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*Review*

# Manufacturing Quality Function Deployment: Literature Review and Future Trends

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**Abstract.** A comprehensive review of the Quality Function Deployment (QFD) literature is made using extensive survey as a methodology. The most important results of the study are: (i) QFD modelling and applications are one-sided; prioritisation of technical attributes only maximise customer satisfaction without considering cost incurred (ii) we are still missing considerable knowledge about neural networks for predicting improvement measures in customer satisfaction (iii) further exploration of the subsequent phases (process planning and production planning) of QFD is needed (iv) more decision support systems are needed to automate QFD (v) feedbacks from customers are not accounted for in current studies.

**Keywords:** QFD, literature review, house of quality, voice of the customer, customer satisfaction, improvement.

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## 1. Introduction

Quality function deployment (QFD) seems to be an important and interesting issue in manufacturing decision making when viewed from both the theoretical and managerial perspectives. Every year, manufacturing budgets and expenses on quality are heavy in terms of quality management program proposals, implementations, project planning, improvements and sustenance programmes. Huge amounts of money allocated and spent on quality-related activities of personnel training, manufactured product quality improvement, provision for claims and warranties due to quality problems and more are sub-optimally utilized due to improper methodology in monitoring costs. Unfortunately, QFD, which appears to be central to quality improvement programmes seems to be not clearly understood and sometimes improperly applied along certain directions. From a global viewpoint of the QFD literature, QFD knowledge base areas could be classified into three from the standpoint of methodology: obe area deals with the enhancement of QFD, which combines QFD with other decision making tools such as Taguchi method [122], cluster analysis and Poisson regression [125] and evidential reasoning [11]. The second QFD mythological area deals with other information, which may include cost/cash flow or customer feedback. The third area of QFD methodology concerns industries such as food or service businesses that have features and attributes different from manufacturing. For several years that QFD has been established, theoreticians and practitioners continue to make mistakes of omissions of important technical attributes of costs and feedbacks from customers in QFD model development and applications [1, 2]. The pioneering work of Bode and Fung [1] on cost incorporation to QFD frameworks has not been taken seriously for several years until recently when Ramanathan and Yunfeng [2] relaunched this idea.

Within this space of time, several models have been developed, enormous investments made on quality programmes and several practical realisation of quality programmes have been made without cost. In addition, important artificial neural network (ANN) knowledge in its predictive ability of future technical values are missed while improved prioritisation techniques are not explored. These serious problems need to be solved with an urgent attention. Consider solving product quality problem through the popular channel of listening to the "voice of customer (VOC)" and the "customer satisfaction (CS)" concept using QFD methodologies that totally exclude costs. Does manufacturing success not hinge on cost optimization? What can we say about QFD models that use prioritization schemes through the VOC and CS concepts without due recognition for customer feedbacks in product improvement? Although we are in an age of QFD maturity, but we do not have due regard for QFD model robustness in terms of including all the necessary technical attributes in QFD. The results of most efforts are the generations of sub-optimal models, which least explores all the potentials of QFD to the best. There is therefore the need for a radical re-orientation of ideas and the ways we work develop and implement QFD models. Theoreticians and practitioners should provide solutions that are more useful to the quality scientific community. This is the great problem that is addressed in the current work.

Having put forth the motivation of this study by clearly identifying the research gap in the literature and the phenomenon that is observed in real-life situation, the current work positions itself in the QFD literature by arguing that a systematic literature review using extensive survey method is appropriate to investigate the research questions stated later in this work. Clearly, one sure way of extending knowledge is through documentation of new ideas. These new ideas are obtained through literature sources of journals, conferences, books and other media of information exchange by scholars and practitioners and are applied. Since there has been an organized way of storing and sharing information through reporting worldwide, retrieving QFD information using an extensive literature search may be productive, particularly in this age of information explosion through information technology media. This is therefore suggested as a strong avenue for exploring the QFD literature, identifying important gaps and proffering solutions. This study purports to review the QFD literature and point out the important gaps within the literature. Through an extensive survey methodology that classifies studies to into general, analytical approaches and models, QFD in manufacturing industries, proper analysis of the existing literature is made. Further efforts is made to more specifically classify analytical and modeling literature into fuzzy and goal programming-based QFD systems.

