

## New Product Development

### 2.1 Introduction

New product development is a multi-stage process. Many different models with a varying number of stages have been proposed in the literature. We briefly review these models and propose a new model that is better suited to decision making regarding product performance and specification. In this chapter we start with a discussion of products and product life cycle in order to set the background for the later sections of the chapter.

The outline of the chapter is as follows. In Section 2.2 we look at product classification and decomposition. Section 2.3 deals with product life and product life cycle. Section 2.4 gives an overview of new product development and reviews some of the models proposed in the literature. Section 2.5 deals with the concepts and activities in the different phases of the five-phase product life cycle indicated in Figure 1.1. This sets the background for a new model that is appropriate for deciding on performance and specification in the context of new product development. Section 2.6 deals with this new model.

### 2.2 Products

A narrow definition of products is that they are physical and tangible. This is in contrast to services that are intangible. The distinction between products (as defined above) and services is getting blurred and a more commonly accepted definition is that a product generally involves combinations of the tangible and the intangible as indicated below.

“A product can be tangible (e.g., assemblies or processed materials) or intangible (e.g., knowledge or concepts), or a combination thereof. A product can be either intended (e.g., offering to customers) or unintended (e.g., pollutant or unwanted effects).”  
(ISO 8402).

Consumers buy products for different reasons and can be broadly divided into three categories:

*Households:* These comprise individuals (or families) buying products, such as food items, cosmetics, clothes, televisions, kitchen appliances, household furniture, and so on.

*Industrial and commercial organizations:* These comprise businesses buying a range of products (e.g., furniture, computers, telephones) for use in the office; products to deliver services (e.g., X-ray machines in hospitals, trucks to move goods from factory to markets, trains to move people) and products (e.g., lathes, assembly robots, components) to produce other products for sale.

*Governments:* These not only buy the products consumed by households and industrial and commercial organizations to administer and provide services, but also products (e.g., tanks, ships) to defend the country.

### **2.2.1 Product Classification**

Products can be classified in many different ways, as indicated below.

#### *Classification 1: Based on the type of consumer*

This is the most common classification.

*Consumer non-durables and durables:* These products are bought by households. The non-durables differ from the durables in the sense that the life of a non-durable product (e.g., cosmetic, food) is relatively short, and the product is less complex than a durable product (e.g., cellular phone, television).

*Industrial and commercial products:* These are standard (off-the-shelf) products used by industrial and commercial organizations for their operations. The technical complexity of such products can vary considerably. The products can be either complete units, such as cars, computers, trucks, pumps, and so forth, or product components needed by a manufacturer, such as batteries, drill bits, electronic modules, and toner cassettes for laser printers.

*Specialized defence-related or industrial products:* Specialized products (e.g., military aircraft, ships, and rockets) are usually complex and expensive and involve state-of-the-art technology with considerable research and development effort required of the manufacturers. Customers are typically governments or industrial businesses. These products are usually designed and built to the specific requirements of the consumer. Still more complex are large systems (e.g., power stations, chemical plants, computer networks, and communication networks) that are collections of several inter-linked products.

#### *Classification 2: Standard versus custom-built*

*Standard products:* These are manufactured in anticipation of a subsequent demand. As such, the products are manufactured based on market surveys. Standard products include all consumer non-durables and durables and most commercial and industrial products.

*Custom-built products:* These are manufactured in response to a specific request from a customer, and include specialized defence and industrial products.

*Classification 3: Based on the nature of design and design process*

Parsaei and Sullivan (1993) suggest the following classification:

*Creative designs:* Creative design is an abstract decomposition of the design problem into a set of levels that represent choices for the problem. An a priori plan for the problem does not exist.

*Innovative designs:* The decomposition of the problem is known, but the alternatives for each of its sub-parts do not exist, and must be synthesized. Design might be an original or unique combination of existing components. A certain amount of creativity comes into play in the innovative design process.

*Redesign:* An existing design is modified to meet the required changes in the original functional requirements.

*Routine designs:* An a priori plan of the solution exists. The sub-parts and alternatives are known in advance, perhaps as the result of either a creative or innovative design process. Routine design involves finding the appropriate alternatives for each sub-part that satisfies the given constraints.

*Classification 4:*

Hubka and Eder (1992) suggest a broader classification that captures complexity, usage, appearance, and methods for designing the product. According to their classification, products range from artistic work to industrial plant as indicated below:

1. Artistic works
2. Consumer durables
3. Bulk or continuous engineering products
4. Industry products
5. Industrial products
6. Industrial equipment products
7. Special purpose equipment
8. Industrial plant

Product appearance is more important for products at the top of the list, while methods for designing and use of scientific knowledge are important for products at the bottom of the list. For artistic works, the artist is usually both the designer and manufacturer. Industrial plant is the extreme case of products incorporating other products, and consists of collections of industrial equipment and devices to provide control and/or connections among them.

*Classification 5: New versus used (or second-hand) products*

There are several different notions of a new product and these are discussed in the next sub-section. In contrast, an old product is one that has been on the market for some time.

We need to differentiate between a new item and a used (or second-hand) item. If the useful life of a product is much greater than the product life cycle (discussed in Section 2.3), customers often replace a working old item (old product) with a new one (new product). As a result, a market for used or second-hand products is created.

