Using Quality Function Deployment as a Framework for Teaching Product Design and Development

การประยุกต์ใช้การกระจายหน้าที่ทางคุณภาพสำหรับเป็นกรอบในการสอนวิชาการออกแบบและพัฒนาผลิตภัณฑ์

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Abstract

This article presents an experiential approach to teaching product design and development to industrial engineering students by using Quality Function Deployment (QFD) as a framework. First it describes the industrial engineering discipline and the role of industrial engineers in product design management. Then it reviews the author's experience in the teaching and learning process which is conducted along the different phases of product design and development. It is proposed that quality function deployment should be used as a framework for developing incremental innovation which is most usually found in IE students' project. Besides QFD, other alternative techniques as well as potential opportunities and problems are also discussed.

บทคัดย่อ

บทความนี้กล่าวถึงการประยุกต์ใช้การกระจายหน้าที่ทางคุณภาพ (Quality Function Deployment, QFD) สำหรับเป็นกรอบในการสอนวิชาการออกแบบและพัฒนาผลิตภัณฑ์ สำหรับนักศึกษาในสาขาวิศวกรรมอุตสาหการ โดยเริ่มจากการอธิบายถึงบทบาทของวิศวกรอุตสาหการในการบริหารกระบวนการออกแบบผลิตภัณฑ์ จากนั้นกล่าวถึงประสบการณ์ในการเรียนการสอน ซึ่งจัดรูปแบบตามขั้นตอนต่าง ๆ ของการออกแบบและพัฒนาผลิตภัณฑ์ บทความนี้เสนอว่า การกระจายหน้าที่ทางคุณภาพสามารถใช้เป็นกรอบในการพัฒนานวัตกรรมผลิตภัณฑ์แบบค่อยเป็นค่อยไป ซึ่งเป็นงานที่เสนอโดยนักศึกษาวิศวกรรมอุตสาหการส่วนใหญ่ในการเรียนวิชานี้ นอกจากนี้ยังกล่าวถึงวิธีการอื่นๆนอกจาก QFD โอกาสในการปรับปรุงและปัญหาที่พบอีกด้วย

Introduction

In the past, Thailand has placed great emphasis on attracting investments from abroad. As suppliers of reasonably skillful human resource and relatively inexpensive labor cost, most Thai industries have become manufacturing bases for large multinational corporations. This along with strong dependence on foreign technology has resulted in the lack of chance to heavily engage in product design and development. However, as companies are increasingly open to global competition, new product development is vital to long-term business survival.

According to the forecast by the Office of the National Economic and Social Development Board, there is an increasing demand for engineers and technicians in various disciplines. In particular, electrical and electronics industry has

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the highest demand for design and R&D engineers as reflected by the combined estimates that can be seen in Table 1. Other industries also show increasing need for design engineers each year. In response to this, universities are beginning to perceive the need to supply graduates who are capable of developing new products in a timely manner.

Table 1 Demand forecasts of Thai engineers (From: Office of the National Economic And Social Development Board, August 2004)

Industry	2004	2005	2006	2007	2008	2009
1.Electrical & electronics industry						
• Manufacturing engineers	2,103	2,281	2,471	2,672	2,893	3,126
• R&D engineers	1,255	1,361	1,474	1,594	1,726	1,865
• Design engineers	1,476	1,601	1,734	1,875	2,030	2,194
• Maintenance engineers	923	1,001	1,084	1,172	1,269	1,371
• QC engineers	1,181	1,281	1,387	1,500	1,624	1,755
• Others	2,178	2,361	2,558	2,766	2,994	3,236
TOTAL	9,116	9,886	10,708	11,579	12,536	13,457
2. Automotive Industry						
• Manufacturing Engineers	2,309	2,480	2,660	2,846	3,052	3,264
• R&D engineers	1,007	1,082	1,160	1,242	1,331	1,424
• Design engineers	368	396	424	454	487	521
• Maintenance engineers	369	686	7 3	787	844	903
• QC engineers	1,253	1,346	1,443	1,544	1,656	1,771
• Others	2,677	2,876	3,084	3,301	3,539	3,785
TOTAL	4,986	5,356	5,744	6,147	6,591	7,049
3. Steel Industry						
• Manufacturing engineers	539	567	594	621	660	699
• R&D engineers	142	149	156	163	174	184
• Design engineers	-	-	-	-	-	-
• Maintenance engineers	511	537	563	589	625	662
• QC engineers	454	477	500	523	555	588
• Others	1,334	1,401	1,469	1,537	1,632	1,728
TOTAL	1,873	1,968	2,063	2,158	2,292	2,427

