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The integration of QFD Technique, Value Engineering and Design for Manufacture and Assembly (DFMA) during the Product Design Stage.

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ABSTRACT

This paper deals with the integration of QFD and VE in the product planning process. QFD improves theservice/product performance based on the customer's requirements, whereas VE focuses on the reduction of service/product costs without lowering its quality or performance. The integration of QFD and VE together leads to the reduction of costs and improvements of service/product or performance. In this paper first a conceptual model of integration of these two techniques is provided and then the implementation procedures are explained, During the stage of design, a significant amount of information is gathered and analyzed to support the decision making process that leads to the synthesis of products. Many methodologies have been developed to help collect, organize, analyze, synthesize, and display the information used in the design process. It is conceivable that these techniques may be integrated to enhance the design process. This article summarizes the experiences obtained during the application of Quality Function Deployment, Value Engineering, and Design for Manufacture and Assembly to the redesign of five components. The research work showed that the tools can be used to maintain the team's focus during the design process. In addition, the process can lead to specific recommendations that are well documented and easy to evaluate. The exercise was motivated by the need to establish a methodology that results in functional products designs that are compatible with assembly and manufacture.

Key words: Design methodologies, Value Engineering, QFD, integration of QFD & VE, Conceptual Model.

Introduction

During the stage of design, a significant amount of information needs to be gathered and analyzed in order to support the decision making process that leads to successful products. Nowadays that the competition between firms has increased substantially, the scientific study and planning of service/manufacturing systems has become inevitable. Senior executives of financial institutes are looking for dynamic organizations compatible with the customers' needs and wishes in a way that value overweighs the service/product costs. Various techniques have been developed to help collect, organize, analyze, synthesize, and display the information used in the design process. Quality Function Deployment (QFD), Value Analysis/Value Engineering (VE) and Design for Manufacture and Assembly (DFMA) are among these techniques. Each one of them represents a formal methodology aimed at accomplishing particular objectives. This article summarizes the experiences obtained during the application of QFD, VE and DFMA to five design case studies. The exercise was motivated by the need to establish a methodology that produces designs that are easy to assemble and manufacture, and that perform as intended. The premise of this work is that a process that integrates QFD, VE and DFMA can be used to optimize a product design by streamlining information and by providing a roadmap that guarantees the quality of the proposed design.

2. *Literature Review:*

QFD, VE and DFMA have existed as formal methodologies for several decades. Each one has evolved independently and numerous studies have been reported in the literature about their nature and use. A brief review of work that is relevant to this research is now presented. [1] presents a detailed description of the Value Engineering Process, its philosophy and its current focus as a tool to reduce life cycle costs. [2] also present a description of the technique, and explain how the analysis of functions can trigger the innovation process. They also point out that linking this methodology to other techniques, such as DFMA and QFD, offers potential benefits. [3] present a description of the QFD process and explain the development of the House of Quality

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(HOQ). [3] describes the benefits of QFD on product development: improved quality and performance, customer satisfaction, and shorter lead times [4].

Reports the impact that the use of QFD has had in Toyota's operation, and estimates that it has been able to reduce 60% of manufacturing costs and 33% in product lead times when compared to unstructured approaches.

The benefits of applying DFMA are introduced by [5], who reports cases in which significant reductions in cost and lead time are accomplished by the use of this tool. Several studies address the integration of tools for specific purposes [6].

Proposes the integration of QFD and Failure Mode and Effect Analysis at a strategic level, that is, as a management tool. A draft of this integration is proposed, although no insights from an actual case are provided. Integration of the same tools during the product development cycle is introduced by [7] and an application case from Ford is introduced. [4] describes a model and a case for the integration of QFD and VE for the analysis of market research data in an effort to anticipate consumer's interests. [8] analyzes the weaknesses of the VE approach and discusses how they can be overcome by the DFMA technique. In particular he points how these techniques can be used to account for productivity (DFMA) and function (VE). Based on the domain concepts developed by Nam Shu, [9] proposes the integration of tools such as Triz, QFD, FMEA and DFMA to drive the product design process, and establishes the role of Six Sigma as a catalyst to integrate this process and generate effective designs.

