

Technological Innovation and Strategy Adaptation in the Product Life Cycle

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ABSTRACT

The development of technologies and products, like the growth of organisms, has different stages. Enterprises must continuously upgrade technologies and products due to technological and economic progress. Therefore, the use of different innovation methods and strategies in different stages to reduce disputes and predicaments is essential for the survival and development of enterprises. This study begins with the description of the life cycles of products and technologies. The differences in competition and innovation strategies, as well as in methods of technological innovation at different life cycle stages are also investigated. This investigation also provides and discusses technical examples of conventional mechanical engineering and advanced computer equipment, thus providing a valuable reference for the R & D and managers regarding innovations in products and technologies.

Keywords: life cycle, technological innovation, strategy adaptation, patent, customer requirement, TRIZ

INTRODUCTION

Product life cycle describes the processes that products undergo: from the initial research, through market promotion and, ultimately, the exit of the product from the market, as Figure 1 depicts. Products or technologies behave differently at different stages of the life cycle, and the recognition and demands of products also vary over time. Such dynamic requirements of products and technologies influence the marketing policies of firms and even product design strategies in different industries, which in turn influences the profit of the firm. Many researchers have concentrated on product design and strategic planning in product life cycles. For example, the concept of “life extension” is introduced, in which a preplanned program for market expansion (i.e. exploitation of new uses or new users) is required for original producers [1]. A framework is developed for examining how the requirements of customers are integrated into a product design process [2]. Meanwhile, five kinds of consumers and six stages of technology adoption life cycle are presented to investigate how the environment and marketing strategies are related at different stages of the life cycle [3]. Furthermore, a set of key concepts concerning technological innovation and strategies are defined and their relationships are outlined [4]. That work separately proposed and discussed several strategies and their importance. Finally, a model is constructed by considering relationships of two sets of distributions for the market population and product

use to establish product architectures as a design tool for research and development [5]. However, little information is available on how the design methods, marketing strategies, patent issues and the life cycle link and integrate together. Few studies have investigated the innovation methods and strategies suitable for different stages of product life cycle (PLC). This investigation considers the characteristics of innovation methods and market behaviors at different stages of PLC. The research and development staff and managers can consider the market environment and firm policies together and innovate the product design process by suitable innovation methods. Adaptation of strategic innovations is also presented according different stages of PLC to assist firm managers in handling various conditions during PLC.

LIFE CYCLE OF PRODUCTS AND TECHNOLOGY

The life cycle, as Figure 1 portrays, can be described by a S-curve. From the perspective of profit with respect to time, the curve can generally be classified into four stages as follows:

- (1) Market introduction: The market introduction of products begins when a new and innovative product passes quality and function tests, and is introduced to customers. No products already in the market share the functions or appearance of the product, and thus the market is uncontested.
- (2) Growth: When the innovative products are marketed and gradually approved by customers, profits also increase. If the products have superior functions and technology to existing products, and if this superiority is confirmed by market testing

and use, the products and their corresponding technologies will replace existing products. However, if customers do not appreciate the innovations, the products will quickly vanish from the market. When a product is successful, more and more enterprises will begin to develop similar products and technology. Meanwhile, the original enterprises, which have been involved in researching such products since their beginnings, will seek to constantly improve their products according to the requirements of customers to enhance their competitiveness.

(3) Maturity: Reliability and quality of products peak during this period. Enterprises also profit enormously, but profit growth begins to slow. A few brands of products dominate the market.

(4) Decline: A new generation of products appears. Most enterprises' products lose their competitiveness since the appearance of mainstream brands. Price competition characterizes this period.

Some researchers have also included two stages before the marketing of products, namely pregnancy (or product planning) and birth [6,7]. The two stages in their research are the emergence of design problems and the generation of product design ideas. The turnover profit during these two stages is negative.

In fact, other characteristics of the research process, such as the number of inventions, number of patents of specific products or technologies, and performance quality, can also be

described via individual curves. Managers of firms can understand the stage their products are situated at by observing these various curves. The policy of enterprises regarding technology and products, management strategies, and research and development methods must be modified to fit the evolving market environment when the stage of product life cycles has varied.

Generally, products are developed according to the demands or marketing strategies of an enterprise. Customers expect certain products to have certain functions. Such demands will evolve, but will still endure, as Figure 2 illustrates. Spurred by product demands, technologies will be developed to overcome some technical difficulties and meet customer requirements. Technologies, like products, also have life cycles and can be described by the same four stages, as Figure 2 presents. An applied technology is always developed from theory or applied science. When a technology is developed and located in a specific stage, many products are exploited by that technology in that state. The life cycles of these products will evolve alongside that of the technology. Restated, each stage of the life cycle of the technology may contain many generations of product evolution. Therefore, research and development teams and managers within enterprises must understand the environmental characteristics the locations of enterprises, and must use different innovative methods and strategies in product development to let the products satisfy market requirements.

CHARACTERISTICS OF INNOVATIONS RELATING TO LIFE CYCLES

Because technologies and products in the initial stage of the life cycle, market introduction, are by definition new, research and development teams have no experience of such products and related technologies. Market needs and customer requirements are also uncertain. Additionally, only a few enterprises are pursuing such research because of the higher risks involved in the initial stage of research and development. Necessarily, knowledge and information about the products and technology is very poor. Therefore, technology and product innovation is only possible by combining science or relying on the research and development knowledge base. Since most technologies originate from theoretical sciences, applied sciences or other natural rules, research and development can develop products by combining basic product requirements, knowledge of applied science, social factors and enterprise policy. In this stage, research and development often undergoes a five stage innovation-adoption process: selection of knowledge relating to the innovation, formulation of an attitude toward the innovation, decision to adopt the innovation, implementation, and the decision to retain or discard the innovation once implemented [8]. Owing to rapid developments in computer science, expert systems or databases can be constructed from the engineering and scientific knowledge in all regions that help research and development to grab the required information to help to make decisions regarding knowledge selection for product innovation. As well known, the related information for the new products and

technologies at the market introduction stage are lacking and the resources from the expert systems or database are notional. Therefore, the further design and developments of products and technologies need impetus from research and development to obtain conceptual designs. Embodiment designs and detailed designs can only be implemented by evaluating all possible conceptual designs and choosing the best. Such impetus is often generated from a research and development team using brainstorming. Brainstorming has two steps: (1) Propose individual opinions or ideas as much as possible, with team members refraining from criticism. (2) Categorize the proposals and present them for expert evaluation. The result of this evaluation is then returned to the original team for review.

When products begin the growth stage, an increasing number of enterprises become involved in related research. Because the first enterprises to begin launching the product into the market have accumulated considerable experience, they can support further product and technological innovations. The innovation strategies adopted by enterprises at this stage are to refine the technologies applied to their products (for example, to enhance manufacturing quality and stability) and to add more product functions. However, improving one aspect of the system or adding a new function often harms other system parameters, and thus generates “contradictions”. Research and development traditionally chooses compromises or trade-offs to solve problems of contradictions. However, this traditional compromise approach leaves the core problems unresolved. Additionally, such methods increase

development costs. The Russian inventor, Genrich Altshuller, developed a problem solving method, named “TRIZ” or “TIPS”, to overcome contradictions during the innovation [7]. TRIZ introduces two important concepts and problem solving techniques, namely “contradiction solving” and “ideality”. The first step to solve contradictions in the innovation process involves formulating the right problem by analyzing the interactions between elements in problem systems. Altshuller found that most challenging engineering problems involved physical or technical contradictions. The “physical contradiction” occurs when the performance or the value of one parameter in the system in one condition behaves oppositely to that in another condition due to the requirements of other system behaviors. Sometimes improving a certain system parameter occasionally enhances one aspect of performance, such an improvement is detrimental to another parameter and erodes other aspects of the system performance. Such a condition is a “technical contradiction”. Figure 3 presents the rules of contradictory problem solving. If innovative problems involve physical contradictions, resolving methods by considering the separation of action or appearance of components in space, scale or time are recommended by Altshuller. However, if the contradictions are technical, TRIZ introduces forty principles which can solve approximately 1500 problems formed by a contradiction matrix, as Figure 4 shows [9]. These principles have been derived from patents that solve the same contradictions. These principles include concepts such as “Segmentation”, “Extraction”, and “Do it in reverse”.

The discovery of the contradictions needs research and development experience, however, which can be obtained by using theoretical methods, such as the Theory of Constraints [10, 11]. The Theory of Constraints (TOC) provides the skills of “Conflict Resolution Diagram” and the “Current Reality Tree”, as Figures 5(a) and 5(b) indicate, to help the research and development team locate the contradictions and core problems behind the current problems embedded in the systems.