The Role of Industrial Engineers in Product Design Management

Industrial Engineering (IE) is a domain of engineering involving the analysis, design, improvement, implementation, and management of integrated systems of human resources, process, materials, equipment, energy and information. As industrial engineers apply total system approach to their work, the discipline draws upon the principles and methods of work analysis as well as mathematical, physical, and social sciences. Therefore courses offered at universities are based upon engineering as well as management-related disciplines.

While other engineering disciplines apply skills in very specific area, industrial engineering is applicable to a wide variety of organizations. The role of industrial engineers in most organizations is to improve productivity and quality, leading to overall enhanced competitiveness. Nowadays companies are increasingly aware that a firm's ability to design and develop new products is instrumental in achieving sustainable profitability. Industrial engineer can play an important role in facilitating the process of new product development. It is evident that the management of product design is now a rapidly developing career.

Product development requires a multidisciplinary approach. Besides technical expertise and creativity, other skills required on the part of engineers and industrial designers include understanding of business plans, marketing and financial information (Bonollo, 1999). Skills in managing the design and development process are also needed so that cooperative understanding can be established among team members. Effective communication helps the team to discover problems early in the design process, leading to greater chance for success. According to Lehmann and Winer (2005), the critical skills for product managers are: negotiation, teamwork, communication skills, and analytical ability.

Industrial engineers can serve as a perfect link in managing the process of product design and development as illustrated in Figure 1. Their engineering background gives them credibility when dealing with management of innovation. Since they are able to speak in both technical and management terms, they can effectively liaise with team members from various disciplines. In addition to horizontal integration, industrial engineers can also facilitate vertical coordination from senior managers to shopfloor workers. For instance, they can communicate the economic benefits of design inputs to management, making it easier for executives to review and evaluate the project. Industrial engineer's total system view can also be utilized to establish a system that helps bring the products to market in the most effective manner, leading to reduced time and lower costs. Table 2 summarizes the skills of industrial engineers that are relevant to product design management.

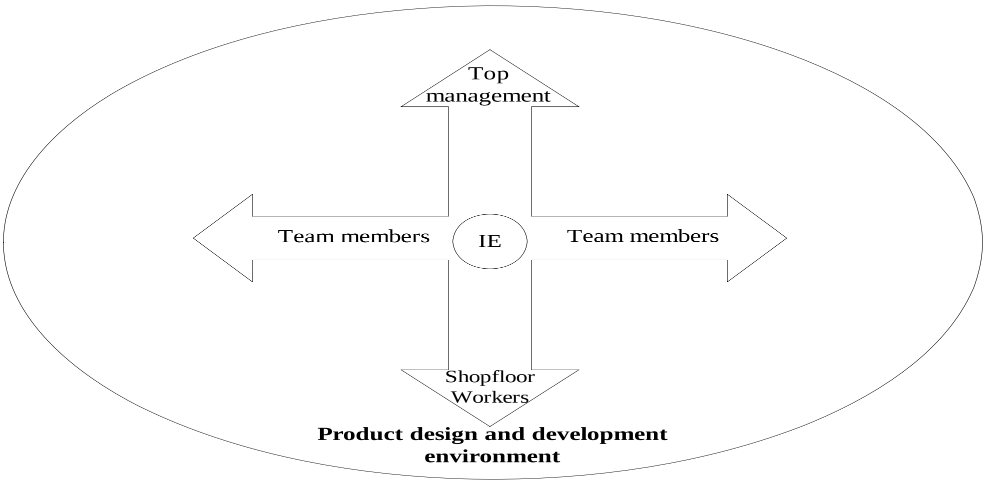

Fig. 1 Industrial engineers can serve as a perfect link in the product design and development process

Table 2 Skills of industrial engineers relevant to product design management

IE skills	How are they applicable to product design management?
1. Total system approach	Industrial engineer's total system view can be utilized to design a system that helps bring the products to the market in the most effective manner.
2. Analytical skills	Can be used in design problem solving
3. Process improvement skills	Can be applied to facilitate the process of new product development, leading to reduced time and lower costs.
4. Skills in engineering economics	Help in communicating the financial benefits of design input to senior management
5. Skills in engineering management/ social sciences	Beneficial in understanding the customers' needs
6. Engineering skills	Help in communicating with engineering designers
7. Presentation skills	Help in communicating with team members and senior management

In response to this movement, universities are adjusting their curriculum to accommodate the management of product design. Some schools offer a special program in product design and management at the undergraduate level. For instance, Aston University (UK) introduced the product design program where students can choose to specialize in product design and management. Several engineering schools are now offering a course in product design and development as a compulsory subject for undergraduate students in manufacturing engineering.