3.Value Engineering:

The society of American Value Engineering defines value engineering as "the systematic application of recognized techniques, which identify the function of product or service, establishes a monetary value for that function and provides the necessary function reliability at the lowest overall cost". In VE, the term\Function" refers to what makes a product work or sell. Elias and Cheah and Ting discussed that it is more beneficial to apply VE at the earlier stages of development, namely; the preliminary design stage.They reported successful achievement of VE analysis in design cost management.

By applying VE for a project or product, one can be sure that all different alternatives that are candidates for satisfying the \Function", have been considered. It has been suggested in this paper that the best alternative should be chosen, based on customer preferences and their associated cost. In this article, the integration of VE and QFD has been proposed, which means that simply presenting different alternatives for the required \Function" is not enough and that customer opinion for these alternatives should be taken into account. This task would be performed using the QFD technique Value Engineering is a technique for determining the manufacturing requirements of a product/service, it is concerned with its evaluation and finally the selection of less costly conditions. VE is a process for achievingthe optimal result in a way that quality, safety , reliability and convertibility of every monetary unit is improved.Value Engineering is usually applied in the analysis and design of a service/product.Different methods for executing the VE have been used . These methods have a general format which contain thefollowing five phases (figure 1).

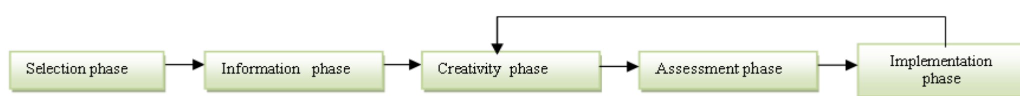

Fig. 1: Five major phases of VE.

4.QFD:

The QFD (quality function deployment) is a tool to translate customer requirements into technical features of a product or service "a method for developing a design quality aimed at satisfying the customer and translating the consumers demand into design targets and major quality assurance points to be used throughout the production phase" [4].An other clear definition give Sullivan [10] who define QFD as "a method that helps a manufacturing company to bring new products to the market sooner than competition with lower cost and improved quality". The definition of Sullivan only includes the manufacturing industry, but the QDF tool can be used in the service industry as well "even when a company is dealing with such intangibles as services, quality function deployment makes it possible to clarify, plan, and design the services to be offered and to conduct quality control activities" [4], The first introduction of the QDF method was 1966 in Japan by [4]. Since then there have been much publications about this topic in Japan, for example by Nishimura and Takayanagi, who introduce the quality charts the first time in 1972. Until Furukawa,[3] introduced QFD in the USA with a four day seminar and article in English in 1983, this method was only used by Japanese companies which had became very successful in these years. The QFD method is know by several names, the most common are the voice of customer (VOC) and the house of quality. According to the four-phase model of [11], the house of quality is just the first of the four steps of QFD (see figure 3: Four-phase QFD model (source: [11]. The house of quality is the matrix to get the customer requirements in the QFD methodology

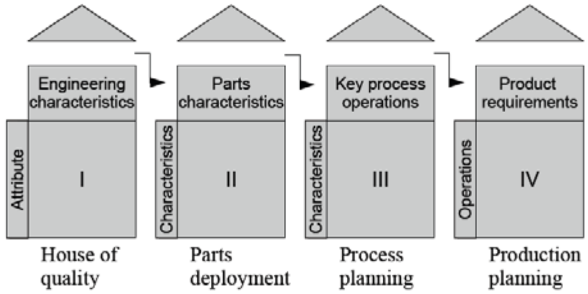

Fig. 3: Four-phase QFD model Source: [11].

5. design to manufacturing and assembling (DFMA):

Design for manufacturing and assembling (DFMA) is a target costing tool to reduce the production costs by improving the manufacturing and assembling process "Design for manufacturing and assembling (DFMA) refers to engineering processes design to optimize the relationship between materials, parts, and reduce time to market by making it easier to manufacture or assemble parts or to eliminate them" [12]. The design for manufacturing and assembling tool is able to reduce the production costs early during the design stage "the goal of DFM is to make a product easy to manufacture during the design phase of the development process " [13].

An example for a design for manufacturing and assembling system is the four step sequence according to Fujitsu systems [3]:

1) Designers select parts and specify their assembling sequence
2) Pre-existing guidelines are used to evaluate ease of (time for) assembly
3) Parts are reduced or their ease of assembly is improved
4) Design are reviewed against prior design experiences stored in a design data base

The user has to choose, if the step 2 or the step 3 is the best for the current project, they are concurrent and not sequential (see figure 6:Fujitus's DFMA System).

