Green Supply Implementation based on Fuzzy QFD: An Application in GPLM System

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Abstract: - Quality function deployment (QFD) has been widely used in many fields; it is one of the structured approaches that are used to translate customer needs into specific quality development. However, in the traditional QFD approach, each element's interdependence and customer requirements (CRs) for green supply are not usually treated systematically. The important function of green product lifecycle management (GPLM) is to develop an attractive system which ensures customer satisfaction for green supply. Therefore, one of the important topics in the development of the GPLM system is to take into green consideration. This study presents an integrative approach by incorporating GPLM with fuzzy analysis into the matrix of QFD and obtaining the priority ranking of engineering characteristics (ECs). To illustrate these findings, we have incorporated an example which suggests that the proposed approach can contribute to the creation of attractive GPLM attributes and GPLM innovation. Several ECs and CRs are identified and analyzed. The results of this study can provide an effective procedure for improving a product's design characteristics under GPLM, enhancing customer satisfaction, and launching a green product in the marketplace.

Key-Words: - GPLM, Fuzzy QFD, Green supply, Engineering characteristics, Customer requirements, Rank.

1 Introduction

Green product lifecycle management (GPLM) is a strategic business system which allows more effective green communication among different stages of the product lifecycle process at dispersed locations in order to facilitate the sharing of ideas and the accessing of information needed for developing new green products and executing the innovation processes. However, the operating methods and customer preferences of developing new green product depend on differences in geographical locality, national characteristics, and economic development resulting in divergence in the various purposes of green products by customers from different countries. Therefore, this study attempts to explore customer requirements (CRs) by questionnaires so that the findings may provide manufacturers of new green products with an in-depth understanding of the requirements of green supply.

This study attempts to achieve:

1. An understanding of the priorities of various factors about the product by customers; and
2. An understanding of what properties are valued most by customers through a GPLM system based on fuzzy QFD while providing manufacturers in realizing green supply for their products.

2 QFD and fuzzy QFD

2.1 QFD

QFD, which originated in 1972 in Japan, has been a successful tool for systematic team development and for assist product designers to translate customer requirements and market research into engineering requirements. According to Bottani and Rizzi [9], QFD is composed of four successive matrices: the customer requirement planning matrix, the product characteristics deployment matrix, the operative instruction matrix, and the process and quality control matrix. The present study concentrates on the customer requirement planning matrix.

The customer requirement planning matrix, also known as the ‘‘house of quality” (HOQ), is the first step in investigating customer requirements and undertaking market research. HOQ begins with CRs which are usually obtained from customer interviews or market surveys. The acquired CRs are translated into a list of measurable ECs. Based on the acquired CRs and ECs, the team can determine the relationships between CRs and ECs, the competitive analysis, and the correlations between ECs. The obtained HOQ information can be used to calculate the importance ranking of ECs [16, 20]. The components of the HOQ are shown in Fig. 1.

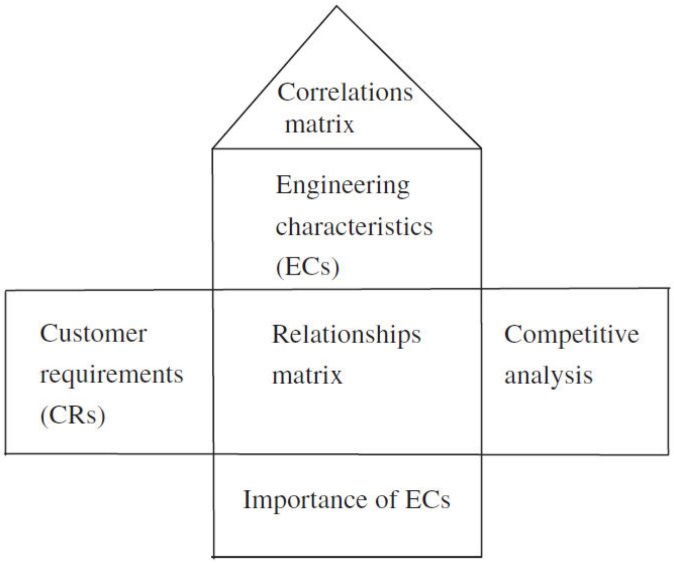

Fig. 1. Components of the HOQ.

