity, where the product's architecture is reconfigurable itself (as opposed to being fixed). Individual modules are configured to yield different products. The most common example is the reconfiguration of software modules to yield different application programs.

2.6.2 Modular Design Process

A three-step procedure has been commonly proposed for developing a modular product architecture:

1. Create a schematic representation of the product, which normally would comprise a set of functional objectives as opposed to physical building blocks (or their components).

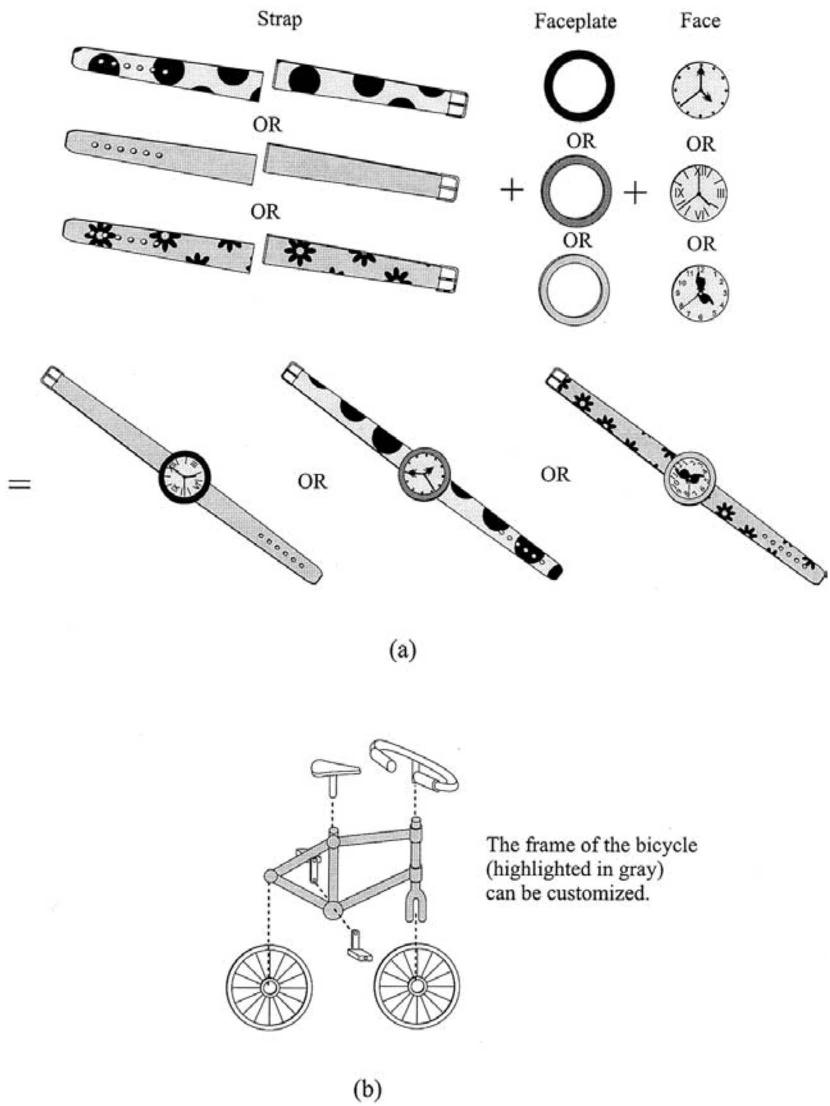
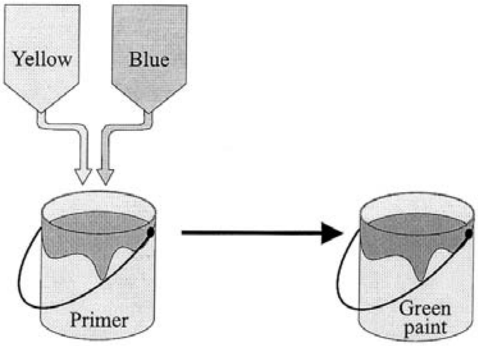
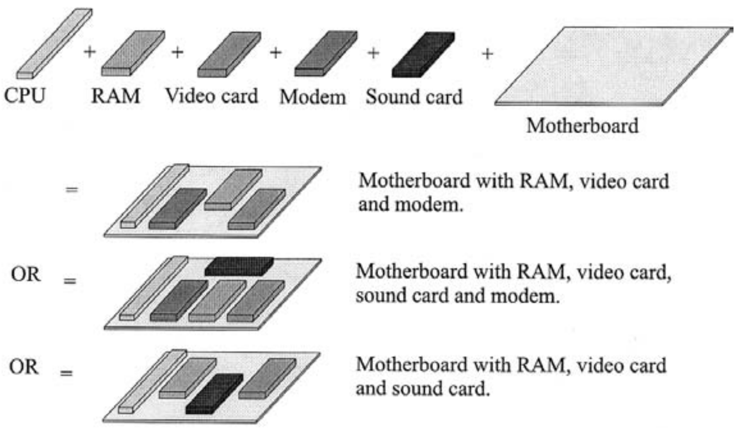