The design to manufacturing and assembling is used to reduce the productions costs, but it can have other positive aspects on the organization itself "DFM forces the development team to think about the production process; it brings representatives from different disciplines into the same room, and it forces a consideration of several alternative detail design strategies" [11].

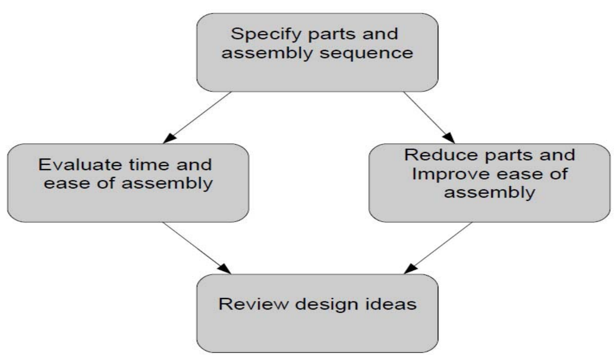

Fig. 6: Fujitsu DFMA System [3].

6. The Integration of QFD & V.E:

Value Engineering and QFD have different orientations. The main objective of V.E is the reduction of operational costs in the main and support process of an organization so that to lead to a reduction in the cost price.V.E selects a solution which produces more value for the customer. Unlike the V.E, QFD focuses on the customers' needs and requirements and tries to bring about innovations in the product/service design in a way that more satisfaction is obtained. In other words this technique looks for changes which produce the greatest value according to the customers' needs. It is worthwhile to mention here that out of the many possible solution, (alternatives), QFD selects the one that is practical (compatible with the organizations' capability) and is economical (requires less investment/operational costs). Needless to say that considering these two criteria (cost reduction & value addition) in a decision- making process may lead to the selection of a better alternative which not only enjoys a higher value by the customers but also imposes less expenses on the organization, a factor which contributes to the price stability / cheaper product/service cost prices. V.E is implemented during the planning phase, because 70% of the future costs depends on this stage (6). The best time for the application of V.E in a project is during this stage (3). Alain Leblanc, a member of American V.E Association and the senior manager of Canadian PW&C company, has demonstrated the relationship between QFD &V.E in this way. (figure 6). Figure 6 presents the sequence in which QFD, VE and DFMA were applied to the different cases in this work. This sequence was established based on an analysis of the characteristics of each tool and experience in their application. The research tried to identify the gaps and overlaps in the information as the design stage proceeds through thedifferent steps. A brief description of each one of the tools follows.

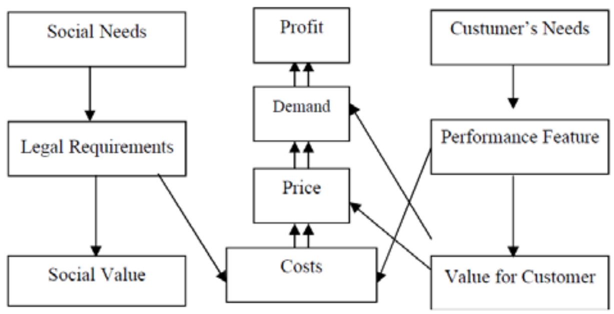

Fig. 6: Relationship between QFD & V.E design by A.lebelan.

The Quality Function Deployment methodology is designed to drive a product development process from conception to manufacture. The House of Quality (HOQ) is a graphic tool that is closely associated with QFD and is used to display the outcome of the analysis at the design stage: the correlation between customer's desires and engineering specifications of the product; the customer's perception about the product with respect to competing products; and the areas of opportunity for design. Value Engineering is a process in which a product is analyzed in terms of the functions it performs. Costs are associated with these functions, and disparity of value, in terms of the cost to importance of the functions are identified and targeted for improvement. Closely associated with this methodology is the Function Analysis System Technique (FAST) diagram, which displays the functional decomposition of the product. In this diagram, functions are classified as basic (what the product must do) and support functions. Function importance vs. Function cost graphs can be used to display disparity of value. Boothroyd and Dewhurt's Design for Manufacture and Assembly methodology is a technique that focuses on product redesign for minimizing manufacturing and assembly costs. The technique provides a ranking system that allows comparison of competing designs in terms of their ease of assembly and the component's manufacturing costs.