The importance scores of CRs, the relationships between CRs and ECs and relationship between the ECs themselves are usually determined subjectively by ambiguous or vague judgments. However, they are usually treated as crisp variables [4, 5, 38, 39]. For example, in traditional practice, the importance score of each CR is set as a crisp value, although linguistic terms seem more adequate for evaluating the CR’s importance. Furthermore, the degree to which an EC affects a CR is expressed on a scale system such as 1-3-9, or 1-5-9, representing linguistic expressions such as “weak”, “moderate”, and “strong”. However, design engineers usually do not have sufficient knowledge and information about the influence of engineering responses on CRs, due to the lack of information or language hedge from the customer [3, 28, 40]. These considerations have made the applications of fuzzy approaches significant in addressing diversified and imprecise problems in the importance score of each CR and the relationships between CRs and ECs and the relationship between the ECs themselves [37, 11, 26].

2.2 Fuzzy QFD

Fuzzy systems are developed using fuzzy logic techniques [19]. They are used in many applications [2, 12, 13, 14, 15, 29]. A number of scholars have applied the fuzzy set theory to QFD and developed various fuzzy QFD approaches. For example, Chan et al. [22] used fuzzy number and entropy approaches to derive the importance weight of CRs, respectively, and combined the results to obtain the final priority of CRs. Shen et al. [32] found it necessary to translate CRs into an analysis of future trends. They added a future tendency index to the priority of CRs to compute the final priority of CRs. Wang [17] viewed QFD as a multi-criteria decision making problem and developed a new fuzzy outranking approach to obtain the priority ranking of ECs. Khoo and Ho [23] proposed the concept of fuzzy QFD and fuzzified linguistic variables to make them more reasonable. Zhai et al. [25] proposed rough-fuzzy QFD system combines fuzzy arithmetic operations with the two novel concepts of rough number and rough boundary interval that are derived from rough set theory. Hassan et al. [18] provided the application of fuzzy QFD to handle the subjective assessments. Due to the impreciseness in a QFD process, Chen and Weng [21] applied fuzzy approaches in this paper to determine these fulfillment levels of ECs for achieving the maximum satisfaction degree of several goals in total in the product design stage. They also considered the correlations among CRs and ECs.

Sohn and Choi [36] used a fuzzy multiple criteria decision making (MCDM) approach to select a design with an optimal combination of reliability and customer satisfaction. Shen et al. [33] mentioned that the priority ranking of ECs may be affected by several factors, including types of fuzzy numbers, defuzzification approaches, and the number of fuzzy numbers. It was found that different approaches to defuzzification led to different results in rankings. Lin [5] was concerned about the difficulty involved in the design of ECs and added this factor to the computation of the priority of ECs. Venegas and Labib [24] used a fuzzy analytical hierarchy process (AHP) approach to derive the priority of CRs and further incorporated factors, such as customer satisfaction, cost, and technical difficulty, to obtain the final priority of ECs. Buyukozkan et al. [10] established a network hierarchy based on the QFD framework and employed fuzzy extent analysis to calculate the weight of each pairwise comparison matrix. The results were later integrated into a super matrix to compute the priority of ECs. Tsai [6] applied fuzzy integral to rank ECs by priority along with an index of a decision-maker's forecast of the market. Chen et al. [35] proposed an integrated fuzzy expected value approach, in which two fuzzy expected value models were established to determine the priority of ECs. Chen et al. [34] integrated the fuzzy weighted average approach and the fuzzy expected value approach to evaluate the priority of ECs. Kahraman et al. [4] employed the analytic network process (ANP) approach to determine the priority of each EC and incorporated resource constraints, such as cost budget, to form a multi-objective programming problem and derived important ECs. Bottani and Rizzi [9] used QFD in logistics management. They translated the linguistic values of customer requirements into fuzzy numbers and computed the priority of ECs using the conventional QFD approach. Kwong et al. [3] developed a fuzzy expert system approach to measure the priority of ECs and the correlations among ECs. These two measures were integrated to calculate the aggregated priority of ECs, etc.