### 2.2.2 “Newness” of a New Product

New products are replacing existing products on a regular basis. The rate at which new products are appearing on the market is growing at an exponential rate. The reasons for this are many and can include one or more of the following:

- Create a differential advantage (product differentiation)
- Support continued growth for the manufacturer
- Capitalize on technological breakthroughs
- Response to changing demographics

There are several different notions of what constitutes a new product. The “newness” of a new product can vary from high to low and depends on whose perspective and what is new.

The different perspectives yield the following:

1. New to the world (e.g., the first aircraft, radio, computer, car)
2. New to the industry (first application in an industry of a product well established in some other industry)
3. New to the manufacturing firm (and familiar to competitors in the industry)
4. New to the market
5. New to the customer

Viewed in terms of *what* is new, yield the following:

1. New technology (digital computer replacing analogue computer)
2. New process (which reduces the production cost and/or increases the quality of conformance)
3. New features (this is most dramatic in consumer electronics, such as, cellular phones)
4. New uses (chips designed for computers being used in domestic appliances)
5. New design (which reduces the production cost)

The degree of newness is an indicator of the difference between the new product and the existing one. The change (depending on the perspective) can vary from minor or incremental to major or radical. For example, a change that reduces the production cost might be viewed as a major change from the manufacturer’s perspective and no change from the customer’s perspective. A radical change is due to a new technology (higher speeds resulting from jet engines that was not possible with the earlier propeller engines) whereas an incremental change is due to advances within an existing technology.

The newness from the customer perspective deals with improvements in the product attributes (e.g., increase in the fuel efficiency of a car) or new features that meet new requirements or result in greater benefits.<sup>1</sup>

*Example 2.1.* DNV RP A203 is a guideline for reliability qualification of new technology for the offshore oil and gas industry. The guideline classifies the products to be qualified into four categories as follows:

Technological status →	Proven in use	Limited field history	New or unproven
Known application	1	2	3
New application	2	3	4

The categories indicate:

1. No new technological uncertainties
  - Both the product, the application, and the environmental conditions are known
2. New technological uncertainties
  - The product has a limited field history, but the application and the environmental conditions are new
  - The product is well known (proven in use), but the application and/or the environmental conditions are new
3. New technological challenges
  - The product is new, but will be used in well-known applications, and under known environmental conditions
  - The product is partly known (with limited field history) and will be used for a new application and/or in new environmental conditions
4. Demanding new challenges
  - The product is new and both the application and the environmental conditions are new.

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### 2.2.3 Product Decomposition

The complexity of products has been increasing with technological advances. The following example, from Kececioglu (1991), indicates the increase in the numbers of components in a tractor over time.

Model year	1935	1960	1970	1980	1990
Number of components	1200	1250	2400	2600	2900

For more complex products, the number of parts may be orders of magnitude larger. For example, a Boeing 747 airplane has 4.5 million components (Appel, 1970).

As a result, a product needs to be viewed as a system comprising several elements and can be decomposed into a hierarchy of levels, with the system at the top level and components at the lowest level. There are many ways of describing this hierarchy and the following description is from Blischke and Murthy (2000):

<sup>1</sup> For further discussion on this topic, see Garcia and Calantone (2002).

Level	Characterization
0	System
1	Sub-system
2	Major assembly
3	Assembly
4	Sub-assembly
5	Component

The number of levels needed to describe a product from system level down to component level depends on the complexity of the product.

*Example 2.2 (Cellular Phone).* The cellular phone is a very complex product. The main elements are:

- Circuit board
- Antenna
- Liquid crystal display
- Keyboard
- Microphone
- Speaker
- Battery

Each of these can be decomposed into lower levels. For example, in the case of the circuit board, it is the heart and brain of the system and contains several computer chips and other components. The different chips and components and their functions are as follows:

- Analogue-to-digital and digital-to-analogue chip: It translates the outgoing audio signal from analogue to digital and the incoming signal from digital back to analogue.
  - Microprocessor chip: It handles all of the housekeeping chores for the keyboard and display, deals with command and control signalling with the base station and also coordinates the rest of the functions on the board.
  - ROM and flash memory chips: These provide storage for the phone’s operating system and other features, such as the phone directory.
  - Radio frequency and power section: This handles power management and recharging, and also deals with the hundreds of FM channels.
  - Radio frequency amplifiers: These handle signals travelling to and from the antenna.
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*Example 2.3 (Safety Instrumented System).* All safety instrumented systems have at least three main sub-systems: (1) input elements, (2) logic solver, and (3) final elements. The number of assemblies and components in each sub-system may range from a single item, to a large number of items. The final elements (e.g., shutdown valves) often have a fail-safe design and are equipped with electric, hydraulic or pneumatic utility systems. The input elements usually have features for diagnostic

testing. The logic solver often has a duplex or triplex configuration to facilitate self-testing. The sensors are often configured as a  $k$ -out-of- $n$  system, meaning that at least  $k$  out of  $n$  input elements have to give signal to the logic solver to raise an alarm.  $\oplus$

## 2.3 Product Life and Product Life Cycles

### 2.3.1 Product Life

The useful life of a product is the age beyond which the product is deemed to be unsuitable for further use due to its inability to perform satisfactorily. This is a random variable due to variation in manufacturing and/or usage. For a repairable product, a component of the product can fail several times over its useful life and is restored to operational status through corrective maintenance actions.