The current study captured four extensive literature reviews on the QFD subject: Chan and Wu [3], Chan and Wu [4], Lager [5] and Carnevalli and Mignel [6]. While all these reviews provide adequate information on the QFD progress, all but one was carried out several months ago. Since their publications, a large number of studies have further extended the frontier of knowledge, which must be accounted for. Apart, these new studies not reported in the reviews have opened up several interesting and insightful research areas that would improve the quality of decision making in customer satisfaction drive and QFD in general. Also, the most recent literature review (i.e. [6]) has not included the references after the publication and has not summarized major research areas such as presented in the current work. Thus, the present work is an effort geared towards bridging this gap in the QFD literature. The following questions are answered: (i) how did the QFD field evolved? (ii) how do we classify the totality of studies till date in the QFD literature? (iii) what can we learn from documented works and their applicability to areas not yet explored? (iv) what does the future holds for the QFD field? While detailed research has been conducted on several aspects of QFD, several important issues seem untouched. It is important to know how the dynamic nature of QFD through enrichment with other concepts has been affected by cost; give the prioritisation of technical attributes in QFD philosophy, is the customer satisfaction attribute always being maximised by considering the cost aspects? This has not been previously reported in the literature. Furthermore, having known that neural networks have been successfully validated as a predictive tool in several disciplines and areas such as marketing, industrial engineering and control, are the principles and knowledge of neural networks being explored to the advantage of QFD area? This investigation seems undocumented previously in the literature. Another issue is this: having concern to know how much work has been done on other phases of QFD, vis-à-vis process planning and product planning processes, there is need to review the literature to understand this fact. Furthermore, since QFD is customer focused, there seems to be little information on how the feedback system from customer complaints could be integrated to the existing frameworks on QFD; this is previously undocumented and requires investigations. In addressing these issues, we present the historical development of QFD in the current section. Section two discusses the QFD literature by classifying them into general, analytical approaches, and QFD in manufacturing systems. A strong critique of the literature is offered to reveal the gaps that the study bridges. Section three, results and discussion then discusses the main gaps in the literature with emphasis on important areas that scholars could invest their research resources for productive output. Section four then presents concluding remarks and managerial implications of the study.

## 2. The QFD Literature

### 2.1. QFD Historical Development

The present millennium has experienced publications of several dozens of papers on Quality Function Deployment (QFD) [5-9] against less than a dozen in the late 1960s when the QFD drive newly started. Thus, the field of QFD is portrayed as one that has grown both in depth and coverage, presenting a wide spectrum of problems. As such, there is a clear understanding that QFD is stronger today when compared with four decades ago [10-12]. Theoretical knowledge about QFD and modelling has also increased significantly during the last two decades [2, 13, 14]. Unfortunately, the diverse papers on QFD as an advanced quality tool for improving the performance of manufacturing systems seems to be scattered in several publishing outlets [15-19]. Also, efforts made in the present decade to understand how such knowledge could be integrated so as to benefit investigators seeking to extend the QFD knowledge frontier seem to have produced studies published years ago, which exclude recent literature on the subject. The objective of this work is to bridge this important gap in the QFD literature.

The honour of great pioneering work on QFD research could be credited to Akao [20] who initiated studies that formed the bedrock upon which further research evolved [21, 22]. The development of the QFD concept could be traced to Japan in the late 1960s [3] when Japanese industries broke from their post-World War II mode of product development through imitation and copying. The smart Japanese manufacturers bought equipment and technologies, dis-assembled and tested them under varying conditions to ascertain their strengths and weaknesses, manufactured imitations with low cost and high durability for extensive usage, but had little patronage from customers since the output was crude and unattractive. The Japanese government then controlled importation and encouraged Small and Medium Enterprise (SMEs) which prompted the current high status of technology in Japan [3]. Since the initial development of QFD in Japan, it has rapidly spread to the US in the 1980s and later to diverse industries in many nations [3]. The development of the QFD field was also enhanced by the introduction of computers which made computations very easy and prototyping easily attainable. The impact of computers on QFD is complex and many-sided by considering the multiple manipulations of data which electronic data processing makes possible and performable. Easy QFD data analysis was aided by computers for collecting, recording, retrieving, analysing simple and complex QFD problems, as well as distributing tremendous masses of QFD information. Countless years of tedious work by QFD researchers and practitioners was saved and the necessity to monitor and control tedious and repetitive processes eliminated. Despite the importance of computers to QFD, its potential is not fully explored to achieve its full impact.