Most technologically leading firms (TLFs) or first-to-markets firms generally dominate the supply of new products and enjoy the added value of their inventions at the growth stage since they entered the market before others, and have more research and development experience. Meanwhile, rising enterprises (REs) can independently research and develop competing products and technologies if they have comparable research and development abilities. However, most REs hope to shorten the research and development period of their products so that they can gain a market share. Additionally, product function and performance must closely mirror that of the TLF products. Consequently, the research and development strategy for the REs during the growth stage is imitative innovation. The REs develop products and technologies by using general innovation methods, including reversal, transfer, combination, change of direction, extension and reduction [12], hereinafter termed the six general innovation methods. These six general innovation methods are applied to the appearance or functions of existing commercialized products. Some REs will directly copy

the products of TLFs in the hope of greater profit.

As the products mature, product and technological competition between enterprises has intensified. To increase competitiveness, enterprises must enhance the performance of original products or redesign products to fulfill customer requirements. Therefore, researching customer requirements is crucial for innovation at this stage. The Quality Function Deployment (QFD) method is often employed as a research and development strategy to help the research and development and market research staff to study customer requirements and their relative importance [13, 14]. Market research staff cooperate with the research and development team to list expectations of all users (including manufacturers, assemblers, and other end users) and evaluate the relative weight of these expectations. The requirements obtained directly from customers are usually ambiguous or merely qualitative descriptions, accounting for why they cannot be used as design criteria in engineering for research and development. Thus, the research and development team must translate customer requirements into physically measurable values. All the competitive products in the market can be rated quantitatively. Figure 6 displays the overall flowchart for implementing this work. The innovation methods used for product development according to customer requirements can not only be used by the TLFs to produce products that match customer requirements and market flows, but can also be adopted by REs that begin to exploit the market at the maturity stage. Since the corresponding product information is abundant

and the applied product technologies are complete, the concept of “evaluation of subsystem function” can be used as another innovative research and development strategy. The research and development team can decompose the products of competitors into several subsystems according to the functional requirements. A complete product can then be obtained by evaluating the corresponding subsystems and related technologies of those competitive products. If the QFD method alone is used for innovation, the design outcome may still have the possibility of infringing on existing patents [15] since there are numerous competitors’ patents at this stages (even this design outcome can be granted a patent).

Besides satisfying customer requirements, enterprises have to control or enhance the quality and performances of their products at the maturity stage. Restated, further innovation on manufacturing is needed. In practice, the Taguchi Method or Method of Experimental Design is frequently employed to discover the key parameters influencing product quality. No additional cost is necessary when the competitiveness can be increased by performing the innovation using such a method.

When products approach the decline stage of the life cycle, other new products and technologies may emerge. However, the newly emerging products remain embryonic and hence unable to replace the established ones. Therefore, the existing products retain their market value despite being old fashioned. Since the functions and technologies employed differ little among all kinds of products and technologies, price competitiveness is the main

issue. If enterprises hope to survive, then when their ability to lower costs to extend profits is exhausted, other innovations should be considered. Because most products have similar functions at this stage, product performances (for example, weights or strength) can be promoted by selecting advanced materials to add value and expand lifetime. Besides the strategy of using different materials, development of side products will become mainstream.

Product cost directly relates to the number of parts in the system. However, research and development often increases product elements or subsystems to increase product functions during the growth or maturity stage of the products. If product cost cannot be reduced without compromising the original functions or performances, the products will be superannuated easily during the decline stage. Thus, research and development at this stage emphasizes ways to reduce costs by reducing elements in products. TRIZ, developed by Altshuller, conceives of the “ideal machine” to overcome the problem. The conception of “ideality” introduced in TRIZ is such that an ideal machine could perform all required functions without actually existing. No extra cost would be required to build or maintain such a machine. In fact, the “ideal machine” is a kind of innovation method that combines the functions of product subsystems. Eliminating the elements in products is one means to achieve this purpose. Three methods can be categorized by considering the relationships between the function carriers and function receipt carried out by elements in products:

(1) The recipient of the function is unnecessary: The research and development team

investigates the product functions through value analysis. If the products do not need the specific functions or if the efficacy generated by the specific functions is too small, the recipient and the corresponding carrier of the function can reasonably be eliminated from the product. Such eliminations reduce manufacturing costs.

(2) The recipient of the function can provide the function itself: Here, the recipient and the corresponding carrier of the function are integrated. The system retains the same functions, but has fewer elements. Consequently, manufacturing, assembling and maintenance costs are reduced.

(3) The function can be performed or delivered by other elements of the system: This method can eliminate redundant elements.

Importantly, the innovation methods or research and development strategies discussed above in relation to different stages of life cycle are not limited to their corresponding stages. Take the concept of “ideal machine” for example. Applying this concept at the market introduction or growth stage would produce more added value and more reliable products, helping the enterprise to fortify its market position. Additionally, the innovation methods are not considered in isolation. Some innovation methods presented in the foregoing are interrelated. Take TOC, “six general innovation methods” and TRIZ for example. The “six general innovation methods” can be viewed as more generic approach than the forty principles in TRIZ. The former methods provide research and development with a new

thinking-process, while the later simply embody the former methods. The research and development team can discover whether there are contradictions behind product improvements or innovation process, and discover the core problems by TOC. Core problems can then be solved by using the Altshuller contradiction matrix or separation principles.

Since the recognition of and demand for products and the related acquirable information vary with product life cycle, the emphasis and direction of innovation in an enterprise at different stages change according to firm policies and the market environment. However, innovation methods at a specific stage of product life cycle are certainly not invariable, and they must be modified according the market requirements.

COMPETITIVE STRATEGIES OF PRODUCTS IN LIFE CYCLES

The competitive strategies of products can be treated as the research and development policy of a firm. In addition, manufacturing and marketing can be done by the strategies to maximize market share or profit when promoting products. Different strategies and plans have been proposed and employed according to industry characteristics or the visions of firms. Professor Michael Porter [16] has presented “three generic strategies” which can be chosen:

- (1) Cost leadership: Minimizing product cost by standardizing product elements;
- (2) Differentiation: Manufacturing or providing distinct products and services, such as the high quality products;

(3) Focus: Establishing niche markets by focusing on special customers, geographical environments, marketing channels, or distinct segmentation of product lines.

In fact, a firm with innovative products must modify its competitive strategies according to environmental changes. Therefore, enterprises must develop different research and development and marketing strategies when their products are at different stages of the life cycle.

At the market introduction stage, the applied sciences and technologies for products are immature, and the marketing position and the required functions of products are often undetermined. Therefore, the research and development strategies basically involve innovation-leadership, which has unheard-of functions, performances or characteristics. Because customers are unfamiliar with the new products and technologies and their innovative inertia, enterprises should use “propagation of product functions” as the marketing strategy, introducing the merits and characteristics to the market. Enterprises should further use “local encroachment” to call the attention of certain individuals to the innovative products. The products and their employed technologies can then be easily accepted by customers through the power of the specific persons in their company or in the market.

Besides, since product knowledge is poor and the corresponding technologies are ill defined, many enterprises are concerned about research and development risks. Only a few firms involve themselves in the product innovations. Each of these firms develops its own product

standards and specifications. The market is in a state of “disunion”.

At the growth stage, an increasing number of enterprises begin to innovate related products since they understand the profit potential from such innovative products. Thus, the market is characterized by fierce competition. The REs that want to share the market must develop products that differ in function or appearance from others. Simultaneously, the TLFs that want to maintain or extend their market share enhance their products with more functions. Therefore, the aim of research and development at this stage is functional leadership. Because each product brand has its own characteristic functions, the REs often advertise or hold sales promotions as marketing strategies. To protect their own markets and intellectual properties rights (IPRs) on technologies and products, the TLFs, besides using advertisements and sales promotions, actively protect their IPRs, such as patents, trademarks, and copyrights. Enterprises emphasize patents above all else since the patent right can provide wide protection on inventions and innovation, and is highly exclusive. Accordingly, the patent portfolio is an important competitive strategy at this stage. Meanwhile, enterprises may sometimes consider strategic alliances to develop compatible products in specifications, lower research and development costs, and utilize competitors IPRs.

Because the selection of product related functions and the path of research and development mainly rely on the policies of firms or on the viewpoints generated from the research and development department during the growth stage of the products life cycle, the design process

often ignores customer demands. Therefore, a customer has no opportunities to buy a product with functions or performances that match his/her requirements. By the maturity stage, there the same type of products share almost exactly the same functions, and specifications become standardized due to cooperation and information distribution between enterprises. The major opportunity for creating difference thus arises from considering customer requirements. Restated, the innovation strategies at the maturity stage should mainly focus on customer-requirement-leadership.