In the context of new products, a related notion is the time for which a consumer uses the purchased product before it is replaced by a new one. This can be called the *period of ownership*. This is also a random variable as different consumers keep the purchased product for different lengths. If consumers keep the products for the useful life, then the products are scrapped at the end of their useful life. In this case, there are no second-hand products. If the period of ownership is shorter than the useful life, a market for second-hand products is created.

### 2.3.2 Product Life Cycle

The product life cycle concept is quite different in meaning, intent, and importance for consumers and manufacturers.<sup>2</sup> From the manufacturer's perspective there are two different notions.

The product life cycle can be viewed in a larger overall context, with important strategic implications (Betz, 1993). Here, the product life cycle is seen as embedded in the technology life cycle where there are several product life cycles within a technology life cycle. Revolutionary technological innovations result in a new technology platform (e.g., internet access) with multitudes of technology generations developing over time (e.g., phone modem, ISDN, ADSL) with each technology generation characterized by four phases: introduction, rapid growth, mature, and decline. Within each technology generation, a multitude of products are developed, following similar product life cycles. The technology platform also follows a similar technology life cycle.

#### *Consumer Perspective*

From the consumer's point of view, the product life cycle is the time from the purchase of an item to its discarding when it reaches the end of its useful life or being replaced earlier due to either technological obsolescence or the item being no longer of any use. The life cycle involves the following three phases:

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<sup>2</sup> See Rink and Swan (1979) for more on product life cycle.

1. Acquisition
2. Operation and maintenance
3. Discard (and leading to replacement by a new one)

### *Manufacturer Perspective*

There are two different notions – marketing and manufacturing.

*Marketing:* The product life cycle is the period from the instant the product is launched on the market to the time when it is withdrawn from the market and involves the following four phases:

1. Introduction phase (with low sales)
2. Growth phase (with rapid increase in sales)
3. Maturity phase (with near constant sales)
4. Decline phase (with decreasing sales)

*Manufacturing:* The product life cycle is the period from the initial conception of the product to the final withdrawal of the product from the marketplace. It can be broken into five phases as indicated in Figure 1.1.

## **2.4 New Product Development**

The US based Product Development & Management Association defines new product development as

“A disciplined and defined set of tasks and steps that describe the normal means by which a company repetitively converts embryonic ideas into saleable products or services.” (Belliveau et al., 2002).

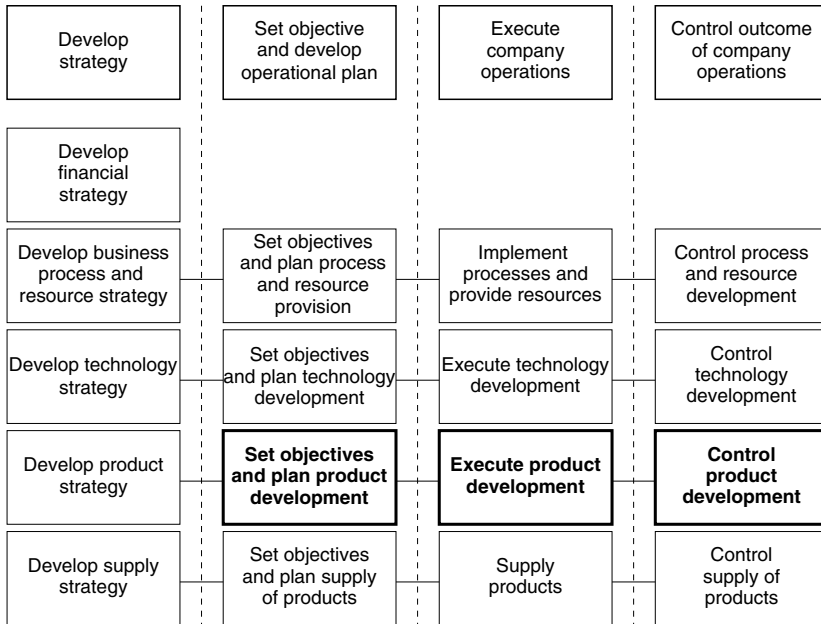
### **2.4.1 New Product Development in the Overall Business Context**

Businesses use strategic management to achieve their long-term objectives. This requires formulating strategies for various elements of the business in a coherent manner so that they are consistent and integrated. Once this is done, procedures to implement the plans need to be devised. The resulting actions need to be monitored so that changes can be made and the process controlled in an effective manner. Figure 2.1 (adapted from Fairlie-Clarke and Muller, 2003) shows some of the key strategies with product development strategy being one of them. The success of the new product development depends strongly on formulating and implementing strategies.