Teaching and Learning Process

A course in product design and development should provide IE students with the skills in product design and management in order to prepare for working across a broad range of business functions and design opportunities. At the Department of Industrial Engineering, Thammasat University, product design and development is a required course for students in the Twinning Engineering Programmes which offer courses in the first two undergraduate years for students who wish to complete their studies in the partner universities abroad. It is also a required course for the Thammasat English Programme of Engineering which is an undergraduate international program where courses are taught in English for the entire curriculum.

Product design and development is a project-based course covering modern tools and techniques for product design and development. To ensure that students gain a thorough understanding of fundamental design process as well as practical skills, classes are conducted in workshop mode for about 50 % of the time and employ hands-on exercises to reinforce the key idea. Students are grouped in teams where they conceive, design, and prototype a physical product. Class sessions are administrated along the process of product design and development as shown in Figure 2.

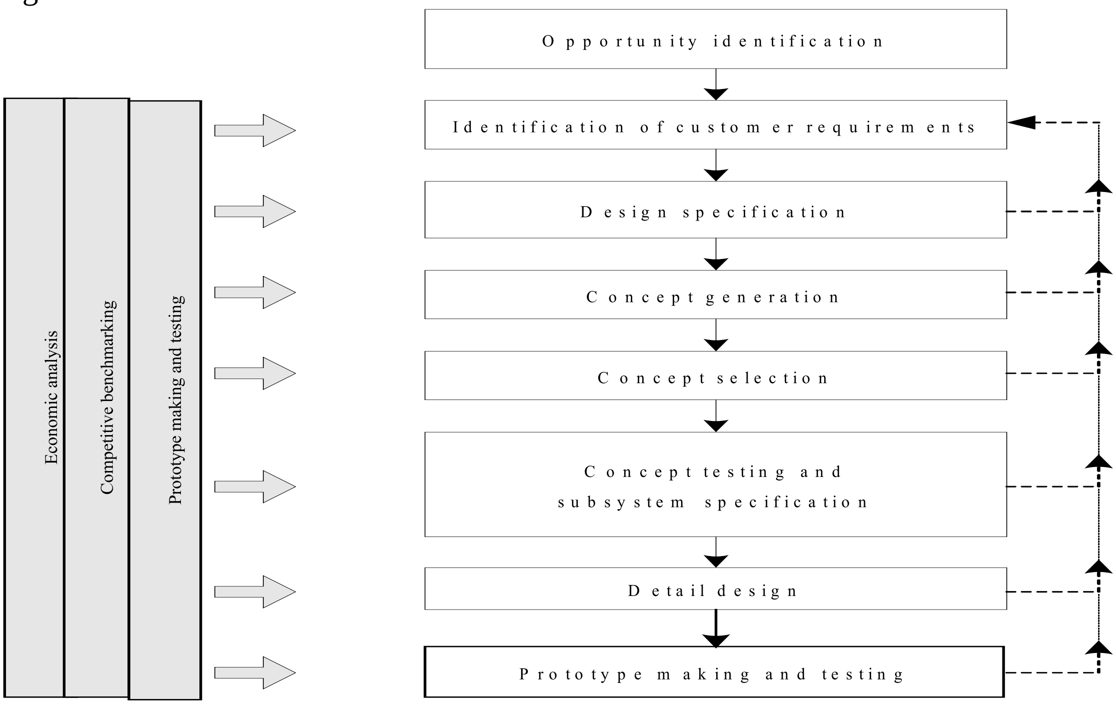

Fig. 2. Product design process (Adapted from Wright, I.. Design Methods in Engineering and Product Design. McGraw Hill, 1998)

Opportunity Identification and Mission Statement

Before developing any new products, students need to learn how to identify attractive opportunity. This part of product planning is important since successful product commercialization depends on the ability to recognize the right opportunity. While some classes assign a specific product for all students, this class allows the teams to choose their own projects. Each approach has its own merits. If students are to work in a pre-assigned project, they can immediately embark on prioritizing customer requirements and focus on innovating distinctive features or making incremental improvements to the product. In such case, more time can be allocated to the manufacturing part of the project, which is the approach usually adopted by a more “hard-core” engineering discipline like mechanical engineering.