Note that these fuzzy QFD approaches usually focus on obtaining priority rankings, but are not concerned with the importance of the product lifecycle management for green supply.

2.1 GPLM system and its major benefits

Product lifecycle management (PLM) is a strategic business approach that helps enterprises to achieve their business goals of reducing costs, improving quality and shortening the time to market, while innovating their products, services, and business operations [27]. The core concept of PLM provides a definition of a completed product including all information and processes required for planning, developing, manufacturing and supporting the product from concept through the end of its life. PLM allows effective communication among different groups at dispersed locations to share ideas and access information needed for developing new products and executing innovative processes. PLM is also a strategic business approach that forms the product-information backbone for a company and its extended company [1]. PLM can help enterprises to quickly develop and deliver products that drive their business. With PLM, enterprises gain the following benefits:

- Improved manufacturing operations
- Higher productivity
- Better business decisions
- Lower cost of ownership
- Reduced costs
- Better business results
- Higher product quality
- Faster development

The broadest benefits of PLM can be achieved through greater performance at the extended enterprise level which involves information management, program management, and collaboration across separate groups and companies. These benefits are achieved through the aggregate benefit of the many different groups and departments within the company using PLM. By working together on a common PLM platform, companies can forge strong design chain partnerships which combine their best-in-class capabilities to deliver differentiated value to customers.

Note that these benefits usually relate to the business goals of enterprises, but not the importance of green supply. GPLM, a strategic system, allows more effective green communication among different product development stages at dispersed locations to access information needed and shares ideas for developing new green products and executing the innovation processes. This study presents an integrative approach by incorporating GPLM with fuzzy analysis into the matrix of QFD and obtaining the priority ranking of ECs under green supply consideration.

3 Establishment of fuzzy QFD

If Ã=(a1,a2,a3), and Ẽ=(b1,b2,b3) are related to two triangular fuzzy numbers, then the arithmetic operation approaches for addition +, subtraction −, multiplication *, and division ÷ are shown, respectively, as follows [7, 8]:

Addition:
Ã + Ẽ = (a1, a2, a3) + (e1, e2, e3)
= (a1 + e1, a2 + e2, a3 + e3)

Subtraction:
Ã - Ẽ = (a1, a2, a3) - (e1, e2, e3)
= (a1 - e3, a2 - e2, a3 - e1)

Multiplication:
Ã * Ẽ = (a1, a2, a3) * (e1, e2, e3)
= (a1 * e1, a2 * e2, a3 * e3)

Division:
Ã / Ẽ = (a1, a2, a3) / (e1, e2, e3)
= (a1 / e3, a2 / e2, a3 / e1)

Table 1 shows the triangular fuzzy number of linguistic value adopted and its associate functions.

Table 1 Triangular fuzzy number & its associate functions

Linguistic Value	Fuzzy Number	Associate Functions
1	$\tilde{1} = (0,2.5,5)$	$\mu_{\tilde{1}}(x) = \begin{cases} x / 2.5, & 0 \le x \le 2.5 \\ (5-x) / 2.5, & 2.5 \le x \le 5 \end{cases}$
3	$\tilde{3} = (2.5,5,7.5)$	$\mu_{\tilde{3}}(x) = \begin{cases} (x-2.5) / 2.5, & 2.5 \le x \le 5 \\ (7.5-x) / 2.5, & 5 \le x \le 7.5 \end{cases}$
9	$\tilde{9} = (5,7.5,10)$	$\mu_{\tilde{9}}(x) = \begin{cases} (x-5) / 2.5, & 5 \le x \le 7.5 \\ (10-x) / 2.5, & 7.5 \le x \le 10 \end{cases}$

