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Introduction

While facing intensive global competition, rapid technological change, and the shifting patterns of world markets, a firm is expected to maintain a competitive advantage. Therefore, shortening the duration of the product design chain (PDC), depict as in Figure 1, which is defined as a series process of product concept, detail engineering, process engineering, prototype manufacturing, and post-launch activities, is a necessity (Song & Montoya-Weiss, 1998; Twigg, 1998). The key factors identified in the PDC offer the primary strategy for determining its future. Failing to identify the factors not only affects an organization's competitiveness, but also affects corporate image, financial value, research and development (R&D), marketing, production and operations, and human resources. As a result, the factors that influence the PDC process must be taken into consideration as relates to the types of products. The PDC is normally applied to three types of products: new products, upgraded products, and customized products (Globerson, 1997; Thomas, 1993).

The PDC can be considered from two aspects: technical factors and customer feedback. Technical factors that has implications for manufacturing are; strategic planning, market analysis, technical development, and product commercialization (Song & Montoya-Weiss, 1998). On the other hand, customer feedback also plays an important role in successful product development. Customers have many ideas in mind when considering new products or services in regard to the PDC. Hence, designers and manufacturers must listen to their customers' suggestions and keep closer ties with them. If products fit the customers' expectations, then this implies a higher likelihood of completing projects successfully (Crawford, 1997; Veryzer, 1998). When taking all of this and their interactions into consideration, one can imagine how complex the activities in the PDC can be. Many businesses employ techniques such as quality function deployment (QFD), concurrent engineering (CE), design for manufacturing (DFM), design for assembly (DFA), and modular design to help in focusing on key factors, in other words, these techniques are systemically focused on the core problems and also solutions to them. Although, these techniques contribute immensely during the conceptual stage, in respect to implementation, there still exists much room for improvement (Schroeder, 2000; Stevenson, 1999).

When addressing planning issues and attempting to solve problems, it is imperative to ensure that core problems, and not just the symptoms, are addressed. So developing systematic thinking is one of the effective methods for improving and accelerating the PDC. However, also needed is a method that increases the probability that core problems will be uncovered and solved. The thinking process (TP) of theory of constraints (TOC) is an emerging philosophy providing a systematic approach to identifying the core problem in any system (Goldratt, 1990; Klein & DeBruine, 1994; Scheinkopf, 1999). Under TOC, where satisfying the necessary condition or supporting the process of continuous profit improvement, the TOC thinking process (TP) increases the probability that core problems will be addressed by substantiating the supposed cause with effects or entities (Stein, 1997).

Therefore, it is appropriate to adopt the TP as a means of improving the PDC.

The primary goal of this study is to explore the efficient ways of integrating the thinking process within the PDC cycle. Consider the following two prospects, on the one hand, since the different product types feed back the different customers' suggestions, implies that different logic tools are needed. On the other hand, the five logic tools of TP: current reality tree (CRT), conflict resolution diagram (CRD), future reality tree (FRT), prerequisite tree (PRT), and transition tree (TT), can be used individually or in concert. These two prospects develop our main theme for this study. Three integrating modes; series, parallel, and feedback are applied to integrate the TP with PDC. Series mode is integrating with new product design processes, parallel mode is integrating with upgrading product development, and feedback mode is integrating with customized product development.

Background

Challenges to strategic success in faster new product development include the uncertainty of increasingly turbulent business environments and market friction from potential buyers and stakeholders, such as labor market demands, the need to be competitive; the demand of customers for just-in-time products, etc. Shortening the length of time it takes to complete the product design chain (PDC) is a necessity in maintaining a competitive advantage. Song and Montoya-Weiss (1998) stated that there is an increasing interest in making product development faster. Hence, production cycles are shortened and costs are reduced as a consequence.

Thomas (1999) indicates that there are two perspectives from which to view the above problems: operational view and the product view. As regards the operational view, the activities of product development processes may be described in three ways. For one firm, product development may appear to be implemented using a sequential approach, with occasional looping back to previous steps. For another firm, it may seem like it is overlapping or holistic, with interacting and parallel processes that carry out multiple activities. For other corporations, product development may seem like a chaotic activity.

The product view has three categories; new products, upgraded products, and customized products, with each category having a different focus. In new product design, product development should start by analyzing the customer's needs and planning products with the required functions, plus the manufacturing action plan. In upgraded product design because the manufacturer already has experience in manufacturing technology and has a product on hand, product development can start with repositioning and focus on improving the factors found necessary to maintain a competitive edge. In customization, customers explicitly define the required functions and specifications of the products. The primary focus is on how to fulfill the requirements.