Since the product performance and the corresponding technologies are almost fully developed at the maturity stage, the relationships among the technical features of subsystems adopted by the REs in the design process may infringe existing patents developed by competitors during the market introduction stage or growth stage. Therefore, patent disputes and lawsuits about patent infringements are the main characteristic of competition at the maturity stage. To avoid serious property damage and avoid bringing bad influence to enterprises, patent-licensing is often treated as the means to solve the patent disputes. Besides being used for solving patent disputes, patent-licensing is also required for some enterprises to develop their products since their patents may be developed under competitors' existing patents.

TLFs obtain the maximum rate of profit increase once they struggle beyond the market introduction and growth stages. Meanwhile, the competitors or REs can reduce research and

development costs if they begin their development at the maturity stage since information on product innovation is rich and the corresponding technologies are mature. However, if the REs use non-licensed patents when developing their products, the impacts may be serious. Therefore, the maturity stage is when the survival and profitability of enterprises is determined.

To enhance profits, enterprises at the maturity stage frequently use marketing segmentation by choosing the markets and customers appropriate to firm policies and product position. Once the specific markets have been determined, managers of firms strive to increase their production and hence profit.

As the maturity stage passes, representative product brands (that is, mainstream brands) are generated. However, the products also enter into the decline stage of the life cycle. Simultaneously, other innovative products and technologies that can replace those declining ones begin to appear. This development does not mean that those declining products have no marketability, but it does force enterprises to set up different marketing methods or competitive strategies, such as lowering product prices, improving product aesthetics, or developing auxiliary parts of the products. Meanwhile, because mainstream brands have been generated, new enterprises are forced to develop compatible products. The major driver of market competition at this stage is price.

Innovations should consider product competition strategies. Once the marketing

strategies or competitive environment have been varied, the corresponding modifications to product design should be considered to face different market challenges. Similarly, the product competition strategies are also not fixed. The strategies discussed for each stage are typical of each stage, but not unique to it, and hence they can be employed in advance or repeated later. For example, introducing the patent allocation plan at the stage of market introduction and QFD at the growth stage can enhance profit and market shares for an enterprise.

PATENT INNOVATION FOR PRODUCTS' COMPETITIONS

Many industrial cases revealed that if innovations can proceed at the market introduction stage, and if enterprises can overcome innovation gaps (for example, risks of innovations, and the acceptability of new products to customers) and enter the growth stage, the enterprises can easily dominate the market and become very profitable. However, few enterprises have the means of desire to embark on the risky, laborious and costly process of product innovation. Meanwhile, customer hesitancy to adopt new products is a further barrier to innovation. However, once the innovative products and technologies have been propelled by pioneers to the maturity stage, they become readily accessible in the markets, and thus standards and specifications of related technologies and products come to be fully developed. Once this stage is reached, customers become more likely to accept the products. Meanwhile, the REs can rapidly develop and promote the products by improving the defects of existing products.

In fact, most enterprises begin research and development to improve the mature products. However, since enterprises want to protect their intellectual property, the risk of patent infringements increases despite the lower research and development costs for REs that enter the market at the maturity stage. Hence, the only way to both avoid patent infringements and reduce research and development costs is to incorporate the patent database in the product development process.

The World Intellectual Property Organization (WIPO) revealed that 90% to 95% of all the inventions in the world can be found in patented documents, and 80% of these techniques do not appear in other professional articles [17]. Thus, patent literature is an enormous and unique database. Research and development can exploit newly developed technologies to obtain the required concepts by searching the patent database. This is advantageous in that it decreases research and development time, reduces risks, and increases the patentability of products.

The patent database makes two innovation methods possible: (1) combining QFD with patent information, and (2) designing around the granted patents by combining the skills of patent infringement justification and patent laws [15]. The former method, while incorporating QFD, examines the requirements and importance of subsystems in products. Each patent search of the related products proceeds concurrently. Techniques that have been applied in each subsystem as disclosed in the patent database are listed. The techniques for

the same subsystem are evaluated and the best one is selected. New products can be generated by reconstructing the connection between the optimum techniques through experience and knowledge of research and development. Figure 7 displays the flowchart for implementing the method described above. The techniques applied in the system, when viewed as a whole, will differ from existing patents because of new connections developing among the subsystems.

The other method, designing around the existing patents, is based on a sound understanding of the legal justifications required to prove patent infringement. Some risk of infringement remains because of the uncertainty of judging whether there are substantial differences between the new design that results from designing around a given patent and the claims made by the owners of that patent. Therefore, this method is somewhat uncertain. However, designing around patents remains an economic but practical product development method when compared with most research and development methods. The process of designing around can be represented as follows:

- (1) List the claims in diminishing order of breadth.
- (2) Eliminate first the broadest and then the less broad claims.
- (3) Use the characteristics of novelty and non-obviousness to continuously eliminate claims by reference to commercialized products and related techniques in the market.
- (4) Substitute other elements, obviously different in appearance, for the elements in the

claims.

- (5) Make at least one condition of the triple test of the way/function/result substantially different in the step of the doctrine of equivalents, or eliminate an unimportant element.

Both “the ideal machine” of TRIZ and the process of designing around patents share similar ideas. The ideal machine eliminates the subsystems or elements with low value based on the results of value analysis. The other existing subsystems are substituted for the eliminated subsystems in the original functions acted by the eliminated subsystems. Briefly, the application of the concept of the ideal machine can reduce the number of elements in the systems to lower product cost and enhance product reliability. Meanwhile, innovation by designing around existing patents hopes to reduce the elements that construct the claims or to replace existing elements with different ones, and thus get around existing patents. Both approaches aim to reduce the number of elements in the products.

In fact, the two patent based innovation methods described above (that is, patent database in combination with QFD and patent designing around), avoid the scope of existing patent claims so as to prevent infringement of the exclusive rights of patentees in manufacturing or selling. Because the defects or disadvantages of existing patents can be investigated by studying the specifications or/and claims, research and development teams can use the these two methods above to develop their products speedily and market them at a lower cost and

higher profit. For the TLFs to maintain their market lead, one strategy is to have good patent allocations and write patents carefully so as to prevent others from designing around them.

STRATEGIC INNOVATION OF INDUSTRY

Besides innovating and improving products and technologies by aiming at product characteristics and market requirements, enterprises should also consider innovation in the value chain to maximize profitability. Enterprises cannot be completely competitive if they overlook the steps between product manufacturing and marketing, even if they have the very best product development teams. Restated, maximizing competitiveness in product innovation is not equivalent to maximizing profitability. Therefore, enterprises require industrial strategy innovations as well as product and technological innovation. The policy of firms must be determined according to such factors as the characteristics of product life cycles, technologies, manufacturing [18], and the competitive environment. Davis [19] also considered that technological, manufacturing, marketing and human resource strategies should be integrated. Therefore, for enterprises with specific well-developed marketing channels that want to introduce new products, new marketing channels (such as Internet and electronic media) should be considered in addition to existing marketing channels. For REs or enterprises with few marketing resources, a common means of quickly introducing products to the market and establishing a brand, is to hold sales promotions or/and develop products fully matching customer requirements. For enterprises that would not like to have their

trademarks on their products, or for enterprises that are OEM (original equipment manufacture), their survival depends on success in price competition. To extend their OEM life, increase profits, and maintain cooperation with consignors, quality control and technological innovation to improve manufacturing are required to enhance manufacturing quality and thus competitiveness. However, OEM enterprises should strive for the transfer of key technology from consignors, thus becoming ODM and obtaining more profit.

Thus, in addition to considering the roles and vision of enterprises, different strategies should be adopted to fit of the changing industrial ecology when the products of enterprises are at specific stages of product life cycles. Since enterprises face different issues at different stages of their product life, as Figure 8 shows, corresponding strategies should be proposed to deal with these problems. These strategies can be considered from three aspects, namely, cooperation and competition (co-opetition) status, enterprise operation and industrial values. Tables IA and IB list the strategies considered during the market introduction period for improving the values of the three aspects mentioned above when facing problems of marketing exploitation and how to develop and apply technologies in product planning, respectively. The strategies that should be presented inside enterprises during the growth period are indicated in Tables IIA to IIC to deal with the issues of over-demands, competition of substitutable technologies and time to market, respectively. When products reach maturity, problems of intensification of product qualities, product diversification and emergence of

professional OEM become dominant. Tables IIIA to IIIC represent strategies that can be adopted to improve the values of the three aspects and enhance competitiveness. Once the decline stage arrives, enterprises must become aware of price competition, product substitution, and related factors. Increasing the added value of accessories of products, exploiting another applied areas of products and other strategies listed in Tables IVA and IVB can be effective here.