Formula 1 shows the triangular fuzzy number integral value [30, 31]:

$$I(\tilde{S}) = (1-\alpha)\int_0^1 [a+(b-a)y]dy + \alpha\int_0^1 [c+(b-c)y]dy$$

4 Empirical analysis

In this section, an example is given of a bicycle design and production company to explain the research steps of the proposed approach. This company is a medium sized manufacturer in central Taiwan. Most of its production (about 85%) is sold to local distributors and the rest is exported to Mainland China and Southeast Asian nations. Bicycles produced by this company are mainly sold to downstream firms and customers via sales distributors. Currently, this company is faced with two major issues: (1) Due to the green demands of environment in Taiwan, the green design and manufacturing processes of bicycle have become an imperative issue. (2) With rising living standard, customers now demand more for green products. However, the bicycles produced by this company are still much behind the products manufactured in European nations in terms of quality, yield rate, and surface processing. How to enhance product functions and quality to meet customer green demands is an imperative issue that it needs to cope with. According to documentary research and interviews with professionals, the GPLM of this company includes four successive stages, namely manufacturing, use, packaging, and refuses. The CRs include seven main factors of voices of customers, namely appearance, functionality, reliability, responsiveness, service, popularity and environmental as shown in Table 2.

Table 2 Seven main voices of customers

	Voices of Customers (VOC)
Appearance	Styling
	Color
	Fashion
	Material quality sense
Functionality	Front absorber
	Rear absorber
	Speed changing function
	Folding function
	Easy portability
	Glove rack
Reliability	Front warning lamp
	Horn or buzzer
	Rear warning lamp
	Bike-laden tools
Responsiveness	Agile gear switching
	Agile braking strength
	Width of handle
	Size of bike
	Size of rim
Service	After sale service
	Easy parts replacement
	Duration
	Assembly quality
Popularity	International leading brand
	Local leading brand
	Added value
Environmental	Parts allowing detailed breakdown for service
	Parts compatibility
	Impacts of waived parts on environment
	Reclaim and reuse of parts and accessories

4.1 Quality houses

One thousand and seven hundred valid questionnaires were received from customers in this study. This study employed green quality development and gap 5 in SERVQUAL dimensions (gap between as recognized and as expected) in the construction HOQ for a bicycle. According to documentary research and interviews with professionals, quality elements are classified into seven properties and further divided into thirty items; and GPLM characteristics are considered two main categories: forward ligistics and inverse logistics, and further classified into four aspects, including manufacturing process design, use, packaging, and refuses, that are further converted into fifteen items as shown in Table 3.

1. Relation matrix: 9 indicates strong relation between two items; 3, medium, and 1, weak.
2. Extent of respect: averaged scores of extent of respect.
3. Competition criteria: averaged scores of extent of satisfaction.

4. Vital accidents: extent of impact from accident occurrence under this question is solved by the averaged scores of “extent of serious” in the questionnaires.
5. SERVQUAL scores: the gap between averaged scores of extent of respect and average scores of extent of satisfaction.