On the other hand, if students are given the chance to search for their own project, they will acquire the skills necessary for entrepreneurs, i.e. how to identify and evaluate the right opportunity. For IE students, it is important that they have the ability to conceive new business ideas and evaluate them so that they can communicate the benefits to their future managers and product development teams. Students must also demonstrate that their projects show promising chance for commercial success although financial feasibility is not required at the initial stage.

The decision on the type of project to be pursued has great influence on the upcoming development process. Therefore it is the responsibility of the lecturer to give advice or screen the proposed team project. For instance, a project on developing mobile phone battery or compact power generator may have less room for creativity in comparison with a more radical product. Each situation will require different levels of efforts to be spent on product development activities.

Balachandra and Friar (1997) proposed a model which can be used as a guideline for evaluating a project. In teaching new product development, this model can also be applied when reviewing the students' projects. As shown in Table 3, the model consists of three contextual variables (innovation, technology, and market), each of which representing various situations in product development. This Table recommends the relative importance to be place on the factors leading to success or failure of new product development. Those factors are: market factors, technology factors, and organization factors.

Table 3 A suggested Scheme of Relative Importance of Project Evaluation Factors for Combinations of Contextual Variables. (From Balanchandra, R. and Friar, J. H. , "Factors for success in R&D projects and new product innovation: a conceptual framework", IEEE Transactions on Engineering Management, Vol. 14, No. 3, August 1997. pp 276-287)

	Contextual variables					
Combination No.	Innovation	Technology	Market	Market Factors	Technology Factors	Organization Factors
1	Incremental	Low	Existing	Very Imp.	Less Imp.	Very Imp.
2	Incremental	Low	New	Very Imp.	Less Imp.	Very Imp.
3	Incremental	High	Existing	Very Imp.	Very Imp.	Imp.
4	Incremental	High	New	Imp.	Very Imp.	Imp.
5	Radical	Low	Existing	Imp.	Imp.	Imp.
6	Radical	Low	New	Less Imp.	Imp.	Imp.
7	Radical	High	Existing	Imp.	Very Imp.	Imp.
8	Radical	High	New	Less Imp.	Very Imp.	Very Imp.

This model can be used to assess the level of commitment on different project situations so that the lecturer can give appropriate supervision to each student team. For instance, if students decide to take up a project in Combination 1, they must spend a great deal of effort on marketing analysis to identify the customer requirements. It is important that they discover latent needs so that delightful product features can be offered to customers. On the contrary, less emphasis is placed on technology factors since innovation is incremental. Organization factors are very important since low-tech products usually face strong competition and success depends on operation efficiency to achieve cost advantage.

Once the right opportunity is identified, a mission statement is established for the product. Mission statement includes the product description, business objectives, customer targets, constraints, assumptions, and stakeholders. It can be used as a general roadmap for the rest of the tasks.

Identification of Customer Requirements

The next task is understanding of customer needs. Students should be introduced to useful marketing concepts like market positioning and market analysis. This step is especially important if the products are of incremental innovation. To identify the product features that delight the customers, passive understanding of customer needs is required. Traditional techniques in marketing survey are not sufficient, and more useful tools should be applied to uncover hidden needs of users. Several techniques for finding latent needs are available such as user observation and experiential approach. However, for radical product, the market may not exist at all and product design may be based solely on the creative instincts of the designer (Balachandra and Friar, 1997). Therefore, students undertaking such project can place less emphasis on market analysis but more emphasis on the technical factors as shown in Combination 5-8 in Table 2.

It should be noted that most of the projects that IE students select fall into Combination 1-4 since they are more familiar with incremental innovation. Therefore, greater emphasis is placed on the market and organizational factors rather than on the technological factor. In terms of market factor, students carry out further market analysis to identify the importance of customer needs as well as competitive performance. In this respect students learn that the team must rely on marketing expertise while in the next process they realize that the role is shifted to engineering experts.