In fact, many successful enterprises innovate on their industrial strategies in addition to their skill in technological innovation. The leading bicycle components supplier, Shimano, is an example. It has a high market share because of its quality products, innovative technologies, and the numerous good quality patents. Customers had to buy a complete set of transmission components of bicycles in one deal before the 1990s, reducing the competitiveness of other enterprises. Rivals cannot even imitate related products with similar performances due to the Shimano's patent strategies. Because of antitrust disputes, the products of Shimano cannot be tied in recently. However, owing to Shimano's leading status on the market, other enterprises can only design and manufacture compatible products with lower prices, and the product-development-orientation of all products continues to follow Shimano. Competitors often delay product innovations in similar functions and features with those of Shimano until after Shimano announces its new products. Such a strategy reduces the market share of Shimano for the products with medium and low prices. To

improve this condition, Shimano decided to delay its own announcement of new products, causing the enterprises of complete cycles to postpone orders from the suppliers. This strategy disrupts manufacture and operation plans of bicycle component suppliers.

Enterprises of other industries have also developed specific strategies to match their environments and firm policies. Figure 9 depicts the innovation of UMC on the segmentation of its industrial value chain. The original policy of the firm was to proceed integrated design and manufacture (IDM), from the design of IC chips through the cutting of wafers to product testing. After considering the whole competitive environment, the firm segments the entire product development process and focuses on the aspect of manufacturing services. Figure 10 displays the innovation on the rearrangement of the value chain of Dell's computer. Dell's direct computer company integrated the chain-links between the brand marketing and sale channels. The company provide computers to customers directly through its sale channels and Internet. Suppliers can also understand the situations of the assembly process from communicating via the Internet and knowing which components are out of stock.

Innovation of industrial strategies clearly follows some rules. However, although patterns of innovation across different industries can be imitated, they cannot be transplanted directly. Different enterprises must modify strategies to fit firm policies and competitive environments during product life cycle.

CASES STUDIES

Two industries are presented below as illustrative examples to explain how the innovation strategies are applied to product design.

Case 1. Sprockets of Freewheels in Multi-speed Bicycles

Figure 11 schematically depicts the speed-changing system in a bicycle. The shape of teeth was regular before 1980. The shifting process for reducing speed in a multi-speed bicycle forces the chain to shift from a smaller sprocket to a larger sprocket by pulling the rear derailleur. Similarly, to accelerate, the chain is forced to shift from a larger sprocket to a smaller sprocket. However, varying the speed of a bicycle by forcing the chain to shift in two adjacent sprockets causes serious friction between the chain and sprockets, reducing the life of the transmission subsystem, generating noise, and destabilizing the changing process. To enhance the speed-changing performance for sprockets, different suppliers of bicycle components design the sprockets of freewheels with various methods. Table V summarizes the several important inventions (patents) in the sprocket development process and Table VI lists the evolution of Shimano's sprockets. The two tables reveal that the basic concepts and principles of sprocket innovations were introduced by slanting the tip of teeth directly so that the sprockets have the basic functions in smooth chain-shifting in the early 1980s. This design is characteristic of the market introduction stage. By the late 1980s, almost all sprocket designs incorporated the up-shifting (chain-shifting from the smaller sprocket to the

larger sprocket) aided mechanism in stair-shape, and had the additional function of shifting at the fixed positions on sprockets. This period was thus the growth stage, indicated by the characteristic of adding functions to products. Meanwhile, in the mid-1990s, customer requirements for sprockets for smooth down-shifting (i.e. chain-shifting from the larger sprocket to the smaller sprocket) appeared. Thus, freewheels (composed of several sprockets) with aided mechanisms for smoothly up-shifting and down-shifting become standard equipment on medium and high-priced bicycles. Almost all freewheels incorporate such functions. Meanwhile, drilled-out profiles and new materials (for example, magnesium alloy) are considered to save weight and increase strength, thus increasing the added value of the product.

Case 2: Input Apparatus of Computers

Computer input apparatus means keyboards. The user interface on keyboards basically follows that of typewriters. Therefore, the appearance and functions of keyboards have not obviously changed, with the exception of the addition of some functional keys before the 1990s. However, other developments have occurred. For example, because of working environment requirements or space limitations, keyboards cannot always be connected to computers by wires. Thus, demand for wireless keyboards was generated. In early designs, the transmission signals of wireless keyboards were infrared rays, which is the direct concept for such design. These early products can be viewed as the market introduction.

However, using infrared rays as the signal transmission media is hampered by signal interruption by objects. Therefore, during the mid-1990s radio was employed in the design of wireless keyboards to enhance the ability of computers to receive long distance signals. Receiving long-distance signals without any interference is the main added function of the products at this stage.

Since computer mice face the same issue, a wireless mouse has since been added to keyboards. Besides, due to rapid multimedia and Internet development, customers now hope to use multimedia programs and browse websites quickly and conveniently, and most keyboards of medium to high level have extra function keys to meet these requirements. In other words, wireless keyboards are now in the maturity stage.

Above description of product evolution in these two different industries reveals that despite differences in properties, environment, and development requirements among industries, the product development orientation and research and development innovations remain similar. The only differences may be the details of the innovation methods themselves.

CONCLUSIONS

This study characterizes product life cycle. This study also investigates the innovation methods that should be employed at specific stages of the life cycle according to the demands and characteristics of the product life cycle at different stages. Based on the investigation,

the REs can use the patent database combined with other innovation skills to rapidly develop their products and maximize profits at the maturity stage, since information relating to the products and technologies is very abundant. It is undeniable that different countries have developed different modes of industries, and different enterprises also have specific policies and culture. Thus, it is impossible to expect all enterprises to follow fixed innovation methods and strategies. Besides, not all enterprises are first-to-market at the beginning of the market introduction stage, and so their strategies must differ. Therefore, enterprises should modify the innovation methods and strategies presented in this study to match their individual situation. However, it can be concluded from this study and other cases that the development of products in different industries still obeys specific modes, as Table VII illustrates. Each RE can break the patent portfolios of competitors to develop next generation products by observing the evolution of products, technologies, and innovation strategies. Information on different problem solving techniques from the patent database is the most useful tool for REs in the innovation process.

This study also examines different strategic adaptations when products are at different stages of their product life cycles. Strategies should be developed to improve enterprise efficiency from three aspects by aiming at the different issues that arise. These strategies can range from product design, manufacture, market integration or segmentation, to service and much more besides. Although these strategies may be individually discussed on different

occasions, they are seldom integrated and applied according to the attributes of product life cycles. Enterprises can deal with new problems more efficiently and flexibly if they can understand the stage of their lifecycle their products are at and adjust their strategies to competitive surroundings. The ploys discussed in this study can improve firm efficiency and the related adoptable strategies. In short, managers should not only use suitable research and development innovation at the different stages of the product life cycle, but also proceed with strategic innovations and apply and integrate them into product development, manufacturing and marketing, as described in this study, to bring maximize business profitability and competitiveness.

References

- [1] Levitt, T. (1991) Exploit the life cycle. In: Harvard Business Review Staff (eds.) *Management Product Life Cycles-From Start to Finish*, Harvard Business Review, Boston, 93-106.
- [2] Bailetti, A. J. and Litva, P. F. (1995) Integrating customer requirements into product design, *The Journal of Product Innovation Management*, **12**(1): 3-15.
- [3] Moore, G. A. (1995) *Inside the Tornado: Marketing Strategies from Silicon Valley's Cutting Edge*, Harper Business.
- [4] Burgelman, R. A., Maidique, M. A., and Wheelwright, S. C. (1996) *Strategic*

Management of Technology and Innovation (2nd edition), Irwin, Chicago.