7.The Presentation of a Conceptual Model:

As was mentioned in the beginning of this paper, QFD looks for an increased customers' satisfaction and consequently more sale in order to earn more profit. Whereas V.E aims at earning more profit through a reduction of costs without lowering the quality of product/service. The main purpose of incorporating the techniques of QFD & V.E in the design of product/service or production process is the selection of suitable alternatives which while lead to the increased value for the customers do not increase the product/service cost. In other words through improving the costs, customers' satisfaction is obtained .The conclusion of this is that the process of product/service planning based on QFD principles begins in this manner. i.e. The customers' needs and requirements are taken into account. Certain characteristics of the product/service related to these needs are determined. The solutions (alternatives) contributing to the materialization of these needs are identified .Then using the V.E technique, those solutions (alternatives) which have a higher value index for the customers are chosen .The integrated conceptual Model of QFD &V.E has been offered in figure 7.

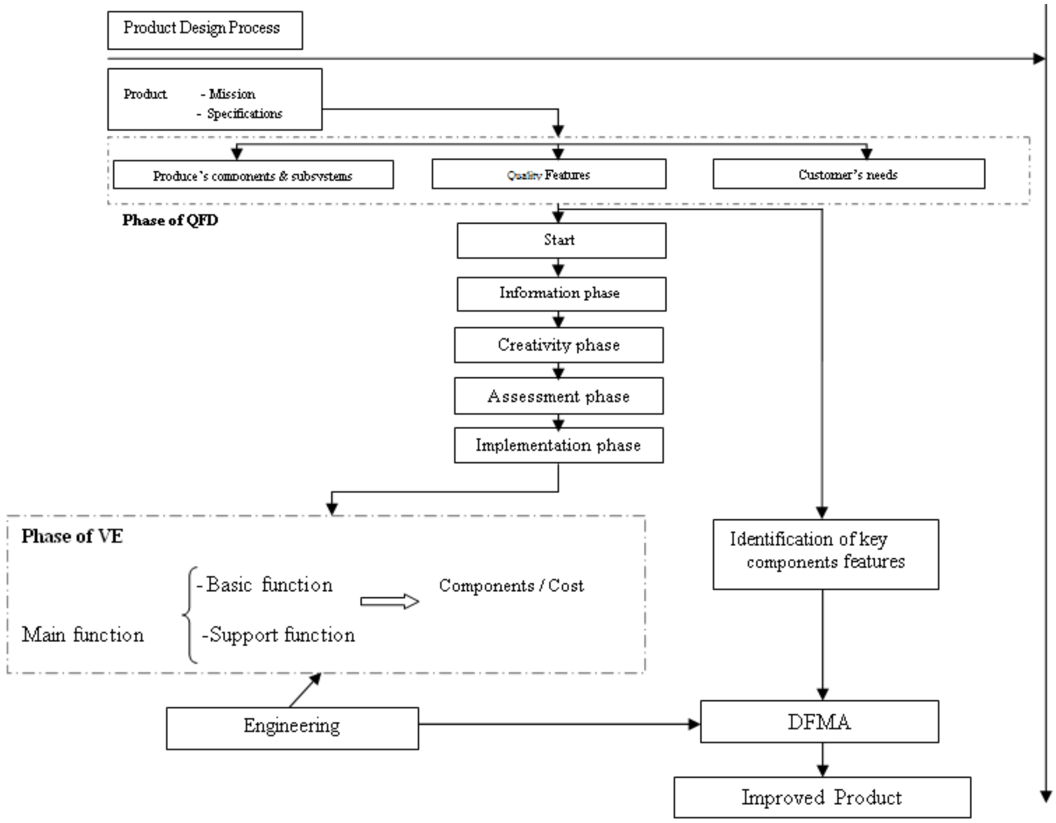

Fig. 7: The method of integrating V.E stages in the second Phase of QFD.