One of its first QFD applications was at the Kobe Shipyards, by Mitsubishi Heavy Industries in 1972 [23]. It was mainly aimed at ensuring that all those actions needed to ensure high quality for a product were done, and that scarce resources were focused on as the most important areas. Unfortunately, the application of QFD at Kobe Shipyards and similar applications at that time were not documented for public interest. As such, the use of QFD at this time was limited to a few privileged organisations that had quality management experts with creative abilities. Consequently, the dissemination of QFD information to the public affected its spread worldwide. With the discovery of scientific *Japanese Management* in the West in the 1980s, QFD was discovered and adopted enthusiastically around the world [4]. The catalyst of QFD growth at this stage was that the philosophy of QFD blended with the culture of the Japanese. Hauser and Clausing's article [24], and King's book [25], among many others, catalysed and fuelled its widespread adoption worldwide. The formation of the QFD Institute in USA in 1993 further extended QFD knowledge to many areas. The growth was further enhanced by the first International QFD Symposium in 1995, organized by the Japanese Union of Scientists and Engineers (JUSE). The International Council for QFD, formed in 1996 in the US instituted the Akao Prize for outstanding contributions to the development of QFD and the German QFD Institute, founded in 1996, also led to the spread of QFD to other parts of the world [26]. QFD is one of the advanced quality techniques used only by organizations that are far advanced in the quest for world-class quality or international competitiveness [27]. For such organizations, operational quality systems must be in place; they should be utilising tools and techniques such as Taguchi's Design of Experiments, Statistical Process Control and Concurrent Engineering (CE). They may have been using analytic methods such as Value Analysis, FMEA, Failure Tree Analysis, Process Ability Analysis, Pugh's concept selection method, and so forth. Under these circumstances, QFD could certainly be utilized to support these existing tools and methods. High level of performance and superiority is then achieved through clear strategic intent, commitment, visionary leadership, a strong focus on the development of competencies within the organization, a total change in organizational culture, significant investments in information technology, and adequate resources.

The field of QFD covers a wide variety of topics, which include models, approaches, methodologies and application in manufacturing systems [28-38]. What follows is a review of a number of articles in different areas.

### 2.2. General Studies on QFD

A large body of highly proliferating research in QFD application exists. Prominent players in the area of QFD applications are Carpinetti and Peixoto [39], Curry [40], Tan [41] and Chen *et al.* [42], among others. Carpinetti and Peixoto [39] bring together the models developed by Clausing (enhanced QFD), and the identification of relationship among different parameters of the product development process. Curry [40] focused on a strategic approach to best value involving measurement of customer perceived quality, operational planning using ranked priorities and a framework for continuous improvement. Sivaloganathan *et al.* [43] explained design function deployment using a chair as an example. The study by Walden [44] employed a House of Quality (HOQ) to facilitate a detailed, quantitative analysis of how well the various strategic thrusts and initiatives at A&T address the individual items within the criteria. Lu and Kuei [45] explored the application of QFD concept in strategic marketing planning. The QFD approach maximizes benefits for both customer's needs, and then translating these needs into corporate goals and marketing objectives. Gustafsson *et al.*, [46] illustrated a possible work flow for conjoint analysis and provided an example of the kind of information that can be collected by using the technique. Each step in the work flow is illustrated using a survey regarding the development of a TQM course curriculum.

Gustafsson [47] utilised QFD method in the product development process to narrow the gap between an engineering based tools (i.e. QFD) and marketing based tools (i.e. customer satisfaction modelling) and conjoint analysis. Kathawala and Motwani [48] offered an integrative perspective of QFD, including its benefits and shortcomings and described companies that have used QFD. Tan and Shen [49] presented an integrative approach by incorporating Kano's model into the planning matrix of QFD to help accurately and deeply understand the nature of the VOC. Harding *et al.* [50] demonstrated how a CE environment and QFD techniques can be brought together to provide an extended design team with valuable, shared information throughout the design process. Shen *et al.* [51] proposed an integrated process model for innovative product development by incorporating Kano's model and the QFD technique. Martins and Aspinwall [52] described the design, development, implementation and findings of a survey conducted in the U.K. which showed that QFD-users regarded Behavioural Management as the key to successfully applying the techniques and revealed a considerable lack of knowledge about the methodology expressed by many respondents from top companies and universities. Finch and Luebbe [53] examined the potential of using conversational information from the Internet to enhance product quality. They examined and sorted archived messages to evaluate potential for using them to supplement the QFD and quality improvement (QI) story processes.