- [5] Yu, J. S., Gonzalez-Zugasti, J. P., and Otto, K. N. (1999) Product architecture definition based upon customer demands, *Transactions of the ASME, Journal of Mechanical Design*, **121**: 329-335.
- [6] Pahl, G. and Beitz, W. (1996) *Engineering Design-A System Approach*, (2nd edition), Springer, New York.
- [7] Terninko, J., Zusman, A., and Zlotin, B. (1998) *Systematic Innovation-An Introduction to TRIZ*, St. Lucie Press, Boca Raton, Florida.
- [8] Rogers, E. M. (1995) *Diffusion of Innovations* (4th edition), Free Press, New York.
- [9] Altshuller G. (1998) *40 Principles: TRIZ Keys to Technical Innovations*, Translated and edited by Shulyak L. and Rodman S., Technical Innovation Center, Inc.
- [10] Dettmer, W. E. (1997) *Goldratt's Theory of Constraints: A Systematic Approach to Continuous Improvement*, ASQC Quality Press, Milwaukee, Wisconsin.
- [11] Moura, E. C. (1999) TOC trees help TRIZ, *TRIZ Journal*, September.
- [12] Lee, M. H. (1995) *Become More Creative-How to Invent and Innovate*, Unalis Corporation, Taipei.
- [13] Ullman, D. G. (1992) *The Mechanical Design Process*, McGraw-Hill, New York.
- [14] Terninko, J. (1996) *Step-by Step QFD: Customer-Driven Product Design* (2nd edition), St. Lucie Press, Boca Raton, Florida.

- [15] Chen, J. L., Liu, S. J., and Tseng, C. H. (2000) Integrating innovation and imitation: developing technology by inventing around patents, *Submitted to R & D Management*.
- [16] Porter, M. E., *Competitive Strategy: Techniques for Analyzing Industries and Competitors*, The Free Press, New York, 1980.
- [17] Liu, S. J. and Shyu, J. (1997) Strategic planning for technology development with patent analysis, *International Journal of Technology Management*, **13**(5/6): 661-680.
- [18] Abernathy, W. J. and Townsend, P. L. (1975) Technology, productivity, and process change, *Technological Forecasting and Social Change*, **7**(4): 379-396.
- [19] Davis D. D. and Associates (1986), *Managing Technological Innovation*, Jossey-Bass Inc., San Francisco.

TABLE IA Improvements of values of the three aspects during the introduction period on facing the issue of development and application of technologies

Direction of Improvements	Strategies
Co-opetition status	1. Establish common visions of setting up the standards and specifications of products and technologies
	2. Use the theoretical knowledge
	3. Develop related technologies separately to increase the possibility of generating useful technologies
	4. Cooperate with other enterprises that have products with similar functions in different applied areas
Enterprise operation	1. Initiate new professional talents and hold research and development training
	2. Add more capital to the research and development department
	3. Encourage innovation to stimulate the generation of possibly useful technologies
Industrial values	1. Technological breakthrough
	2. Setup specification or standards of products

TABLE IB Improvements of values of the three aspects during the introduction period on facing the issue of marketing exploitation

Direction of Improvements		Strategies
Co-opetition status	1.	Strategic alliance with potential competitors and partners
	2.	Promote the industrial network and vertical value chains
Enterprise operation	1.	Determine product position to give an obvious direction to research and development to develop complete products
	2.	Take the requirements of products from a similar area as references
Industrial values	1.	Resolve the requirements of specific enterprises to set up a base of related technologies
	2.	Educate potential customers
	3.	Exploit new marketing channels

TABLE IIA Improvements of values of the three aspects during the growth period on facing the issue of demands over supply

Direction of Improvements	Strategies
Co-opetition status	1. Avoid competition in the same markets
	2. Establish common visions of sharing markets
	3. Increase the cost advantages against the competition through allied purchase
	4. Establish alliances with the downstream agencies.
	5. Develop cooperation with international enterprises
Enterprise operation	1. Intensify the after sales service and enhance brand identification
	2. Improve manufacturing management and automation instruments
	3. Increase product performance and diversity
	4. Develop firm policies, culture and welfare to keep talent
	5. Search for continuous capital flows to help investment in research and development
Industrial values	1. Merge with and acquire the companies of competitors
	2. Participate in research and development activities of upstream agencies

TABLE IIB Improvements of values of the three aspects during the growth period on facing the issue of competition of substitutable technologies

Direction of Improvements	Strategies
Co-opetition status	1. Develop joint stock or strategic alliances with other enterprises to build professional manufactories 2. Develop joint ventures for research and development organizations or to acquire technologies from other sources
Enterprise operation	1. Acquire advanced technologies 2. Concentrate on schemes to improve product functions and materials with minimum cost 3. Intensify enterprise production management and level of automation
Industrial values	1. Define marketing positions of s products 2. Exploit other applied areas and markets 3. Focus on the improvements and research of upstream systems

TABLE IIC Improvements of values of the three aspects during the growth period on facing the issue of time to market

Direction of	Strategies
Improvements	
Co-opetition status	1. Define a common target of encroaching on the market shares of specific applied areas
	2. Cooperate with other foreign enterprises to build new factories in joint stock to access better technologies or key components
	3. Cultivate exclusive suppliers
Enterprise operation	1. Hide product time to market
	2. Reflect the required specifications of products flexibly
	3. Maintain competitive price advantages for non-standard products
	4. Enter the market as soon as possible to shorten the break-even time
	5. Contract with customers in advance to promise special preferential prices
	1. Reflect customer requirement directly
	2. Become involved in niche markets that satisfy special customer demands
Industrial values	3. Vertically integrate the industry to produce its own key components or material supply of products

TABLE IIIA Improvements of values of the three aspects during the maturity period on facing the issue of intensification of product qualities

Direction of	Strategies
Improvements	
Co-opetition status	1. Cooperation with foreign enterprises to introduce new manufacture technologies
	2. Alliance with professional OEMs to increase the quality of manufacture
	3. Let competitors as professional OEMs and ODMs
Enterprise operation	1. Enhance the ability of online and offline control
	2. Automate control in manufacturing
	3. Seek authentication by international organizations.
	4. Proceed with product design with reference the defects of competitors' products
Industrial values	1. Improvement of the manufacturing process
	2. Concentrate on source supplies from professional OEMs

TABLE IIIB Improvements of values of the three aspects during the maturity period on facing the issue of product diversification

Direction of	Strategies
Improvements	
Co-opetition status	1. Pursue market segmentation
	2. Provide enough volume of products to satisfy the requirements of customers
	3. Provide products with high quality or special performance
	4. Have alliances with cross-industry marketing channels
Enterprise operation	1. Design products according to customer requirements
	2. Focus on niche markets
	3. Establish a good reputation by advertisements to attract the attention of more customers
Industrial values	1. Set up a complete system from research and development to market research
	2. Provide specific and comprehensive post-sale service
	3. Develop a database of customer requirements from the sales department
	4. Establish sufficient productivity by integrating upstream firms and suppliers

TABLE IIIC Improvements of values of the three aspects during the maturity period on facing the issue of emergence of profession OEM

Direction of	Strategies
Improvements	
Co-opetition status	1. Pursue Strategic alliances with upstream factories
	2. Actively exploit the application of products for the firms' niche markets
	3. Share information and knowledge with customers to increase the value added by service
	4. Scramble for orders from competitors
Enterprise operation	Continue to enhance the yield rate, product quality, and flexibility of manufacture
Industrial values	1. Requirements of high product quality and diversification
	2. Sedulous attention to new product development and discontinuous innovation

TABLE IVA Improvements of values of the three aspects during the decline period on facing the issue of price competition

Direction of	Strategies
Improvements	
Co-opetition status	1. Integrate with industries in specific applied areas
	2. Develop communication channels with upstream and downstream enterprises
Enterprise operation	1. Adopt advanced materials to increase added value
	2. Concentrate on developing accessories of main products
	3. Reduce component numbers by value analysis
	4. Enhance quality control to increase competitiveness
Industrial values	1. Exploit other applied areas of products
	2. Capture material cost advantages

TABLE IVB Improvements of values of the three aspects during the decline period on facing the issue of the rise of product substitution

Direction of Improvements	Strategies
Co-opetition status	1. Provide complete and full products and service 2. Ally with enterprises that have substitutable products and exploit the marketing channels and new technologies of the adversary
Enterprise operation	1. Enhance the level of technology and improve the manufacturing process 2. Enhance service quality 3. Increase added value of accessories of products
Industrial values	1. Transfer the emphasis from function design to figuration or modeling design 2. Pay attention to the development of substitutable products 3. Transfer some capital and emphasis to the development of new generation products