Table 3 House of Quality for a bicycle

VOC \ VOE		GPLM															Extent of Respect	Competition Criteria	Vital Accident	Scores of SERVQUAL
		Forward logistics											Inverse logistics							
		Mfg. Process Design							Use			Packaging		Refuses						
		Overall Color	Material	Volume	Weight	Overall Style	Functional Design	Safety Coefficient	Tire	Inner Tube	Transmission Chain	Packaging	Carton	Reclaim	Reuse	Reproduction				
Appearance	Styling	3				9											3.9	3.9	3.4	0.01
	Color	9				3											3.7	3.8	3.3	0.09
	Fashion					1											3.5	3.7	3.3	0.19
	Material quality sense		9									1					4.1	3.9	3.6	0.19
Functionality	Front absorber				1		3	1									4.1	4.0	3.9	0.14
	Rear absorber				1		3	1									4.0	3.9	3.7	0.11
	Speed changing function				77		3				1						4.2	4.0	3.9	0.10
	Folding function			9			1										3.0	3.5	3.0	0.50
	Easy portability			9	9												3.7	3.7	3.3	0.01
	Glove rack						1										2.7	3.2	2.7	0.48
Reliability	Front warning lamp							9									3.9	3.8	3.6	0.06
	Horn or buzzer							3									3.6	3.7	3.4	0.1
	Rear warning lamp							9									4.0	4.0	3.7	0.01
	Bike-laden tools											1					3.4	3.5	3.1	0.11
Responsiveness	Agile gear switching										1						4.2	4.0	4.0	0.19
	Agile braking strength							9									4.5	4.2	4.1	0.26
	Width of handle							3									3.7	3.7	3.4	0.00
	Size of bike			3	1												3.8	3.8	3.4	0.01
	Size of rim				1			1									3.6	3.6	3.3	0.08
Service	After sale service						1										4.3	3.9	3.8	0.39
	Easy parts replacement						1										4.0	3.8	3.6	0.14
	Duration		9				3										4.3	3.9	3.8	0.4
	Assembly quality							3									4.3	3.9	3.8	0.34
Popularity	International leading brand	1	1			1											3.3	3.6	3.0	0.25
	Local leading brand		1			1											3.4	3.6	3.0	0.15
	Added value	1	1			1								1	1	1	3.4	3.6	3.1	0.14
Environmental	Parts allowing detailed breakdown for service														9	1	3.8	3.7	3.7	0.02
	Parts compatibility						1				1				3		4.1	3.8	3.7	0.32
	Impacts of waived parts on environment		1						1	1		3	3		3	3	3.9	3.8	3.7	0.08
	Reclaim and reuse of parts and accessories		1						1	1				3	3	1	3.7	3.7	3.7	0.04

Table 4 Development of GPLM system based on fuzzy QFD

VOC \ VOE		GPLM															Extent of Respect	Competition Criteria	Vital Accident	Scores of SERVQAL
		Forward logistics												Inverse logistics						
		Mfg. Process Design							Use		Packaging			Refuses						
		Overall Color	Material	Volume	Weight	Overall Style	Functional Design	Safety Coefficient	Tire	Inner Tube	Transmission Chain	Packaging	Carton	Reclaim	Reuse	Reproduction				
Appearance	Styling	0.97				1.39											3.9	3.9	3.4	0.01
	Color	9.72				6.77											3.7	3.8	3.3	0.09
	Fashion					7.77											3.5	3.7	3.3	0.19
	Material quality sense		23.1									9.11					4.1	3.9	3.6	0.19
Functionality	Front absorber				7.21		12.8	7.21									4.1	4.0	3.9	0.14
	Rear absorber				5.47		9.68	5.47									4.0	3.9	3.7	0.11
	Speed changing function						10.1				5.71						4.2	4.0	3.9	0.10
	Folding function			45			17.7										3.0	3.5	3.0	0.50
	Easy portability			0.64	0.64												3.7	3.7	3.3	0.01
	Glove rack						13.9										2.7	3.2	2.7	0.48
Reliability	Front warning lamp							7.17									3.9	3.8	3.6	0.06
	Horn or buzzer							7.28									3.6	3.7	3.4	0.1
	Rear warning lamp							1.93									4.0	4.0	3.7	0.01
	Bike-laden tools											4.28					3.4	3.5	3.1	0.11
Responsiveness	Agile gear switching										10.4						4.2	4.0	4.0	0.19
	Agile braking strength							39.3									4.5	4.2	4.1	0.26
	Width of handle							0.23									3.7	3.7	3.4	0.00
	Size of bike			1.18	0.67												3.8	3.8	3.4	0.01
	Size of rim				3.25			3.25									3.6	3.6	3.3	0.08
Service	After sale service						19.6										4.3	3.9	3.8	0.39
	Easy parts replacement						6.56										4.0	3.8	3.6	0.14
	Duration		50.6				35.3										4.3	3.9	3.8	0.4
	Assembly quality							30.3									4.3	3.9	3.8	0.34
Popularity	International leading brand	8.98	8.98			8.98											3.3	3.6	3.0	0.25
	Local leading brand		5.64			5.64											3.4	3.6	3.0	0.15
	Added value	5.49	5.49			5.49								5.49	5.49	5.49	3.4	3.6	3.1	0.14
Environmental	Parts allowing detailed breakdown for service														3.28	1.29	3.8	3.7	3.7	0.02
	Parts compatibility						15.1				15.1						4.1	3.8	3.7	0.32
	Impacts of waived parts on environment		3.83						3.83	3.83		6.77	6.77		6.77	6.77	3.9	3.8	3.7	0.08
	Reclaim and reuse of parts and accessories		1.84						1.84	1.84				3.26	3.26	1.84	3.7	3.7	3.7	0.04
	Total	25.2	99.5	46.9	17.2	36	141	102	5.67	5.67	31.2	20.2	6.77	8.75	18.8	15.4				
	Rank	7	3	4	10	5	1	2	14	14	6	8	13	12	9	11				