FIGURE 6 (a) Component swapping; (b) cut-to-fit modularity.



(c)



(d)

FIGURE 6 (c) Mixing; (d) bus configuration modularity.

2. Group the functional objectives into functional clusters, where possible. At this stage the designer can consider issues such as physical relationships (and proximity) between components, the potential for standardization, and even the capability of suppliers to provide clusters.
3. Create a rough geometric layout of the product in order to evaluate operational feasibility through analysis of the interactions between the clusters, as well as the feasibility of production and assembly while maintaining a high degree of quality and economic viability.

2.7 MASS CUSTOMIZATION VIA PRODUCT MODULARITY

Mass production adopted in the earlier part of the 20th century was based on the principles of interchangeable parts, specialized machines, and division of labor. The focus was primarily on improving productivity through process innovation. The primary objective was to reduce cost and thus cause an increase in demand. Most large companies ignored niche markets and customer desires, leaving them to the small companies. This manufacturing management paradigm started to loosen its grip on most consumer industries around the 1960s and 1970s in response to developing global competition pressures. A paradigm shift toward customization was full blown by the late 1980s in several industries, naturally, at different levels. The objective was set as "variety and customization through flexibility and quick responsiveness."

The key features of today's marketplace are (1) fragmented demand (the niches are the market) (2) low cost and high quality (customers are demanding high-quality products, not in direct relation to the cost of the product), (3) short product development cycles, and (4) short product cycles. The result is less demand for a specific product but increased demand for the overall product family of the company, whose strategy is to develop, produce, market, and deliver affordable goods with enough variety and customization that almost everyone purchases their own desired product.

The primary (fundamental) prerequisite to achieving mass customization can be noted as having customizable products with modularized components. Examples of customizable (reconfigurable) products include Braun's flex-control electric razor, which is self-adjusting to the user's facial profile, Reebok's Pump shoes that can be (air) pumped for better fit (similar to customizable "removable" casts for foot fractures), and finally Dell's personal computers, customized by the buyer and assembled specifically for them. In this context, standardization for customization is a competitive tool for companies marketing several related products, such as Black & Decker's line of power tools, which use a common set of standardized subassemblies (clusters, modules, etc.).

The primary steps for the design of a mass customizable product are

1. *Identifying customer needs*: This stage is similar to any product (concept) design stage with the exception of identifying potential personal differences in requirements for a common overall functional requirement for the product.
2. *Develop concepts*: Concepts (alternatives) should be developed and compared with a special emphasis for allowing modularity

in final engineering design. (QFD and Pugh's methods should be utilized.)

3. *Modularization of chosen concept*: The chosen design concept should be evaluated and iteratively modified with the objective of modularization (i.e., mass customization) and fit within the larger family of products, with which the proposed design will share modules.