TABLE V Evolution of patents for bicycle sprockets

Date of publication	U. S. Patent No.	Applicants	Characteristics	Stages
1980	4,181,033	Shimano	Slanted at the teeth tips with respect to the center line of axial thickness of the sprocket body	Introduction
1981	4,268,259	Shimano	Teeth twisted to generate fixed positions of up-shifting on sprockets	
1983	4,384,865	Shimano	The teeth of the larger sprocket are modified so as be easily engaged, while those of the smaller sprocket are designed to be easily disengaged	
1985	4,519,791	Shimano	Each tooth is modified for the chain to be easily up-shifting	Growth
1989	4,889,521	Shimano	The side of the larger sprocket adjacent to the smaller sprocket is modified as a stair-shape to act as the aided-mechanism for the chain during up-shifting	
1993	5,188,569	Maeda	Smooth down-shifting function is established by cutting the teeth with different appearances	
1995	5,409,422	ITRI	The non-linear engagement mode is considered to have smaller rotation angles for the chain in the engagement process	Maturity

TABLE VI Evolution of Shimano's sprocket

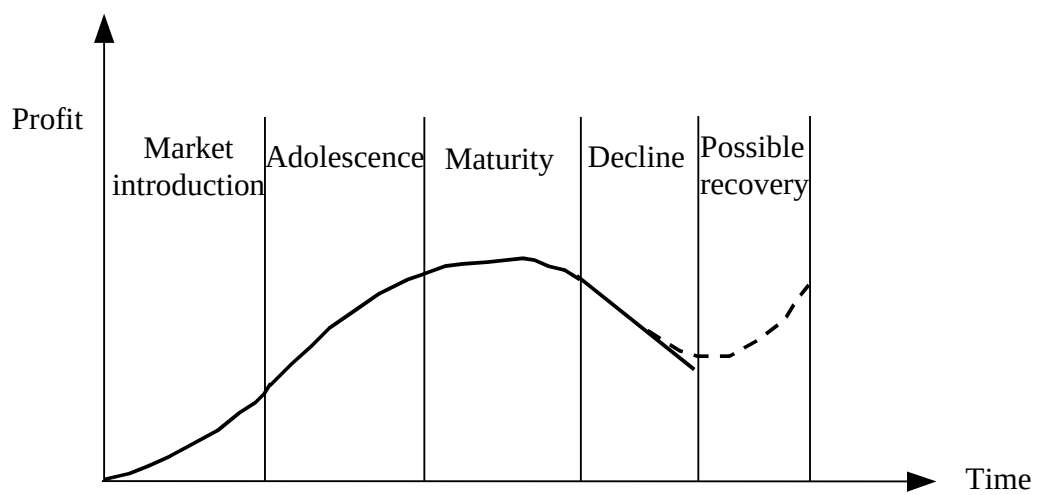
Year	Type	Characteristics
1980~	UG	Teeth are twisted to generate a fixed position for up-shifting
1989~	HG	Teeth are modified to be stair-shaped to act as the aided-mechanism for the chain during up-shifting
1995	IG	Teeth are modified to be stair-shaped to act as the aided-mechanism for the chain when up-shifting and down-shifting
1997~	HG-I	The IG-type products are modified and some considerations are added to drill-out profiles

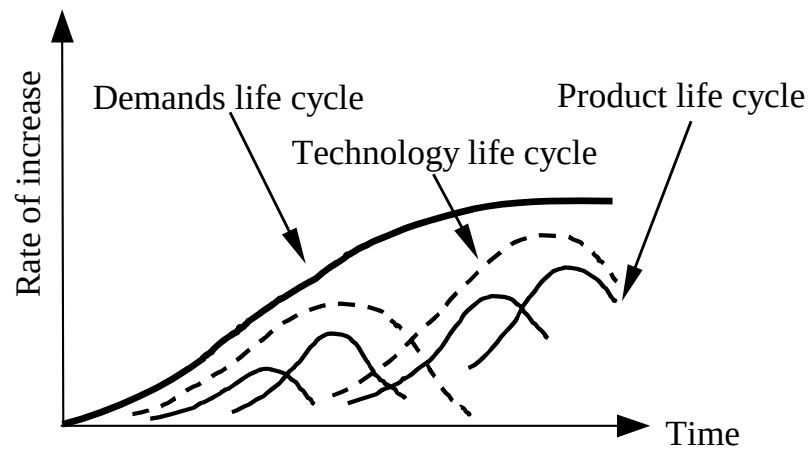
TABLE VII Enterprise Strategies at different stages of the life cycle.

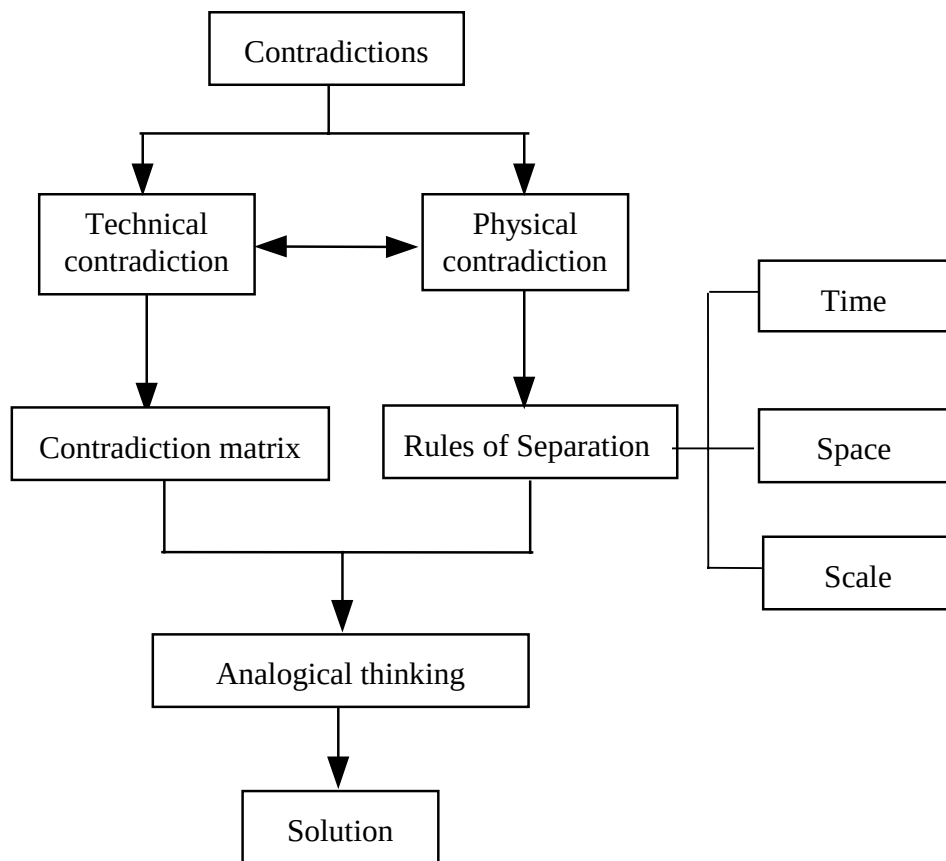
Items	Stages	Introduction	Growth	Maturity	Decline
Product characteristics		Basic requirements on functions	Added functions on products	Standard design	Minimization of differences of Technologies
R & D Strategies		Innovation leadership	Function leadership	Customer requirements leadership	Price leadership
Co-opetition status		No interaction between enterprises	1. Strategic alliances 2. Mergers and acquisitions	Patent disputes	Main brands ship
Patent strategies		Application for as many patents as possible	Patent allocation	License	1. Industrial design (design patent) 2. Patent developments on accessories

TABLE VII (Continued)

Items	Stages			
	Introduction	Growth	Maturity	Decline
Innovation methods	1. Personal inspiration	1. Experience from	1. QFD	
	2. Brainstorming	research and development	2. Robust design	1. Combinations of
	3. Combination with	2. Contradiction solving	3. Improvement on	functions
	applied science	(TRIZ)	manufacturing process	2. Alternative material
Marketing strategies		3. Imitation	4. Patent design around	and technologies
	1. Propagation of			
	product concepts	1. Advertisements	Market	Competitions
	2. Endorsement by persons	2. Sales promotion	segmentation	on prices
	with decision-making or			
	market influence			