The product development process becomes more complex by considering these four mixed factors: the complexity of the process, the variability of product functions, the characteristics of the environment, and the volume of components. The PDC requires the consideration of tradeoffs between these mixed factors. Also, PDC focuses on the vital core problems. Techniques such as QFD, CE, DFM, DFA, and modular design are employed by many businesses to help in focusing on key factors and thereby reaching their goal. But these techniques are operationally oriented, thus there still exists great room for product design chain (PDC) improvement while product consideration is mixed in. Developing a systematic thinking approach is one of the applicable methods to elicit and map the structure of complex systems and relating those structures to their dynamics. Thinking Process (TP) is a systematic thinking tool used to identify the core problem by modeling and simulation of the complex system.

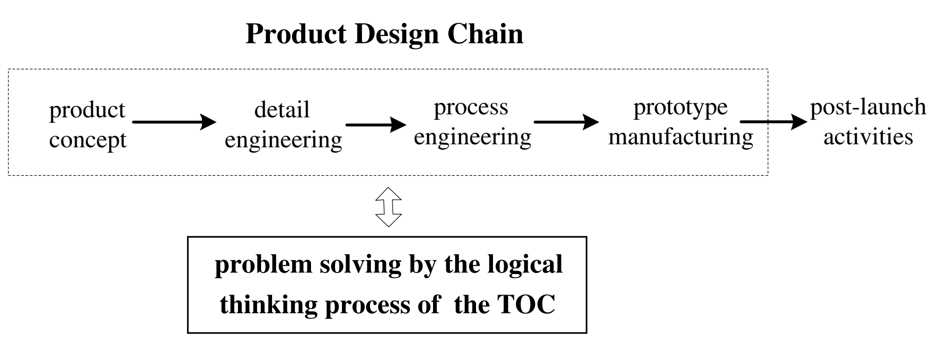
The Thinking Process and Its Application

The thinking process (TP) logic of the TOC is a systematic thinking approach, developed by Eli Goldratt. The process can be utilized to help a company enhance product development capabilities in the PDC (Klein & DeBruine, 1994). Figure 1 illustrates the conceptual process of using the TP to assist the PDC.

Establishing and planning the PDC involves a series of internal and external managerial activities. The cross-related activities form a complex design chain network. Within the PDC cycle, there are many problem-solving activities performed within the network. These activities are cost-intensive in nature. Therefore, improving crucial activities within the network is essential. Improving crucial activities will lead to a reduction in PDC costs and enable full-scale manufacturing to commence.

The thinking process (TP) provides five, tree-type logic tools: current reality tree (CRT), conflict resolution diagram (CRD), future reality tree (FRT), prerequisite tree (PRT), and transition tree (TT). These five logic tools assist in answering the questions about what to

Figure 1. Product Design Chain Process by Applying the Thinking Process



change, to what to change to, and how to cause the change.

The current reality tree (CRT) is a logical structure designed to depict the state of reality existing in a given system. It articulates the undesirable effect (UDE) and the causalities that exist in the PDC. It also connects the UDE to Effect-Cause-Effect (E-C-E) analysis in order to identify the core problem.

The conflict resolution diagram (CRD) is an idea generator that allows the invention of new breakthrough solutions to troubling problems. The CRD is used to identify the design problem as a systemic conflict that is perpetuating the major problem of product design, to produce solutions to this core conflict, and to select the initial elements of the solution.

The future reality tree (FRT) is a simulation model of the future and enables effective testing of new ideas before committing resources to implementation. FRT provides an effective tool for persuading decision-makers to support a desired course of action. The FRT is used to examine the product development process by logical analysis of current technology, the compatibility of equipment, and the partial process arrangement.

The prerequisite tree (PRT) is a logical structure designed to identify all obstacles and the responses needed to overcome them in realizing an objective. The PRT identifies obstacles preventing achievement of a desired course of action, objective, or injection. It also identifies what should be done and what is the best way to overcome obstacles. Additionally, it tells what critical sequence is needed to complete a project and depicts unknown steps to a desired end when one does not know precisely how to achieve it.

A transition tree (TT) is a cause-and-effect logic tree designed to provide step-by-step progress from initiation through completion of a course of action or change. It is an implementation tool and additive process, combining each successive expected effect with subsequent specific actions to produce new effects. Creating a TT will define specific, detailed step-by-step instructions and plans for implementing a course of action.

As authors knowledge, some successful applications of thinking process in the literature. For example, Dettmer (1997) used CRD for conflict resolution. Klein and DeBruine (1994) applied full thinking process analysis (FTPA) in establishing management policies. Peach (1996) demonstrated in manufactured coatings that CRT is an invaluable aid to identify core problems, and CRD is a technique-focused effort to structure win-win solutions. Roadman, Roadman, Benge, McGinnis, Yurkosky, Adams, Cockerham, and Flowers (1995) detailed the use of FTPA to address performance issues and theorized about the value of applying TOC in their military medical service organization. Hsu, Ching, Yang, and Hwang (1999) use the partial thinking process of the TOC to analyze the planning, executing, and evaluating of a New Product Development (NPD) project, and propose a three phases, hierarchical evaluation model. Stien (1997) illustrate improving the quality function deployment (QFD) process by applying the TOC thinking process to support the process of product/process design in order to satisfy the necessary condition of customer needs and support the process of continuous profit improvement.