Establishment of Design Specification

In translating the customer needs into design specifications, a number of techniques can be used. Quality Function Deployment (QFD) is a powerful tool that facilitates the organization of product development projects. Developed in Japan in the late 1960s by Professor Yoji Akao and Professor Shigeru Mizuno, QFD provides a systematic approach in translating the customer needs into technical requirements and further specific actions thus it helps designing customer satisfaction into a product before it is manufactured.

QFD utilizes a series of matrices, each of which contains information along different phases of product design and development. As shown in Figure 3, the first matrix consists of six parts. Part (1) and (2) include the customer requirements that students obtain from the previous section. Before placing the data onto the QFD matrix, it should be organized into a meaningful form by using such method as Affinity Diagram. Part (3) is the technical specifications that are translated from the customer requirements. Part (4) is the relationship matrix that relates the customer data with technical specifications while Part (5) shows the relationship among the technical specifications. Part (6) is the relative importance of technical specifications that are calculated from the previous parts.

QFD allows a large amount of information to be managed effectively on a small number of documents. Its format can be adjusted according to the purpose of use and the nature of products. It is also applicable for both products and business processes therefore students learn to adopt QFD and modify it accordingly.

Figure 3 demonstrates how QFD can be used as a framework for product development process. The application of QFD yields several valuable outcomes. First, the relative importance of technical specifications can be established based on the customer data, thus revealing the priority of design problems. In practice, there are usually numerous design specifications, and it is not possible for the design team to make improvements on all of them. Pareto analysis can be used to identify the key technical requirements that are critical to the product success. Students can then focus on those “vital few” and use them as the design problem in further stages.

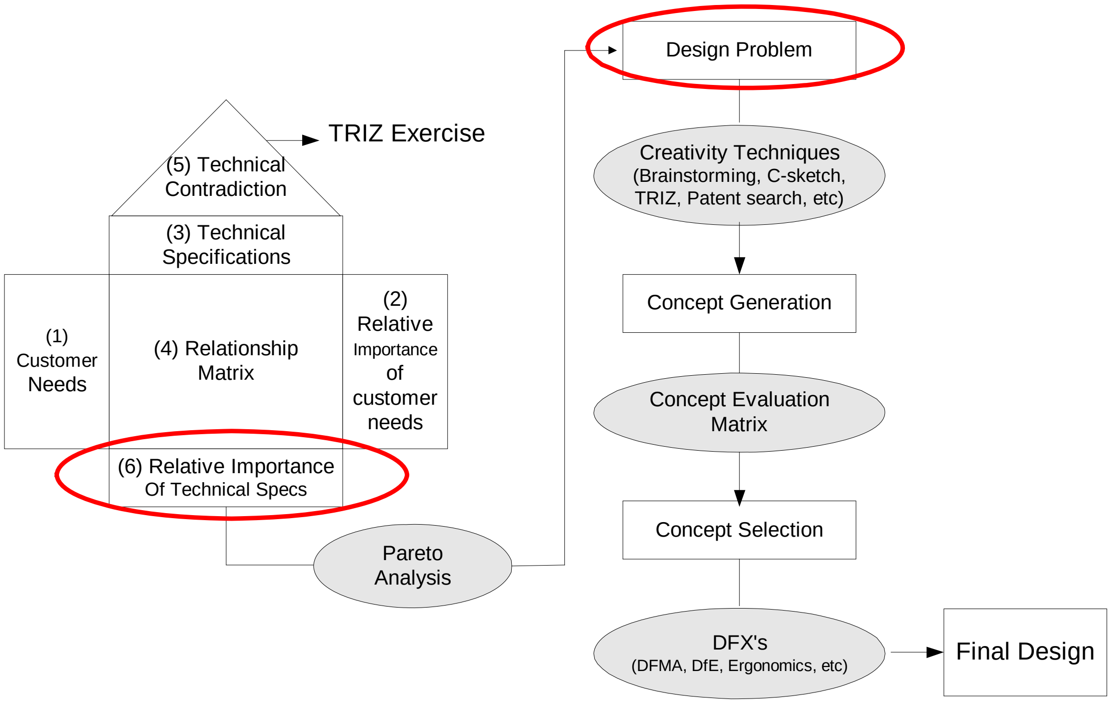

Fig. 3. A conceptual model of how QFD can be used as a framework for product development process

The results obtained from Pareto analysis also reveals whether QFD process is carried out appropriately. If the specification data does not conform to the Pareto principle, it implies that there are pitfalls in one or several parts of QFD table, e.g. the relative importance of customer needs, competitive performance, or the relationship between customer requirements and technical specifications. The team can then investigate whether their data collection or decision making is legitimate. Therefore the Pareto analysis performed on data obtained from QFD is helpful for cross validation purpose as well as identifying the design targets.