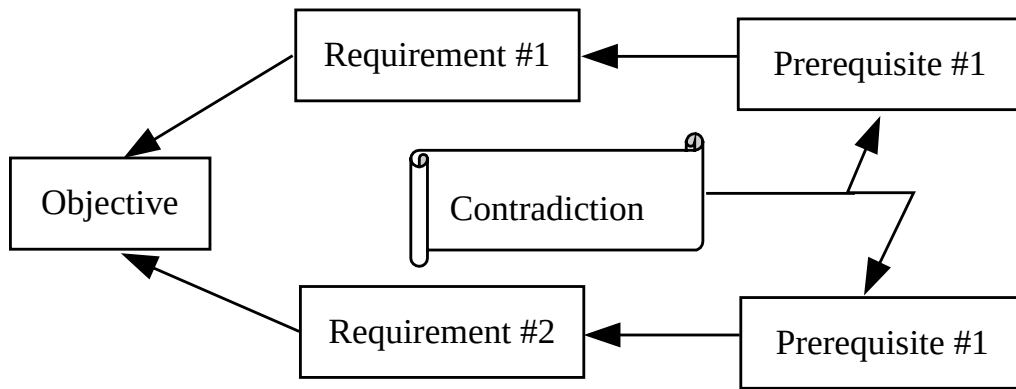


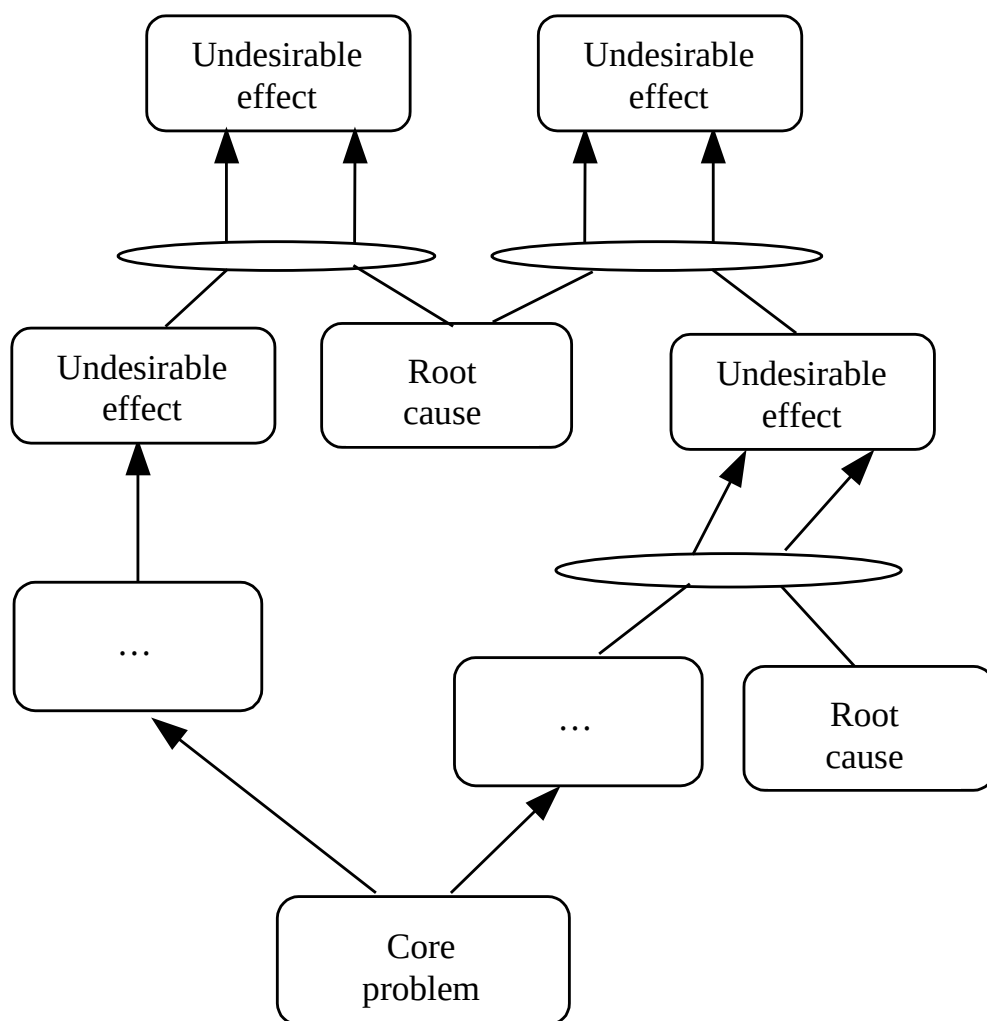
Deteriorated parameters Improved parameters	Weight of moving object	Weight of a stationary object	:	:	:	Measurement accuracy	Manufacturing Accuracy	Level of automation	Productivity
Weight of a moving object									
Weight of a stationary object									
.									
.									
.									
.									
.									
.									
.									
Measurement accuracy									
Manufacturing accuracy									
Level of automation						28, 26 10, 34	28,26 18,23		5, 12 35, 26
Productivity	35, 26 24, 37	28, 27 15, 3				1, 10 34,28	18, 10 32, 1	5, 12 35, 26	

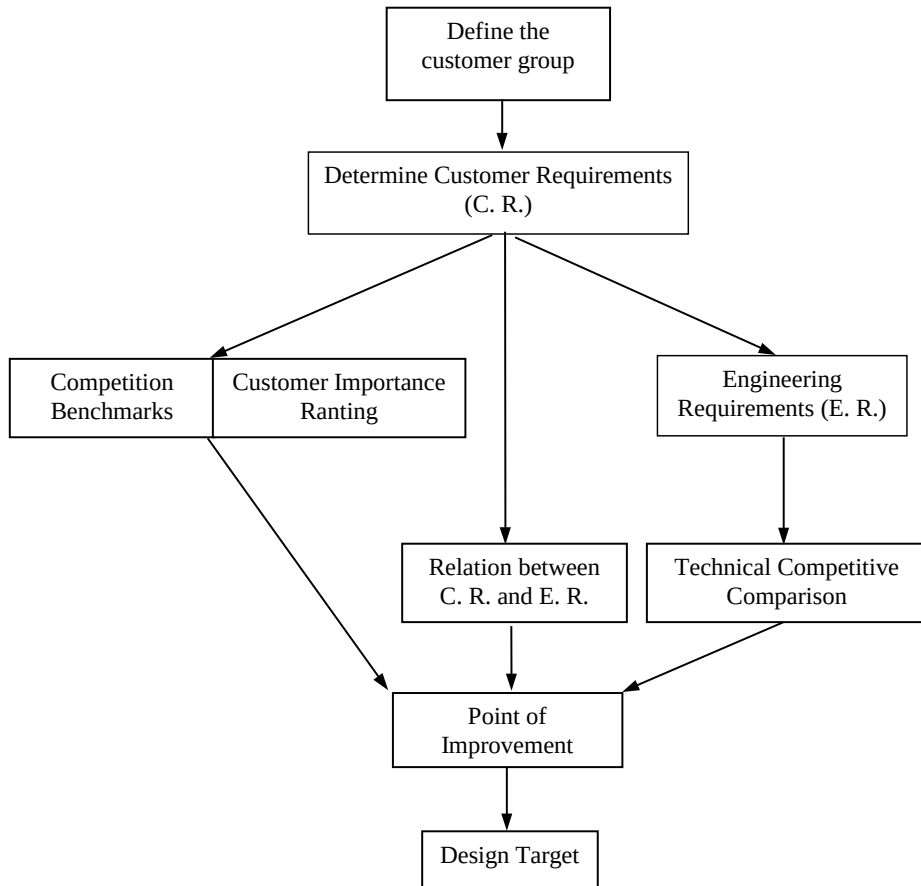
40 principles derived from 40,000 inventive patents

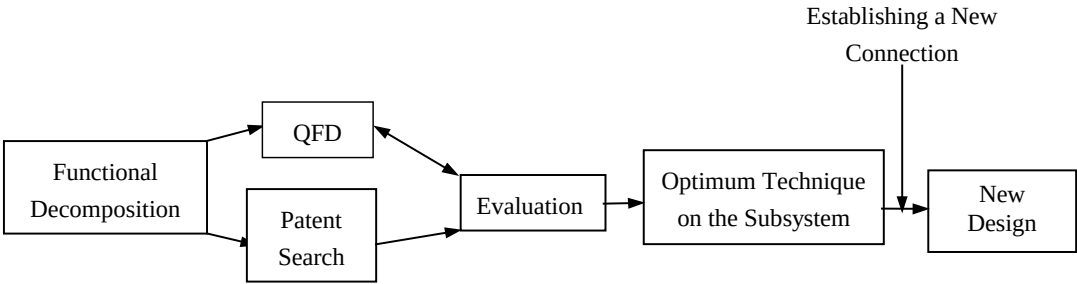
- 5 Consolidation
- 12 Equipotentiality
- 35 Transformation of properties
- 26 Coping