According to Wheelwright and Clark (1992), companies succeeding in the global and dynamic competition are those that are able to bring new products fast to the market, products that satisfy the expectations of the customer. Those:

1. approaching new product development in a structured manner are more successful than those with an ad-hoc approach
2. emphasizing early stages, have a higher chance of success than those not doing so





**Figure 2.1.** New product development as part of business processes

### 2.4.2 A Brief Review of New Product Development Models

A variety of models have been proposed to get better insight into the new product development process and its management. The process starts with an idea to build a product that meets specific requirements (or create new requirements for radically innovative products) defined by customers and/or the manufacturer, and ends when the product is launched on the market. It involves several phases and the number of phases and descriptions of the phases vary from model to model. An illustrative sample is given in Table 2.1.<sup>3</sup>

The diversity in the number of phases, the different terminology used, and different interpretations of the same terms may best be explained by the different contexts, such as (1) type of product (mechanical, electrical, mechatronic, electronic), (2) degree of innovation (redesign vs. routine design), (3) product complexity, (4) production process (manual, highly automated, existing production facilities), (5) type and number of suppliers/original equipment manufacturers (OEMs), (6) tech-

<sup>3</sup> Other models and further discussion can be found in Hubka and Eder (1992); Fairlie-Clarke and Muller (2003); Aoussat et al. (2000); Büyüközkan et al. (2004); Cooper (2001); Cross (1994); Drejer and Gudmundsson (2002); French (1985); Ottoson (2004); Sim and Duffy (2003); Suh (2001); Ullman (2003); Weber et al. (2003)

**Table 2.1.** Different phases for an illustrative sample of new product development models

Model	Phases
Model 1 (Roozenburg and Eekels, 1995)	Analysis → Concept → Materialization
Model 2 (IEC 60300-1)	Concept and definition → Design and development → Manufacturing and installation
Model 3 (Fox, 1993)	Pre-concept → Concept → Design → Demonstration → Production
Model 4 (Pahl and Beitz, 1996)	Clarification of task → Conceptual design → Embodiment design → Detail design
Model 5 (Cooper, 2005)	Scoping → Build business case → Development → Testing and validation → Launch
Model 6 (Blanchard, 2004)	Conceptual design → Preliminary system design → Detailed design and development → Construction → Production
Model 7 (Pugh, 1990)	Market → Specification → Concept design → Detail design → Manufacture
Model 8 (Andreasen and Hein, 1987)	Recognition of need → Investigation of need → Product principle → Product design → Product preparation → Execution

nologies involved, (7) availability of resources (e.g., manpower), and (8) time and budget constraints.<sup>4</sup>

**2.5 Product Life Cycle Phases: Basic Concepts and Activities**

In this section we discuss the basic concepts and activities in the five different phases of the product life cycle model shown in Figure 1.1. This is needed for a proper understanding of the new model for decision making regarding product performance and specification in new product development.

**2.5.1 Front-end**

*Opportunity, Idea, and Concept*

These three terms are closely related and important in the context of new product development, and may be defined as follows (adapted from Belliveau et al. (2002)):

<sup>4</sup> For further discussion on these topics, see Hales (1993); Maffin (1998); Nellore and Balachandra (2001); Song and Montoya-Weiss (1998); Tatikonda and Rosenthal (2000); Veryzer (1998).

*Opportunity:* An identified business or technology gap that exists between the current situation and a potential future that can be exploited to gain competitive advantage or solve a problem.

*Idea:* The earliest perception of a new product or service. It may be an early view of a solution for taking advantage of the opportunity.

*Concept:* Has well-defined form and description, and includes an understanding of the technology needed, the primary features, and customer benefits.

The aim of the front-end phase is to process and select ideas that may exploit emerging opportunities, and further develop the selected ideas to feasible concepts.<sup>5</sup>

### *New Product Development Drivers*

The trigger (need or opportunity) for a new product idea can be one or more of the following factors:

*Technology:* Advances in technology (either in-house or outside) provide an opportunity to improve existing products.

*Market:* The manufacturer has to improve his existing product in response to (i) competitor actions (e.g., reducing the price or an improvement to their product) and/or (ii) feedback from customers through complaints about product performance.

*Management:* The motivation for improvement could be (i) internal (e.g., to increase market share, or improve profits by reducing warranty cost) and (ii) external (e.g., new legislation related to product performance).

### *Screening of Ideas*

The new product drivers above generate a continuous flow of new product ideas. Thus, there is also a continuous screening of ideas to decide which ones to pursue further. Screening is concerned with answering the following questions (adapted from Cooper (2001)):

1. Does the idea fit within the business market or technology focus area ?
2. Are the business opportunities attractive (e.g., potential market size and growth)?
3. Is it technically feasible to develop and produce the product?
4. Are there any potential hindrances that may stop the project (e.g., legislative and/or environmental issues)?

Once an idea is selected for further investigation the subsequent activities that need to be carried out can be grouped into three groups: (i) product definition, (ii) project plan, and (iii) project definition review.<sup>6</sup>

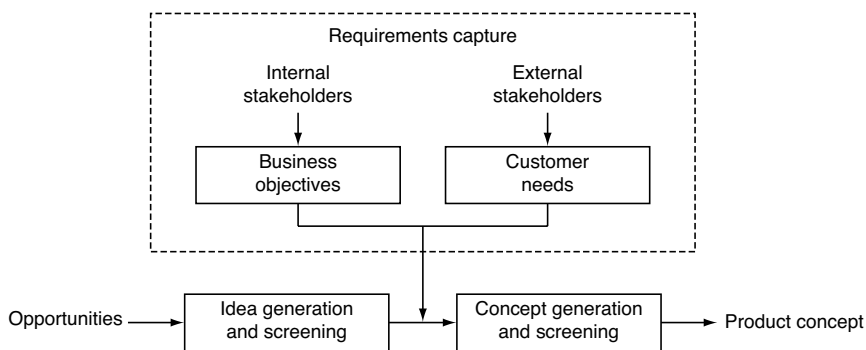
<sup>5</sup> This process is very selective, since up to 90% of the ideas and 80% of the concepts may be dismissed (Cooper et al., 1998).