Miguel [54] reported a case of some companies in Brazil that experienced difficulties, driven data sources and perceived benefits. The study showed that companies that applied QFD are restricted to a limited population. Vonderembse and Raphunathan [55] presented a survey on the application of QFD to product development. Leaders from these project teams claimed that product designs and customer satisfaction improved significantly with QFD while product costs and time-to-market showed only modest improvements. It concluded that QFD's implementation issues, specifically the organizational dimensions, have a significant impact on product design outcomes and resource consumption. In another article, Balthazar and Gargeya [56] explored the robustness of QFD for translating the available knowledge within a product design group into appropriate design choices. The work discussed the role of group support systems (GSS) to improve the qualitative discussion of the *whats* and the *hows* in the QFD process. Smith [57] compared the requirements of the International Quality Assurance Management System Standard (ISO 9000) with the philosophies of five of the leading gurus: Crosby, Demming, Feigenbaum Ishikawa and Juran using QFD matrix. The 20 requirements of ISO 9000 are identified as the *What* on the vertical axis and the main points of the five gurus as the horizontal *hows*. The roof of the HOQ was used to analyse the correlation between the philosophies of the gurus. Consideration is then given as to how the model presented can be customized to allow companies to use this approach to help develop a total quality strategy. From the review, the QFD literature has been made richer with the application of design for six sigma, Kansei engineering, TRIZ, etc to QFD. Of particular interest is the integrated QFD and TRIZ framework by Yamashina *et al.* [58]. The innovative algorithm by Wang *et al.* [59] is also an addition to the expansion of the QFD- TRIZ linkage. On the QFD-six sigma integration, the hand book by Ficalora and Cohen [60] and the documentation by Huber and Mazur [61] are instructive. None of the studies described above considered cost elements in their analysis. However, cost is of paramount importance in achieving the desired levels of customer satisfaction. Also, there is no record to show that any of these studies discussed above considered feedback information from customers. Feedback from customer is needed to improve on the current level of customer satisfaction. A third element that has been omitted in the articles reviewed above relates to the non-inclusion of neural networks in the frameworks developed. This prevented possible knowledge of customers' satisfaction level through predictive neural networks for control purpose.

### 2.3. QFD Analytical Approaches and Models

The first approach considered here relates to the study by Adiano and Roth [62] that presented a dynamic approach to QFD in which customer wants and needs are translated into relevant product and process parameters. Using feedback loops, this new approach incorporates updated customer satisfaction data and dynamically links evolving requirements directly back into manufacturing and related processes in an IBM assembly plant. Georgantzas and Hessel [63] presented QFD as a powerful approach to designs for quality. An illustrative example enhances QFD's capability of capturing and representing the effects of multiple interdependencies among specifications and design variables, while the computation that matrix multiplication requires is both simple and efficient. The above approaches which considered Hoshin Kanri concept, the idea of feedback loops and the methodology that links indirect relationship among quality ends and means did not consider cost elements in building up the models. There is also a serious omission of exploring the considerable knowledge about neural networks, which could have been used for improving customer satisfaction.

Furthermore, Mill [64] presented a number of analysis tools that should be used in conjunction with QFD. These tools provide enhancements that help to understand the nature of the product and demonstrate how to use QFD more effectively. Lu and Kuei [45] developed a strategic planning framework for long-range marketing policy using the relationship between marketing orientation and TQM, Kotler's model and two group consensus management techniques (QFD and AHP). Samuel and Hines [65] described the approach one company has taken to develop such a logical, time-phased supply chain improvement plan. This approach involves input from a range of representatives from within the organisation, thereby avoiding the often misguided pursuit of "hobby horses". The approach described has been derived from matrix-based methods of Japanese origins, in particular QFD. The strength of these matrix-based techniques lies in their ability to integrate the many qualitative and quantitative-based variables that impact the supply chain. A closely related study was presented by Krogstie [66] also proposed an approach to requirement specification based on QFD. The author submitted that the quality of requirements specifications can be improved by using the same line of research proposed in a previous study. However, there was no reference to cost issues which may significantly affect customer satisfaction indices in the analytical tools presented by Mill, market orientation-TQM-strategic planning framework by Lu, time-phased supply chain model by Samuel and Hines, and the requirement specification-based model of Krogstie. Also, considerable knowledge which could have helped in improving customer satisfaction indices through the application of neural networks was omitted in the studies. In addition, the studies omitted feedback from customer, which is central to a QI drive. It is worth noting also that these studies did not consider alternative prioritization scheme, which may offer better promise than AHP.