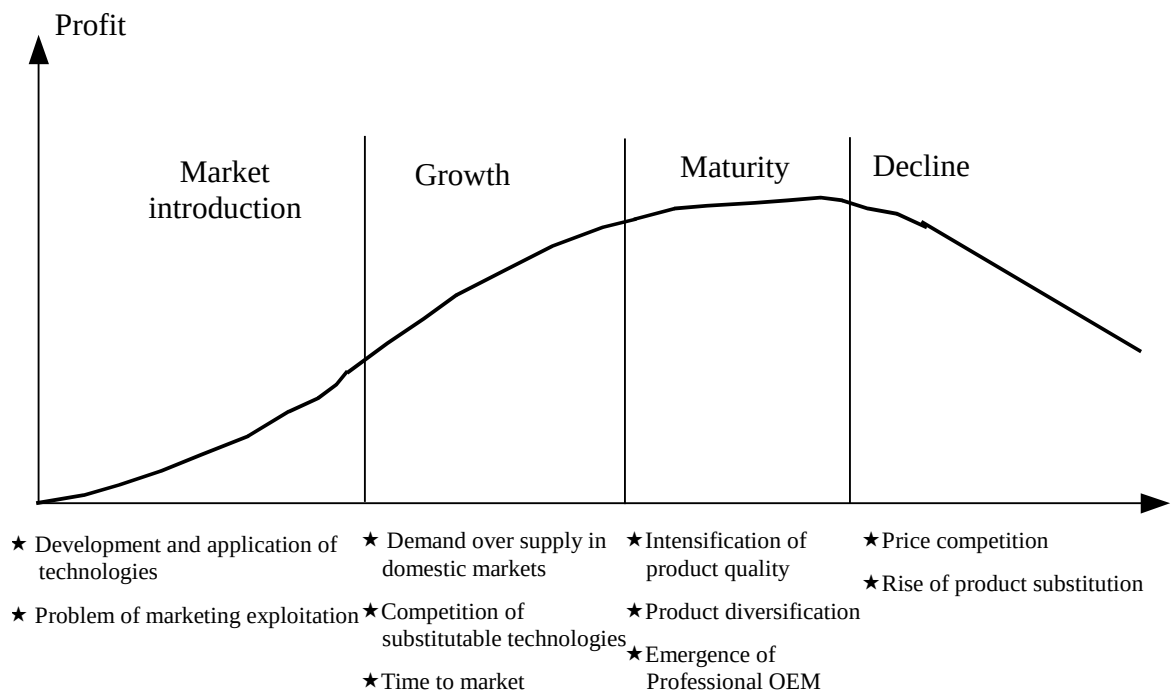
5, 12
35, 26

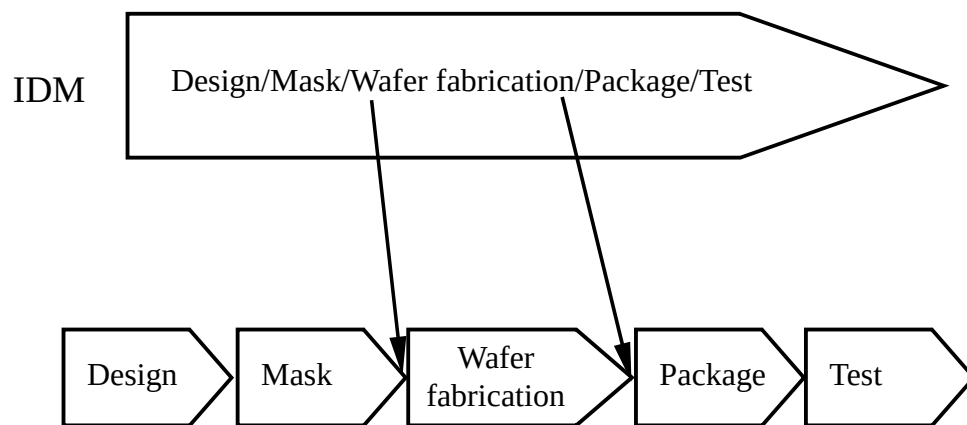


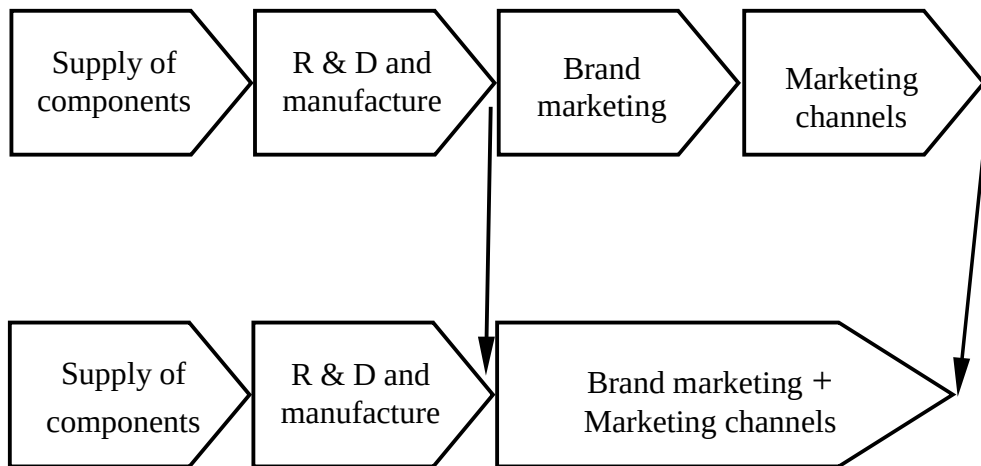












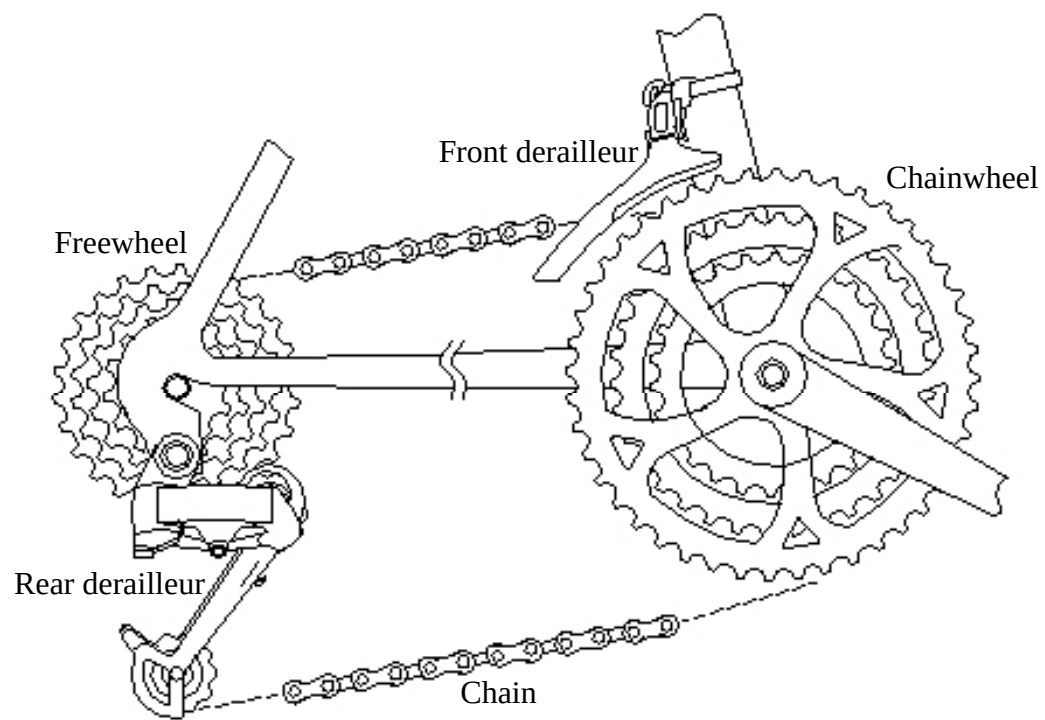


FIGURE LEGENDS LISTS

FIGURE 1 Life cycle of a product.

FIGURE 2 Life cycles of various objects.

FIGURE 3 Rules of contradictory problem solving in TRIZ.

FIGURE 4 Altshuller's contradiction matrix.

FIGURE 5(a) Conflict resolution diagram.

FIGURE 5(b) Current reality tree.

FIGURE 6 Quality function deployment (QFD) method.

FIGURE 7 Flowchart of Combining QFD and Patent Information.

FIGURE 8 Issues arising in the process of product life cycles.

FIGURE 9 UMC's innovation on the segmentation of its industrial value chain.

FIGURE 10 Innovation on the rearrangement of the value chain of Dell's computer.

FIGURE 11 Transmission system of a bicycle.