<sup>6</sup> A review of the literature on front-end indicates a considerable variation in the activities to be carried out in the front-end phase. We include screening of the idea whereas many others view the front-end starting after the ideas have been screened.

### *Product Definition*

The main task in the product definition is to translate feasible ideas into technically and economically feasible and competitive product concepts as shown in Figure 2.2. An important aspect of this process is the capture of business objectives (presented by internal stakeholders) and customer requirements (presented by external stakeholders) such that a concept meeting these may be developed. This process may be called “requirements capture” (Cooper et al., 1998). The product definition states what characteristics (preferably measurable) that the product should have in order to meet the expectations of both internal and external stakeholders. To establish the product definition is an iterative process involving:

1. Market investigations and market research studies
2. Competitive analyses
3. Business and financial analyses
4. Technical and manufacturing appraisals
5. Resource and capabilities assessments, all aiming at ensuring the feasibility of the concept<sup>7</sup>

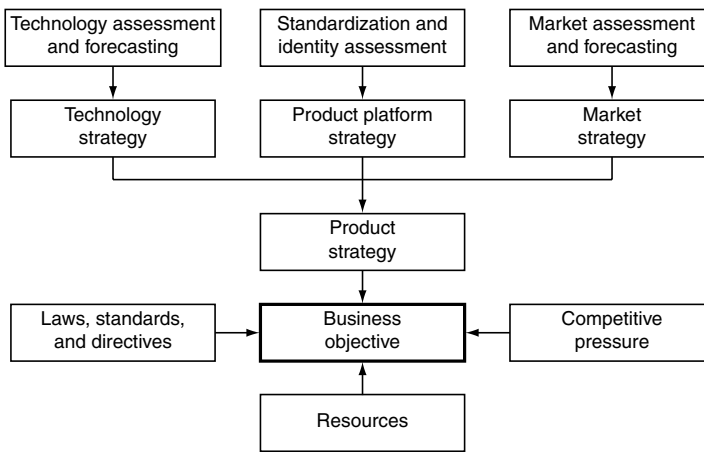


**Figure 2.2.** Deriving product definition

### *Business Objectives*

The business objectives can be defined as “the overall business goals for the new product development process” or “what the product should do for the business.” It can be the required return on investment, desired market share, and so on. The factors that influence the business objectives are as indicated in Figure 2.3.

<sup>7</sup> Refer to Cooper (2001); Khurana and Rosenthal (1998) for more details.



**Figure 2.3.** Factors influencing business objective

### *Customer Requirements*

For consumer durables, customer requirements, wants, and preferences (what the product should do for the customers) are identified through market research. A problem of concern is that customers often state the requirements in a vague manner. This represents a great challenge when conducting market studies and in translating the vague requirements into specific product characteristics.<sup>8</sup> For custom-built products, the customer usually defines the requirements, wants, and preferences in detail.

### *Concept Generation and Screening*

The process of generating feasible concept specifications is concerned with

1. Identifying the possible concepts that can be pursued to meet the business objective and the customer requirements
2. Evaluating the most likely candidates in terms of performance
3. Deciding on preferred concept(s)

The concept generation process starts with determining the overall functions (and sub-functions) of the product. What the product should do, is defined through these functions, prior to exploring product concepts and solutions.<sup>9</sup> Next, solution principles for the sub-functions are generated. A solution principle is

“An idealized (schematic) representation of the structure of a system or a subsystem in which the characteristics of the elements, and the relations

<sup>8</sup> See Urban and Hauser (1993) for the tools and techniques for identifying customer requirements. The quality function deployment (QFD) method is widely used for translating the requirements into specific product characteristics, see ReVelle et al. (1998).

<sup>9</sup> For further discussion, see Blanchard (2004); Fox (1993); Pahl and Beitz (1996); Pugh (1990); Suh (2001); Ullman (2003).

which are essential to the functioning, are qualitatively determined.”  
(Roozenburg and Eekels, 1995).

The solution principles for an overall system are determined from the combination of the solution principles developed for the different sub-systems. Further, the overall solution principles form the basis for concept variants. A concept should define the means of performing each major function, as well as the spatial and structural relationships of the principal components. Concepts should also provide sufficient detail for cost and weight approximations (French, 1985). The concept may be given a schematic representation in the form of a function structure, a circuit diagram or a flow chart (Pahl and Beitz, 1996).

The freedom to choose function structures and solutions depends on the degree of product modularization, as dictated by the product platform strategy set out by the manufacturer.

### *Product Platforms and Modularization*

Platform strategies and modularization have significant impact on the concept generation process. In the ever tougher global competition manufacturers are facing, many manufacturers attempt to reduce design and production costs by increasing the use of the same parts, or modules, across different products. Product platforms and modularization are common concepts in this context. A broad definition of a platform is (adapted from Meyer and Lehnerd, 1992):

“[...] a relatively large set of product components that are physically connected as a stable sub-assembly and are common to all different products.”