Figure 7 represents the role of V.E in the second phase of QFD and DFMA were applied to the different cases in this work. This sequence was established based on an analysis of the characteristics of each tool and experience in their application. The input data from the second phase of QFD is entered into the second phase of V.E. The data include the quality haracteristics of components and the subsystems of the product. Then the various alternatives in the sequence of data collection, innovation and assessment, are identified and evaluated, so that the best alternative(s) to be selected. The data collected as a result of V.E application are entered along the key product/service characteristics are inserted into the third phase of QFD (Improved Product). Since the first stage of V.E (source phase) has been implemented in the opening phase of QFD, it is omitted in the integration. Moreover because after the selection of best alternatives, We return to the third phase of QFD, so the fifth phase (implementation Phase) of V.E is also omitted. The Quality Function Deployment methodology is designed to drive a product development process from conception to manufacture. The House of Quality (HOQ) is a graphic tool that is closely associated with QFD and is used to display the outcome of the analysis at the design stage: the correlation between customer's desires and engineering specifications of the product; the customer's perception about the product with respect to competing products; and the areas of opportunity for design. In Figure 8 more details concerning the incorporation of both QFD & V.E has been shown. Based on these diagrams, first the customers and their requirements are identified. Then in a table their needs are reviewed and questions concerning who, how**,** why, where, and what are answered**.** By completing this table, the first Quality Matrix (house) is formed. In this matrix the relationship between the customers' needs and the factors affecting them (technical specifications of product/service) are analyzed. The collected data from the first matrix – i.e the technical features of product/service (the factors contributing to the materialization of customers' needs) and their values - are added to the second matrix (house of Quality). In this matrix the relationship between the solutions and the technical characteristics of product/service is studied. The aim of this review is the assessment of solutions impact on the technical characteristics of product/service. In addition, the correlation between alternatives is also reviewed . After this stage, We arrive at the V.E process. The resulting output from the second quality house of QFD identifies the list of solutions and their values. As was mentioned, the value of every solution is determined according to its impact on the technical features of product/service.

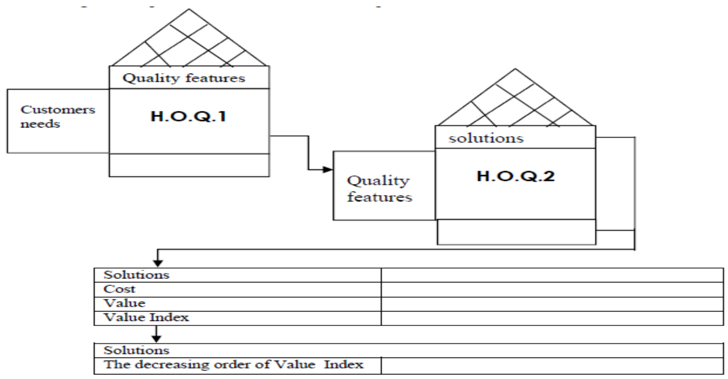

Fig. 8: Relation between H.O.Q and V.E.

this stage the cost of solutions is also estimated. By dividing the solutions value in its costs the value index is obtained. The order of solutions on this list represents their importance in fulfilling the customer's needs with minimum costs. Value Engineering is a process in which a product is analyzed in terms of the functions it performs. Costs are associated with these functions, and disparity of value, in terms of the cost to importance of the functions are identified and targeted for improvement. Closely associated with this methodology is the Function Analysis System Technique (FAST) diagram, which displays the functional decomposition of the product. In this diagram, functions are classified as basic (what the product must do) and support functions. Function importance vs. Function cost graphs can be used to display disparity of value. Boothroyd and Dewhurt's Design for Manufacture and Assembly methodology is a technique that focuses on product redesign for minimizing manufacturing and assembly costs. The technique provides a ranking system that allows comparison of competing designs in terms of their ease of assembly and the component's manufacturing costs.

8.Procedure for Case Studies:

The proposed methodology was applied in different degrees to five cases. In one of the case studies, only QFD and DFMA were applied. In three cases, only VE and DFMA were applied. All of the techniques were applied in the last case. Four of the cases involved subassemblies from industrial components, while the fifth one was a complete product.