The paper by Prasad [67] described an integrated template for product improvement by tactically combining real-time market research data with QFD, value engineering, and a value graph. The focus of integrating market research data with QFD previously had been to develop analysis results - customer importance ratings (CIRs) and technical importance ratings (TIRs). The focus of integrating the QFD analysis (TIRs and CIRs vectors) with value engineering and value graphs, is to prioritize these ratings, to synthesize market research data, and thereby predict a better set of improvement characteristics. This process template gives the product development teams (PDTs) a synthesis tool to predict what product offerings customers would be interested in - which the company can build and market to make a fair profit. Wang *et al.* [68] recommended that AHP could be applied to the customer voice and also directly to the technical responses. Since the decision-maker can select either the prioritization matrix method or the AHP method for HOQ applications, an understanding of their advantages and disadvantages becomes important. They compared these two methods in terms of practical applications in industry leading to the general conclusion that if time, cost and difficulty are the major concerns in product improvement, the prioritization matrix method is preferred; where accuracy is the major requirement, the AHP method would be a better choice.

Prasad [69] proposed an alternate framework to QFD called concurrent function deployment (CFD), suitable for a workgroup-based engineering design process. The methodology exploits the independence of units that manifest itself in a company strategic business unit, TQM, and enterprise knowledge management concepts. Six concurrent value-sets, namely functionality (quality), performance (X-ability), tools and technology (innovation), cost, responsiveness, and infrastructure (delivery) are considered in CFD, running in parallel rather than serially. In the present setting, Don Clausing's QFD process emerges as a special case of this CFD. Chien and Su's article [70] modified the traditional QFD methodology and proposed using "strategy value" as an effective decision basis for CS activities. The use of "strategy value" can strongly supplement the lack of "importance" and "performance" in the traditional analysis. A case study involving an enterprise's strategy decisions is used to analyze the proposed concepts and methodology. The results from this study facilitated enterprises achieving more effective CS strategy decisions and generally increased the probability for CS success rates among enterprises. Although, the above articles considered the integration of QFD to real-time information on market research (Prasad), its merging to AHP methodology (Wang *et al.*), joint application to CE (Prasad), strategy value concept (Chien and Su), none of the studies (but Prasad's) considered cost in developing the approaches. This missing link may significantly affect customer satisfaction. In addition, no indication is given on the possible ways of improving results through the use of neural networks for predicting improvement measures. Also, none of the studies utilized customer feedback.

Franceschini and Rossetto [71] presented two tools to simplify and improve the use of QFD: the first deals with the generation of the correlation matrix of the engineering design characteristics, and the second searches for the minimum engineering design characteristics set. An application of the methods to a real example was also provided. Yang *et al.* [72] proposed a customer-oriented optimization method, called the QFD-based optimization method using the Normal-Boundary Intersection (NBI) method as an effort to reflect customer's preferences in making a trade-off between multiple objectives. Jacobs and Ip [73] presented a method of combining gamer segmentation and QFD methodology with the aim of matching games to gamer requirements and desires more reliably than at present. Ginn *et al.* [74] proposed a methodology for interactions between the two quality tools of QFD and failure mode effects analysis (FMEA), and placed an emphasis on their common features. An example of the method described was be highlighted within Ford Motor Company that demonstrated the quality and resource benefits achievable when these two tools are used in conjunction with one another. The application of neurofuzzy to QFD was experienced in the study due to Abraham *et al.* [75]. The paper by Franceschini and Rossetto [76] prioritized technical design characteristics of a product by developing an interactive algorithm to better support the engineering design process by means of QFD using a numerical application. The algorithm tries to soften customer approach to QFD in those situations in which customers are not able to give a "significant" evaluation of the relative importance of their requirements. Neither the tools presented above nor the NBI method reflects cost, customer feedbacks and neural networks in the framework development. Also, none of the gamer methodology, QFD-FMEA model, neurofuzzy model or the interactive algorithm discussed cost elements, customer feedbacks, and the predictive power of neural networks in the QFD model formulations.