Three Modes of Integrating Thinking Process with Product Design Chain

Applying the thinking process with the product design chain (PDC) could be very beneficial. This application could be used to resolve a problem or to improve a system, based on the characteristics of the product and nature of the design process. In this study, three integrating modes: series, parallel, and feedback of TP logic with PDC of three types of products: new products, upgraded products, and customized products are proposed. Which is summarized as in Table 1, and depth details are discussed as in the following paragraphs.

Series Mode

Series mode, demonstrated in Figure 2, is used for the new product design process to handle the overall activities within the PDC cycle. For new product design, most product characteristics in the four design stages: product concept, detail engineering, process engineering, and prototype manufacturing are unknown and the resulting outcomes are uncertain. FTPA is integrated into the procedure in a series mode after each of the four design stages. Where FTPA uses all five-application tools to analyze a system or situation in order

Table 1. Summaries of Applying Thinking Process in Product Design Chain

Type of Product	Integration Mode	The role of TP	Tools used
New Products	Series	What to change What to change to How to cause the change	FTPA
Upgraded Products	Parallel	What to change to How to cause the change	CRD, FRT, PRT, TT
Customized Products	Feedback	How to cause the change	FRT, PRT, TT

to identify the core problem, develop solutions, and determine implementations right after each of the four stages. For each stage, FTPA plays a role as a problem solver in reviewing the previous steps and overcoming discrepancies that are found. In consequence, the quality of design is improved.

Parallel Mode

When a product already exists and needs to be upgraded, customers have already provided feedback for their specified requirements. In such situations continuous improvement is needed by manufacturers to maintain a competitive edge. Integrating the TP parallel with the PDC is called the parallel mode in this study and is depicted as Figure 3.

While conduct the parallel mode, the manufacturers have already experienced how to manage the process and how to control key technologies. The TP tools CRD, FRT, PRT and TT need only to be applied. The tools act as a consultant for consulting the problems whenever there is a need. The best way to handle upgrading products is consulting the TP tools which helps to resolve conflicts between functions and cost and to focus on the factors that should be considered for the product upgrade process as the reference for improving product function, replacing components, and correcting the specifications. The manufacturers can then devote their efforts to accomplishing the upgrade. For example, the customer feedback that there is a specific specification has not been satisfied. In such circumstances, this specific specification is a core problem, a new specification established directly from the result of CRD and crucial improvements and relevant actions. Consulting TP tools in a parallel mode not only solves the product development problems but also is beneficial for proposing a better alternative for product development.

Feedback Mode

Feedback mode of TP integration, demonstrated as in Figure 4, is normally applied to the customization of products, such as in original design manufacturing (ODM).