Figure 9 summarizes the cases, goals and applied methodologies. Multidisciplinary teams made up of 3-5 members were formed to analyze and recommend modifications. Teams were made up of part-time graduate students who work in industry. Test cases were selected from a list of candidate products that were proposed by the students' companies. All necessary information, including cost data, engineering information, and market conditions were made available by the companies that owned the products. All of these companies are transnational, and their names have been omitted for obvious reasons. As part of their class work, students were trained in the use of tools that are particular to each technique: House of Quality (QFD), Function Analysis System Technique (FAST) diagram and Disparity Charts (VE); and the DFMA [13] technique and software.

9.Analysis of the Cases:

Case 1 originated from a proposal in the sales department. QFD was used to clarify and justify the analysis. The request was to facilitate cable insertion in the load control panel.

Management felt that such a feature would add a distinctive characteristic to the product and quickly approved the project. A modification that met the customer's request was prepared and optimized using DFMA. A few prototypes were built and tested in the field. The new design was not well accepted by the users. Customers complained about two problems: the increase in cost, and a perceived lack of robustness of the new feature. Case 2 was based on a project proposed by the engineering department and the purpose was to reduce costs. A QFD was not conducted. During the VE process the team had a very difficult time in trying to identify all of the functions of the subassembly, and serious discussions about the nature of the system were needed. The DFMA stage was very straightforward and potential modifications were quickly evaluated. In the end, the modifications proposed by the team passed the scrutiny from the designers of the corporate center. The team considered that the VE/DFMA process had allowed them to look at the proposal from all perspectives, and therefore all questions were addressed before the scrutiny from their peers. Furthermore, the team felt that it had full ownership and control of the proposal, and they were willing to push it through the revisions needed for implementation.

Cases 3 and 4 also originated in engineering, primarily with the purpose of reducing costs. The number of parts was reduced in each case, resulting in lower assembly and service costs. However, proposals were halted as manufacturing costs would increase due to the need to buy new tooling. Both products had been in the market for several years, and the costs of tooling are virtually zero at this stage of their life cycle. Case 5 originated in a request by the service department. Customers and field users responded to a survey from which a design HOQ was prepared. The most frequent request was for increased reliability of the cooling system. The VE focused on this system and resulted in several proposals for a redesign. The solution that was chosen was optimized with DFMA. The solution did not address issues such as mean time between failures, because cost increased significantly. Instead, the new design increased the ability to identify failure once it occurred, and it significantly increased erviceability.

Project Name	Description	Objectives	QFD	VE	DMFE	Result
Cable hold	System to feed cables to power distribution board.	Increase market share by adding distinguishing design characteristic,product acceptance	*		*	Design was implemented. Cost increased slightly. customer was not willing to pay more and complained it looked less robust because there were no bolts.
Control handle	Control handle of a small tractor.	Reduce cost		*	*	Design was simplified.costs were Reduced.
Oil pump	Oil pump for an automobile.	Reduce noise. Reduce assembly cost.		*	*	Number of parts was Reduced. Manufacturing cost increased because new tooling was required.
Floating jont	Floating jont switch.	Reduce cost.		*	*	Number of parts was Reduced with out effect on function. Manufacturing cost increased .
Ac Motor Controller	Ac Motor Controller.	Improve reliability	*	*	*	Heat removal system was redesignigned and optimized(DFMA). Manufacturing cost increased.but assemebly cost was reduced even mor.Reliability was not increased,butservice ability was greatly enhanced.Under study for implementation.

Fig. 9: Description of cases and summary of results.

10. Findings about the Integration Method:

The HOQ brings the perceptions of the client in terms that engineers can understand. The study showed that this was an element that was difficult to account for in other VE processes, as seen in Cases 2, 3 and 4. After the QFD stage in Cases 1 and 5, the task at hand seemed clear. The analysis could then focus on a specific component as opposed to the whole product. This is important given that the degree of difficulty grows as the number of elements under analysis increases.

Another outcome of the QFD process was that relevant information was readily available: requests were ranked in order of importance and measurable characteristics of product performance were correlated to the customer's desires. This information allowed the initial step of the VE process, gathering of information, to be greatly simplified. In cases 2 through 4 this first step of VE proved to be an expensive task, mainly due to the lack of focus. In these cases, information was sought and displayed just in case it might be needed, and there was no particular procedure or format for organizing or displaying this information. The resulting VE processes tended to be somewhat erratic, tedious and confrontational. Design teams had no preconceived idea about what direction the roposals could take, and significant effort was required before teams could accomplish any degree of consensus.