Muffatto (1999) describe a module as:

“[...] a large group of components that are physically coherent as a sub-assembly, which often has standardized interface designs. Modules may be common across different products, but they may also be specific to any one model.”

Product platforms allow manufacturers to reduce the number of product specific components, and, in turn reducing the production cost as plants are utilized better, and the logistics are simplified. It also allows manufacturer to better meet individual customer demands.

Long-term benefit from product platforms requires a long-term planning for product development. This allows many products to share the same product platform over some time.<sup>10</sup>

<sup>10</sup> Muffatto and Roveda (2000) discuss this in more detail. Gershenson et al. (2003) and Gershenson et al. (2004) present a review of existing research on measures of modularity and methods to achieve modularity in product development.

*Project Plan*

The project plan deals with planning the remainder of the new product development project in detail and deals with issues such as time and resource allocation, scheduling of tasks, and so on.<sup>11</sup> Blanchard (2004) provides a fairly extensive description of the necessary elements of the planning process and the project plan. The project planning encompasses:

- Activity planning
- Definition of roles and responsibilities
- Resource and service planning
- Risk management planning
- Establishing project performance measures

*Project Definition Review*

The project definition review encompass a final review and evaluation of the product definition and project plan, prior to making the decision whether or not to launch a full-scale development project.<sup>12</sup>

*Note.* Empirical studies show that for most manufacturers, this phase is often the least focused even for high-risk new product development projects, where the success depends very critically on the decisions made during this phase.<sup>13</sup>

**2.5.2 Design**

The design phase is concerned with arriving at product characteristics that may provide the desired product attributes determined in the front-end phase. This phase may consist of several sub-phases and decision points.

The initial efforts of the design phase are concerned with arriving at an optimal product architecture. According to Mikkola and Gassmann (2003), product architecture may be defined as

“[...] the arrangement of the functional elements of a product into several physical building blocks, including the mapping from functional elements to physical components, and the specification of interfaces among interacting physical components.”

<sup>11</sup> Some authors suggest the planning and launch decision to occur prior to the concept generation (Pahl and Beitz, 1996; Roozenburg and Eekels, 1995).

<sup>12</sup> Khurana and Rosenthal (1998) provide a review of the success factors related to the project plan in the context of new product development.

<sup>13</sup> Bulk of the literature deals with products involving incremental innovations and products with discontinuous (radical) innovations has received less attention (Reid and de Brentani, 2004).

The product architecture is established by considering the (physical) arrangement of and interaction between each sub-system, assembly, sub-assembly and components in turn. Functional decomposition and the definition of functional relationships between assemblies, sub-assemblies and, later, components is essential in the establishment of the product architecture, in order to clearly understand the interactions between objects. This understanding is particularly important concerning “modular” products.

Having established the product architecture, the detail design may commence. This is where all properties for each component are defined in detail (e.g., forms, dimensions, tolerances, surface properties, and materials). This is documented in assembly and detail drawings and bill of materials. Further, production documents are produced, as well as the transport and operating instructions.

The design phase involves running many design activities in parallel, and many product characteristics need to be considered simultaneously. Decisions made regarding one product characteristic may have implications for other characteristics, and changes in one component may require changes in other components. Thus, the design phase is strongly iterative. Many different approaches have been proposed in this context. These include the problem solving cycle proposed by Roozenburg and Eekels (1995), and the Design for X approach (see Meerkamm, 1990; Van Hemel and Keldmann, 1996). According to (Blanchard, 2004), Design for X is:

“[...] an integrated approach where design for reliability, maintainability, human factors, safety, supportability, interoperability, availability, life cycle cost, flexibility, transportability, producibility, quality, disposability, environment, and testability are considered throughout the process.”

Sim and Duffy (2003) look at the generic design activities and classify them into three categories:

*Design definition activities:* These activities involve evolving the product design at an ever increasing level of detail, until all details have been laid down, and the product is ready for production.

*Design evaluation activities:* These activities encompass analysis, evaluation, and comparison of potential design options, aiming at finding the best solution and potential improvements of the chosen solution.

*Design management activities:* These activities are concerned with coordinating and managing the design definition and evaluation activities throughout the new product development process.

### *Design Reviews*

Several formal design reviews may be carried out. In the early design phases, one or more reviews (the number depends on the product complexity<sup>14</sup>) may be required to verify the product architecture. Subsequently, more design reviews may be required to verify critical components. A critical design review is usually conducted to verify the final design, prior to the launch of production or construction.

<sup>14</sup> Blanchard (2004), for example, describes the system design reviews in more detail.



### 2.5.3 Development

The development phase is concerned with both component and product prototype testing. Development is mainly necessary when items involve new technologies, or their application is outside the range used in the past.

Tests are conducted using engineering breadboards, bench test models, service test models, rapid prototyping, and the like. The tests may encompass:

*Environmental testing/demonstration:* Temperature cycling, shock and vibration, humidity, sand and dust, salt spray, acoustic noise, explosion proofing, and electromagnetic interference.