Besides providing a systematic way of establishing technical specifications, QFD also brings out technical contradictions among design specifications which call for high-level creativity problem solving techniques such as TRIZ.

Concept Generation

Once the design problem is realized, the next step is concept generation. Although this may not be a typical job expected from industrial engineers, IE students can benefit from the course of action. Taking the design problem as input, students are required to generate as many concepts as possible. This is the most creative part of the design process. A number of techniques are useful such as brainstorming, C-sketch, TRIZ, and analogy. Students are introduced to these creativity techniques and apply them during concept generation. In addition, patent search is undertaken to review possible ideas. In this class students find patent search very helpful in generating design concepts. To properly exploit the knowledge, they also need to learn about intellectual property rights. Through patent search they can additionally discover the trend of technological changes relevant to the products.

Concept Selection

In selecting the final concept, a matrix approach can be employed. As shown in Table 4, the concept evaluation matrix consists of explicit criteria against which each concept is evaluated. The criteria is the design problem derived from QFD table and employed in the concept generation phase, i.e. the technical specifications which are the "vital few" according to the Pareto principle. It should be noted that their relative importance is included for evaluation purpose. Thus information derived from QFD is passed on to the concept generation as well as concept selection phase.

Table 4 Concept evaluation matrix for bathroom tiles

No	Quality characteristics	Reference product	Importance weight	C1	C2	C3	C4	C5
1	Thickness (mm)	TGCI	0.06	+	0	0	+	0
2	Modulus of rupture (N/mm^2)		0.06	+	0	0	+	0
3	Bending strength		0.06	+	0	0	+	+
4	Weight bearing strength (kg/piece)		0.06	+	0	0	+	+
5	% anti-bacteria		0.05	-	+	+	-	+
6	Applicable with 3-D simulation design		0.04	+	-	-	+	-
7	Chemical resistance		0.04	0	0	0	0	+
8	Slip resistance		0.02	+	0	+	0	-
9	Abrasion resistance		0.02	+	0	+	0	-
10	Temperature control range		0.02	+	+	+	-	-
11	Fragrance		0.02	+	+	+	+	-
	Total (by weight)			0.36	0.05	0.09	0.23	0.09

To provide a basis for comparison, a reference concept is chosen as a benchmark for concept evaluation. Each concept is then evaluated against the reference product regarding the ability to satisfy the criteria better than (+1), worse than (-1), or equal to (0) the reference product. Each evaluation is then multiplied by the relative importance of the relevant specification.

It is recommended that the reference product should have an average performance so that assessment can be done in both directions. On the other hand, if the reference product is chosen from a high or low-end product, then it might be difficult to differentiate among the various concepts. In general, the reference concept should be an existing product in the market, or one of the concepts designed by the team in case of absence of existing product.

During the evaluation process, it may be necessary to perform some concept testing to measure performance. Once the final design is chosen, it is usually reviewed for further improvement. Students can then carry out detail design and prototype building. At this point they should be introduced to techniques like Design for Manufacturing and Assembly (DFMA), Design for Environment (DfE), and Design for Ergonomics. Hands-on experience can be gained by using these techniques to refine the students' design.

Teaching, Learning & Assessment

Besides team-based project work, case studies and individual exercises are also given throughout the course. This will enable the students to create a balance between academic lectures and practical work. Assessment is done on a continuous basis, using a combination of design projects, individual exercises, and written exams. At the end of the course each team presents a prototype and the underlying development activities along with suggestions on how to improve its design and development process.

Problems and Opportunities

It should be noted that up to the present time this class has not placed great emphasis on the manufacturing part of the project. Although a working prototype is desirable, it is acceptable to build a physical paper model. Thus a room for improvement is possible for those wishing to integrate the manufacturing aspect into the course. In this class this gap is narrowed by introducing DFMA technique into the learning process. Students must demonstrate how their designs follow DFMA concepts and make necessary improvements on the overall design to improve assembly efficiency.