4.2 GPLM system based on fuzzy QFD

This study employed the triangular fuzzy number integral value approach to solve fuzzy values of GPLM characteristics of the product and rankings of those values are shown in Table 4.

As shown in Table 4, the ranking variance is very significant after the computations have been performed. The highest extent of satisfaction concerns the item of “Functional Design”, followed by “Safety Coefficient”, “Material”, “Volume”, and “Overall Style”. Among those findings described above, fuzzy QFD is a structured and function oriented approach, which can assist manager to find out the important ECs for designing a green product under GPLM consideration. Therefore, bicycle manufacturers may carry out their efforts on green product improvement.

In the traditional QFD approach, each element’s interdependence and CRs for green supply are not usually treated systematically. On the other hand, many fuzzy QFD approaches usually focus on obtaining priority rankings, but are not concerned with the importance of the product lifecycle management for green supply. This study presented an integrative approach by incorporating GPLM with fuzzy analysis into the matrix of QFD and obtaining the priority ranking of ECs. GPLM is to develop an attractive system which ensures customer satisfaction for green supply.

To illustrate these findings, this study has incorporated an practical example which suggests that the proposed approach can contribute to the creation of attractive GPLM attributes and GPLM innovation. These results can provide an effective procedure for improving a product’s design characteristics under GPLM, improving the discernibility of design objectives and thus facilitate the decision making in product development.

4 Conclusion

Green supply is a critical strategic issue for satisfying customer requirements by improving green product design. Many fuzzy QFD approaches usually focus on obtaining the priority ranking of ECs, but neglect the priority of the product lifecycle management with green supply issue. The main function of GPLM is to develop an attractive system which ensures customer satisfaction for green supply issue. Therefore, one of the important topics of the GPLM system developments is to take CRs into green consideration.

QFD has been widely recognized as an effective means to develop quality products that can maximize customer satisfactions. However, little study has been done on an integrated approach involving fuzzy theory and QFD for analyzing the critical quality characteristics for GPLM. This study presented an integrative approach by incorporating GPLM with fuzzy analysis into the matrix of QFD and obtaining the priority ranking of ECs.

The results show that several essential customer requirements and technical characteristics were identified and analyzed. The proposed approach of this study can provide an effective procedure for improving a green product’s design characteristics, enhancing customer satisfaction and launching green products in the marketplace.

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