*Reliability testing/demonstration:* Sequential testing, life testing, environmental stress screening and reliability growth testing.

*Pre-production tests/demonstrations:* To verify that the component may be produced and to reveal potential production problems, and ensure that the component produced has the desired performance.

When product prototypes become available, a range of tests may be conducted to predict or verify the product performance. The types of tests conducted are product dependent, and may encompass, in addition to those discussed in the previous section, the following:

*Maintainability test/demonstration:* Verification of maintenance tasks, task times and sequences, maintenance personnel quantities and skill levels, degree of testability and diagnostic provisions, prime equipment – test equipment interfaces, maintenance procedures and maintenance facilities.

*Support equipment compatibility:* Verification of the compatibility among the prime equipment, test and support equipment, and so on.

*Technical data verification:* Verification (and validation) of operating procedures, maintenance procedures and supporting data.

*Personnel test and evaluation:* Ensure compatibility between the human and the equipment, the personnel quantities and skill levels required, and training needs.

*Pre-assembly tests and evaluation:* Ensure that the product may be assembled as intended, with the equipment and manning specified.

*Field tests:* Verify that the product can be used and maintained when the specified operating personnel, operational test and support equipment, operational spares and validated operating and maintenance procedures are used.

*Market pre-launch:* Test the product on small market segments to verify that it meets customer expectations in the case of standard products.

The development phase serves two purposes. For custom-built products, the purpose is often to verify that the desired performance that was agreed as part of the contractual agreements between customer and manufacturer are met. If the actual (predicted performance) falls below the desired performance, the development process involves understanding of the causes of the problem and then coming up with solutions to fix the problem.

### 2.5.4 Production

Having, throughout the design and development phases, found a solution that meets the desired performance, within given constraints, the challenge of the production and assembly/construction phases is to retain the designed-in performance.

Despite the efforts throughout design and development to ensure optimal production and assembly characteristics,<sup>15</sup> no production system is able to produce two exactly similar outputs. This may be explained by variations in:

- Input materials
- Production process
- Operator skills
- Other factors such as environment (e.g., temperature, humidity)

There are several strategies to ensure that the product performance of the items produced matches that of the prototype. These include the following:

#### *Process Control*

The process state can be either in-control (so that the effects of assignable causes are under control and very few items produced are non-conforming) or out-of-control (due to the effects of assignable causes and resulting in a larger number of non-conforming items being produced). The effect of assignable causes can be eliminated through proper design of the process (e.g., using Taguchi methods) and is referred to as off-line control. Through regular inspection of the items produced and using control charts, we can detect the change from in-control to out-of-control and this is referred to as on-line control.<sup>16</sup>

#### *Inspections and Testing*

In addition to statistical process control, several inspection and testing methods are aimed at ensuring conformance to the built-in performance of produced items. These include:

*Acceptance inspection and testing:* Inspection and testing of raw materials, parts and components upon receipt from vendors, at any point in the production process, or after the final production, to decide whether or not to accept the items.

*Audit inspections:* Periodic random inspections of plant or departmental quality processes and results.

#### *Custom-built (Specialized) Products*

For custom-built products, the demands for conformance may be very high (e.g., satellites, submarines, and nuclear power plants). In these cases, the product is subjected to a series of tests (specified in the contract) prior to being handed over to the customer.

<sup>15</sup> See Boothroyd et al. (2002) for a description of design for manufacture and assembly.

<sup>16</sup> See Thompson and Koronacki (2002), Smith (2004), and Oakland (2008) for more on statistical process control.

### 2.5.5 Post-production

For standard products, this phase involves two sub-phases – marketing and product support. For custom-built products, this phase comprises only the latter.

#### *Marketing*

This sub-phase deals with issues such as the logistics of getting the product to the markets, sale price, promotion, warranty, channels of distribution, and so on. The strategies that we formulate for some of these (e.g., price) would need to change over the life cycle and in response to external factors such as competitors' actions, economy, customer response, and so on.

#### *Price*

There are two approaches to pricing. The first is based on the cost of manufacture (which includes development, production, and marketing costs) scaled upwards to ensure the desired profit. The second is based on market demand and supply considerations. For a product new to the market, the sale price is generally high at the start of the life cycle and comes down during the later stages partly due to reduced production costs, but also because new competitors appear in the market.

#### *Promotion*

Depending on the product, the manufacturer can use different media (e.g., television, radio, newspapers, magazines, mail brochures, and leaflets) to promote the product. The duration or size of a particular advertisement and the frequency of repetition have an impact on consumer awareness and their decision making processes. For expensive products, the kind of product support that the manufacturer provides can also serve as a very effective promotional tool as well as for differentiating from competitor's products.

*Example 2.4 (Cellular Phone).* Any advertising slogan or message has a limited life and manufacturers need to come up with new ones. Sohn and Choi (2001) look at the advertising lifetimes for cellular phones sold in South Korea by five different South Korean manufacturers during 1997-1998. The following data (for LG Telecom 019) is extracted from their Table 1.  $\oplus$

Title of advertisement	Duration of advertisement	Advertisement lifetime (days)	Subscribers during the advertising period	Number of advertisements switching by competitors
The birth	09/08/97 – 31/08/97	23	88,136	0
Family	01/09/97 – 26/11/97	87	218,817	6
Cradle song	27/11/97 – 12/03/98	106	406,223	12
The vivid PCS	19/01/98 – 25/03/98	66	361,346	4
My father	13/03/98 – 04/08/98	145	768,433	11
Shining PCS	11/04/98 – 10/09/98	153	685,103	14

### *Product Support*

When making purchases, customers believe that they are buying more than a physical item. These include maintenance, spare parts, training, upgrades, and so forth. They also have expectation about the level of support service subsequent to the sale of the product and this is called product support.