Figure 2. Series Mode Integration

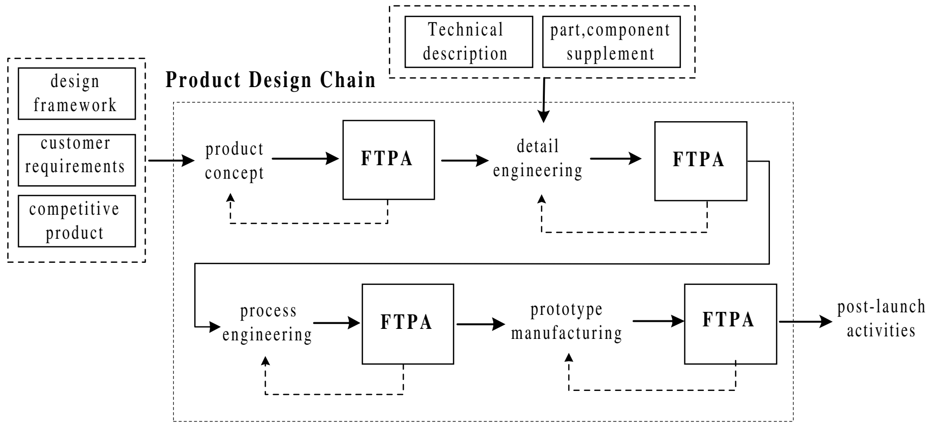


Figure 3. Parallel Mode Integration

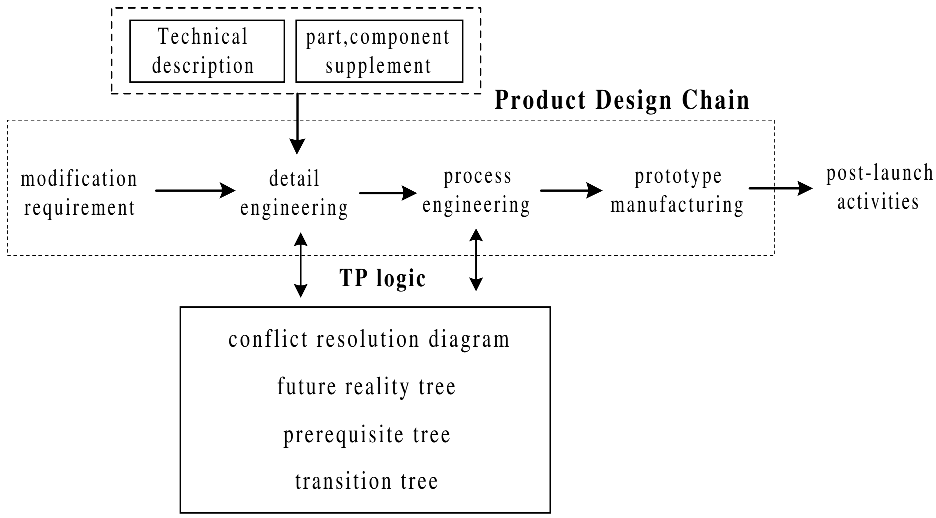
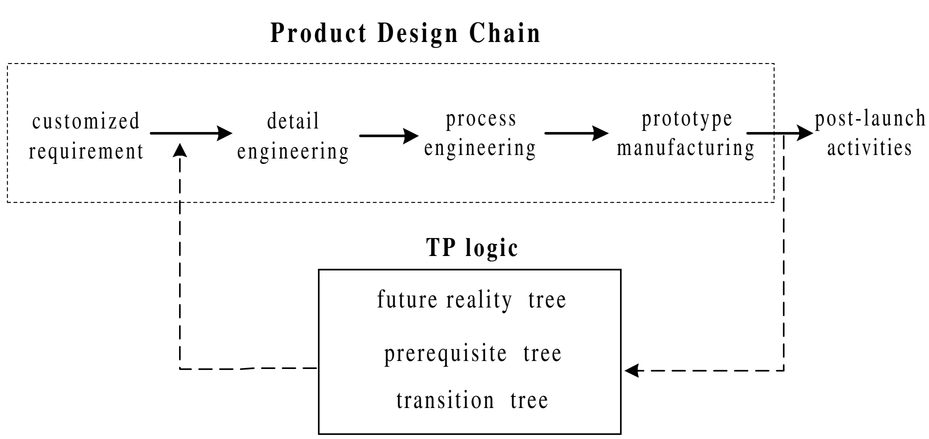


Figure 4. Feedback Mode Integration



Customization of products is defined for existing products that customers have already given the specifications and characteristics for these products. To meet the customer's requirements, the manufacturer needs to review the PDC in order to search for better manufacturing technologies and management methodologies for cost reduction and process improvement. TP tools FRT, PRT, and TT are sufficient for reaching these goals as well as for focusing on the features that need be modified or added.

Conclusion

Global competition, rapid changes in technology, and market fragmentation have resulted in a need for shorter product cycles. Creating a framework for product development is a significant objective for businesses. The following are the four conclusions of this research for integrating the TP into PDC activities.

The PDC can be used to build a framework that links customers, product design engineers, and manufacturing planners. They then can analyze worth and quality, set specifications, conduct design reviews, and plan for the eventual safe reuse or sale of products. The key factors identified in the PDC offer the primary strategy for determining how to shorten the time needed to complete a project and to improve the product manufacturing process and quality.

Three types of product development: new products, upgraded products, and customized products are discussed. The three modes of integrating the TP with the PDC are series, parallel, and feedback. Different product types indicate different product development flow. As a result, the product development flow and the capability of the technology point out which mode of the TP and the PDC integration should be used for the different product development to ensure that products will satisfy the customer's need from design to production.

It is important to evaluate strengths and weaknesses and to compare competitive products and customers' expectations of the products. These insights help an enterprise to comprehend the development perspectives and technology bottlenecks, which aid product positioning and take advantage of technological improvements. Logical tree analysis of the TOC for solving problems was detailed in this article. The procedure needs to be institutionalized to preserve reference documentation that is helpful in improving technology engineering and in accumulating development experience.

In summary, this article describes the application of the TP to PDC activities to find and solve problems of product development in order to ease manufacturing, to shorten time-to-market, and to produce more customer-oriented products. The TP is a well-proven approach, which has been applied in conflict resolution, in establishing management policies, in coatings manufacture, and in a military medical service. This article demonstrates how the TP may be extended to applications in the PDC.

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