Although cost is viewed as a constraint rather than part of the design problem, it can be taken into consideration during such process as concept evaluation and detail design. In this class, students are to calculate the cost of making the product based on a review of the final design.

Based on the author's experience, it is proposed that QFD should be adopted as a framework for teaching product design and development for IE students due to a number of reasons.

- QFD is a process-based tool that provides a large picture of the overall product development process. It helps facilitate cross-functional communication and integrates several aspects of design into the same process. It is therefore consistent with the concurrent engineering approach.
- Most IE projects are of incremental nature therefore it requires strong emphasis on the organizational and market factors. As for the organizational factor, QFD facilitates the management of design process.

It helps the students grab the concept of systematic approach to product design and development, and at the same time allows the inclusion of creative problem solving into the process.

- Market emphasis is also important for product development. QFD is an excellent tool that relates the customer requirements to the design specifications thus bridging the gap between marketing and engineering and bringing the customers closer to the designers. Through Quality Function Deployment, other tools and techniques can also be integrated into the entire process that brings about the final design concept. Therefore QFD is a very effective tool that can be used as a framework for teaching product development.

Other Design Techniques

Besides QFD, there are other design techniques which can be used in product development such as DFMEA, APQP, DFSS. This section discusses these techniques and comment on their suitability and usefulness in the teaching of product development.

Design Failure Mode Effects Analysis (DFMEA) is a technique which makes use of the Failure Mode and Effects Analysis method in product design application. Unlike QFD, DFMEA is typically employed at the concept development stage. It uses the design drawings or documents to identify each component and the potential failure modes and their effects. The output of DFMEA will indicate on which items to focus design efforts and make necessary design changes. When compared with QFD, DFMEA involves a more technical aspect of product development. Its practical application does not include all the activities within the design process. In this sense, QFD is a better tool for teaching product development since it is applied at the earliest stage of gathering customer requirements, thus covering a wider range of activities in product development. However, it can be stated that DFMEA complements with QFD, and can be used as a tool to assist in the technical analysis.

Advanced Product Quality Planning (APQP) is a framework of procedures and techniques for product development particularly used in the automobile industry. Developed in the late 1980's by experts from the "Big Three" American automobile manufacturers, the purpose of APQP is to generate a product quality plan which will support development of a product or service that will satisfy the customers. It is currently adopted by several automobile manufacturers and their suppliers, particularly General Motors, Ford, Chrysler. Like QFD, APQP provides the structure which ensures that Collaborative Product and Process Design takes place. In comparison with QFD, APQP covers a wider range of tools since it was developed after QFD. In practice, APQP acts as a process for product development system by making use of several techniques including QFD, FMEA, DFMA, and other quality disciplines.

DFSS is a design approach popularly used in the Electrical and Electronics Industry. It is similar to APQP because DFSS employs various tools and techniques to ensure customer satisfaction of the product, such as QFD, FMEA, Design of Experiments, statistical optimization, TRIZ. Unlike APQP, the phases of DFSS are not universally recognized or defined. Each company or training organization tends to define DFSS differently, utilizing any of the several possible advanced design tools.

In short, several design techniques are available as discussed in this section. Some techniques (such as DFMEA) are more technical, and are applicable for a particular phase of product development. Other approaches such as QFD, APQP, and DFSS are total system approaches which provide stage for concurrent engineering and serve as platform for communication across various stakeholders in product development. While this article presents the use of QFD along with other design tools, APQP and DFSS act as umbrella approaches covering various techniques. With great emphasis on management and planning, they can be alternatively used as framework for teaching product design and development.

Conclusion

Courses in product development are introduced in several schools ranging from the highly technical disciplines to the softer management discipline. Due to the multidisciplinary nature of product design and development, different emphasis is placed on different topics depending on the main discipline of the students. This article presents the teaching and learning of product design and development for Industrial Engineering Students.

Upon completing the course, students are expected to have a broader perspective of product design and development process as well as better understanding of teamwork. Students should become familiar with the tools that help facilitate the development process, especially QFD, marketing research, and other design and creativity techniques (e.g. DFMA, DfE, TRIZ). Using the Quality Function Deployment as a framework, all the tools and techniques can be integrated into the entire process that brings about the final design concept. Besides the development of products, QFD can also be applied in new service development. QFD is thus an effective tool that can be used as a framework for teaching new product /service development.

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