Product support service refers to the different types of services needed over the useful life of a product (consumer non-durable, commercial or industrial) to ensure satisfactory operation of the product. Product support service can add value to the tangible product in several ways:

- Extending the product life cycle
- Maintenance can give a product further use and postpone replacement
- Direct value in initial sale of product
- Delivery, installation, base and extended warranties add value to the product from the customer perspective

Product support service can include one or more of the following activities:

- Parts, information, training
- Installation
- Maintenance/service contracts
- Warranties, extended warranties, service contracts
- Design modification/customization

## **2.6 A New Model for Product Performance and Specification**

Even though many new product development models discuss product performance and specifications, no model addresses this in an effective manner. In this section we propose a new model that is more appropriate for making decisions relating to performance and specification in new product development. It is closely linked to the product life cycle model given in Figure 1.1 and involves three stages and three levels. The three stages are as follows:

*Stage I (Pre-development):* This stage is concerned with a non-physical (or abstract) conceptualization of the product with increasing level of detail.

*Stage II (Development):* This stage deals with the physical embodiment of the product through research and development and prototyping.

*Stage III (Post-development):* This stage is concerned with the remainder of the product life cycle (e.g., production, sale, use) subsequent to the new product development.

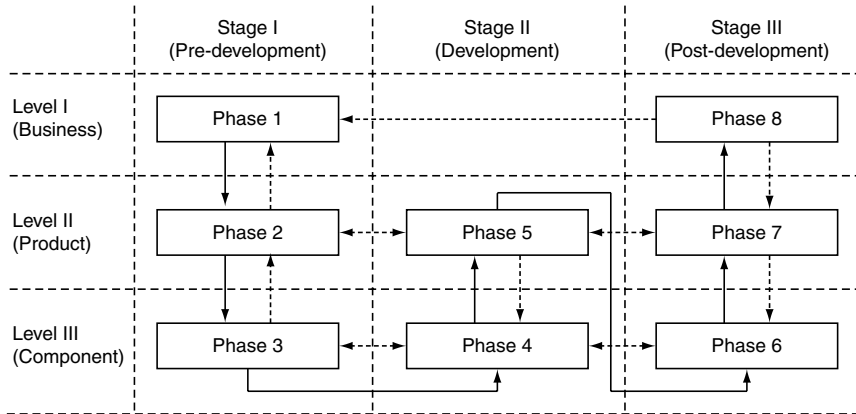
The three levels are as follows:

*Level I (Business level):* This level is concerned with linking the business objectives for a new product to desired product attributes.

**Level II (System, i.e., product level):** This level links product attributes to product characteristics – the product is treated as a black-box.

**Level III (Component level):** This level is concerned with linking product characteristics to lower level product characteristics, at an increasing level of detail.

The new model has eight phases as shown in Figure 2.4. Some of the phases can involve several sub-phases. The activities in the different phases are as follows:



**Figure 2.4.** New model for product performance and specification

**Phase 1 (Stage-I, Level-I):** In this phase the need for a new product is identified and the decisions related to the product attributes (customer's view of the product) are made from an overall strategic management level of a business.

**Phase 2 (Stage-I, Level-II):** In this phase the product attributes are translated into product characteristics (engineer's view of the product).

**Phase 3 (Stage-I, Level-III):** In this phase the detail design (proceeding from product to component) of the product is carried out in order to arrive at a set of specifications that will ensure that the product has the required characteristics.

**Phase 4 (Stage-II, Level-I):** This phase deals with product development, from component to product – and ends up with the product prototype.

**Phase 5 (Stage-II, Level-II):** In this phase the prototype is released to a limited number of consumers to evaluate the customers' assessment of the product features.

**Phase 6 (Stage-III, Level-III):** This phase deals with the production of products starting from component and ending with the product for release to customers.

**Phase 7 (Stage-III, Level-II):** This phase looks at field performance of the product taking into account the variability in usage intensity, operating environment, and so on, from the customer perspective.

**Phase 8 (Stage-III, Level-I):** Here the performance of the product released for sale is evaluated from an overall business perspective.

The link between the phases of the new model and the product life cycle phases in Figure 1.1 is indicated in Figure 2.5.

Phase 1	Phase 2	Phase 3	Phase 4	Phase 5	Phase 6	Phase 7	Phase 8
Pre-development			Development		Post-development		
Front-end		Design	Development		Production	Post-production	

**Figure 2.5.** Comparison of the new model and the product life cycle model in Figure 1.1

The activities in the eight phases are sequentially linked as illustrated in Figure 2.4. Decisions must be made at the end of each phase to either move forward or to iterate back (as shown by dotted lines in Figure 2.4) and this is discussed further in Chapter 3.

Product Reliability

Specification and Performance

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