REVIEW QUESTIONS

1. Define concurrent engineering (CE) and discuss its practical implementation in manufacturing enterprises.
2. Discuss the CE design guideline "design for robustness."
3. Discuss techniques for increasing the effectiveness of the customer-need-identification process.
4. Discuss the role of industrial design in the development of engineering products. Should industrial designers be consulted prior, during, or after a product has been designed and its manufacturing plans have been finalized?
5. Discuss some of the important issues that a human-factor engineer has to deal with for the design of products/systems that allow effective human/machine interface for supervisory control, maintenance, etc.
6. How can the quality function development (QFD) method be used in relating customer requirements to engineering design parameters?
7. The conceptualization stage of design can benefit from uninhibited creative thinking, eventually leading to several concepts for the solution of the problem at hand. Discuss Pugh's method of concept selection and difficulties associated with it.
8. Define product modularity and compare it to standardization. Provide several examples in your discussion, while classifying their level of modularity.
9. Discuss modularity for software products versus hardware products in the computing industry.
10. What is the key product design requirement for mass customization?

DISCUSSION QUESTIONS

1. Most engineering products are based on innovative design, rather than on fundamental inventions. They are developed in response to a common customer demand, enabled by new materials and/or technologies. Review the development of a recently marketed product that fits

the above description from its conception, to its manufacturing and marketing: for example, portable (personal Walkman type) CD players, portable wireless phones, microwave ovens, etc.

2. A common manufacturing strategy advocates assigning responsibility for a product to a team. This team designs the product, plans its fabrication, and remains responsible for it until the product reaches maturity while providing customer support. The team may grow or shrink in its membership during the life cycle of the product. Discuss this strategy versus a compartmentalized strategy, where different groups of people would take on responsibility for the product during the different periods of its life cycle without maintaining a tangible continuity.

3. Discuss the role of computers in the different stages of the (iterative) design process: concept development, synthesis, and analysis.

4. Product marketability is an important factor in the design and subsequent manufacturing of consumer products. Marketing efforts frequently concentrate on highlighting the non-functional, eye-pleasing design features of products in their promotion. Discuss the issue of incorporating such features (versus functional features) into product designs in the context of their impact on the manufacturing of the products. Include specific products and features in your discussion, such as furniture versus refrigerators versus passenger cars and aerodynamic geometry versus colors versus packaging (i.e., exterior of products).

5. Products can be designed for specific ranges of anthropometrics, for a targeted demographics, in two distinct modes: (1) Those that allow reconfiguration via continuous and/or discrete incremental changes, or even through modularity of certain subcomponents, or (2) those that have been already manufactured in different dimensions, etc., for different customer anthropometrics. Discuss these modes of design in terms of manufacturing difficulties, durability, safety, cost, customer response, etc. In your discussion, include specific products/features, for example car seats, bicycles, headphones, office chairs, personal clothing items.

6. Human factors (HF) studies encompass a range of issues from ergonomics to human-machine (including human–software) interfaces. Discuss the role of HF in the autonomous factory of the future, where the impact of human operators is significantly diminished and emphasis is switched from operating machines to supervision, planning, and maintenance.

7. Flexible manufacturing has often been proposed as a (tactical) production strategy. Discuss whether such a strategy can be justified economically for all products. In the same context, also discuss specific product features that would allow customization (e.g., geometry, material, fabrication process, etc.), which in turn requires manufacturing flexibility. Consider products such as furniture, household appliances, bicycles, and personal clothing.

8. Discuss a design strategy for multicomponent products whose support and maintenance would not be negatively affected by significant variations in the life expectancy of their individual components, (i.e., large variations within the same batch of components). In your discussion, assume that these variations would occur for material or technological reasons, such as the absence of machines that can provide high levels of quality in terms of component life, and that they are unavoidable.
9. Discuss the concept of progressively increasing *cost of changes* to a product as it moves from the design stage to full production and distribution. How could you minimize necessary design changes to a product, especially for those that have very short development cycles, such as portable communication devices?

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