The study also showed that the results of the QFD process were not necessarily balanced, because requests focused on improving performance of specific features which may be relevant to specific populations. Customers appear to make assumptions about the product that are not immediately evident from their requests. Tradeoffs beyond the scope of the requests displayed as well as cost issues were not properly displayed by this analysis. As evidenced by Case 1, customer's requests shown by the QFD may have not been set in the proper context. In particular, cost and appearance of robustness were factors that were not properly accounted for. Solutions were designed and implemented without any further filtering and as a result, failed to meet the costumer's expectations. It is clear that customers expected the product to perform their primary function. No credit is given if the product performs them, but the product losses all value when it doesn't. Customers perceptions displayed in the HOQ focused in the manner in which complementing functions were performed. Case 5 showed that the VE methodology can be used as a filter for the results of QFD, because it forces all requests to be weighed against engineering and cost specifications, thus reducing the chances of failure.

VE is an engineering driven process, as shown in Cases 2, 3 and 4. During the construction of the FAST diagrams, basic functions were easily identified by each team. On the other hand, support functions were not immediately obvious to the engineering staff, and as a consequence, the process of establishing the relative importance of the functions and isolating areas of opportunity was very demanding. In particular, the fact that support functions account for a high percentage of the cost appeared to cause concern among engineers and tended to bias their analysis towards reducing their role. As seen in Case 5, QFD helped provide data that could easily be characterized as support functions, with a ranking of importance that is clear to the engineer, thus reducing the VE effort. One of the strengths of the VE process is that it triggers modifications that are not constrained by the product's original architecture or composition, which is a more natural course of action in the QFD. Many of the modifications proposed by the VE process need significant study before implementation. This fact was particularly evident in Cases 2 through 4. The multiplicity of proposals requires that they be screened or validated. The DFMA process helped in performing this validation.

The DFMA methodology is straightforward, and the modifications that it recommends are very specific. In principle, the methodology is not constrained by the particular characteristics of the product, other than the obvious fact that the product needs to be an assembly. However, this methodology lacks of a systematic approach for validation of the recommendations, and it does not account specifically for the impact that the proposed modifications have on product performance. As seen in Case 1, indiscriminate application of DFMA resulted in a product that was optimized for manufacture and assembly, but which was oblivious to the fact that the very recommendations that the methodology made affected an important characteristics of the element (perceived robustness). Without the balance from the VE, this characteristic was missed. Our study showed that by combining DFMA with the results of the VE (Cases 2 through 5), the merits of the modifications proposed by the DFMA were easily evaluated. In those cases, DFMA functioned as an optimization tool, which seemed a better role for its capabilities. Furthermore, the modifications proposed by the DFMA were easily evaluated in terms of the information that was generated during the QFD/VE processes, thus providing a natural closure to the design exercise.

11.Conclusions:

Value Engineering and QFD have different orientations. QFD is after more profit through more sales which is obtained by increasing the customers' satisfaction, whereas V.E focuses on profit increase through cost reductions without lowering product quality. The main objective of integrating QFD and V.E is the selection of better alternatives in product/service planning or product/service process which not only produces a higher value for the customer, but also does not increase the cost of product/service.

This worked studied the integration of QFD, VE and DFMA in a design process. The work shows that:

- QFD is capable of identifying functions that need improvement in a given product. Relevant data about the product/function or component is immediately available for further processing in the VE stage.
- Information from the QFD makes the VE process more focused and manageable. Consensus regarding the identification of potential projects is reached more easily. VE allows for more solutions to be synthesized than the QFD alone. They are also more balanced.
- DFMA can be used to optimize the design proposals and the information from the QFD/VE processes can be used to evaluate the impact that the modifications suggested by the DFMA analysis may have on the product's performance. The study shows that the methodology is better suited to products that are still in early stages of their life cycle. The life cycle value of the product was implicit in the procedure.

A benefit of the integrated methodology is the fact that after each step, the information is summarized, classified and displayed clearly. This allows the teams to have evidence of the project's evolution. Communication is greatly enhanced and information flow is streamlined. The end of each stage allows for natural breaks in the process with few delays to bring team members up to date once the project is resumed.

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