### 2.3.1 Fuzzy QFD

In view of the inherent complexity and fuzziness of customers' requirements in general, analysis of the techniques for customer satisfaction makes it amenable to a soft-intelligence treatment [77]. Fuzzy-logic modelling could be employed in transforming the human expertise into IF-THEN rules. A number of studies in the domain of fuzzy methodology combined with QFD are as follows. Fung [77] proposed a non-linear fuzzy model to offer a more practical and effective means of incorporating the resource factors in QFD planning. Solutions to the non-linear fuzzy model can be obtained using a parametric optimization method or a hybrid genetic algorithm. A case study is also given to illustrate how the proposed fuzzy model and the optimization routine can be applied to help decision-makers in a company deploy their design resources towards gaining better overall customer satisfaction. An important use is made fuzzy sets as a useful tool for dealing with ambiguity in a system as reflected in the work of Lin [78] who visualized customers needs and desires in natural language that can be expressed as linguistic variables. The author argued that linguistic variables contain ambiguity and multiplicity of meanings. Thus the lack of better approach for interpreting the semantics of these requirements and relationships of requirements makes it difficult to analyse and prioritise the requirements.

Bai and Kwong [79] presented a fuzzy optimization model for the determination of target values for engineering requirements in QFD. An inexact genetic algorithm approach was introduced to solve the model that takes the mutation along the weighted gradient direction as a genetic operator. Through an interactive approach, a design team can determine a combination of preferred solution sets from which a set of preferred target values of engineering requirements based on a specific design scenario could be obtained. An example of car door design was used to illustrate the approach. Yet in another study, Verma *et al.* [80] modified and extended the QFD conceptual phase initially proposed by Pugh by applying concepts from fuzzy set theory. The extended approach presented by these authors provides a rigorous mechanism from dealing with imprecise requirements and priorities. It developed a set of correlation as prerequisites to concept selection. The paper presented an expert system based extension of the fuzzy QFD methodology. An expert system was embedded in fuzzy QFD tool to facilitate strategic product planning, early design decision making, and parameter target setting. In another article, Bouchereau and Rowlands [81] outlined how techniques such as fuzzy logic, artificial neural networks (ANNs), and the Taguchi method can be combined with QFD to resolve some of its drawbacks, and proposed a synergy between n QFD and the three methods and techniques reviewed. Bottani and Rizzi [82] also discussed a strategic management approach of logistics service using a fuzzy QFD approach. However, none of the non-linear fuzzy model (Fung), Fuzzy linguistic variable approach (Lin), fuzzy optimization model (Bia and Kwong), extended QFD fuzzy set theory (Verma), combined QFD-ANN-Taguchi method (Bauchereau and Rolands) or fuzzy strategic management approach (Bottani and Rizzi) addressed the issue of incorporating cost concept in the models. Also, the studies omit feedback from customers, which is a principal element in a customer satisfaction drive. In addition, no information is given concerning how to predict customer satisfaction index using the knowledge of neural networks.

Lin [78] studied QFD in new product development in which the foundation of customer's needs and desires are expressed in natural language using fuzzy sets for dealing with ambiguity in a system. Wang [83] considered the QFD planning as a multi-criteria decision problem and proposes a new fuzzy outranking approach to prioritize design requirements recognized in QFD using an example of a car design was used to illustrate the approach developed. Vanegas and Labib [84] proposed a novel method for determining optimum targets in QFD. Fuzzy numbers are used to represent the imprecise nature of the judgements, and to define more appropriately the relationships between ECs and Customer Attributes (CAs). Constraints such as cost, technical difficulty and market position are considered. An example of a car door is presented to show the application of the method. Fung *et al.* [85] proposed an intelligent approach which extends the applications of QFD beyond its conventional boundary and adopted the fuzzy inference technique to accommodate the possible imprecision and vagueness during VOC interpretation. The conclusions drawn from the fuzzy inference process are aggregated and defuzzified to yield the crisp design targets which can be used to guide the downstream manufacturing planning and control activities. Bovea and Wang [86] introduced a novel approach for identifying environmental improvement options by taking into account customer preferences. The Life Cycle Assessment (LCA) methodology is applied to evaluate the environmental profile of a product, using eco-Indicator99 as the impact assessment method. A fuzzy approach based on the HOQ in the QFD methodology provides a more quantitative method for evaluating the imprecision of the customer preferences. Fung *et al.* [77] proposed a novel approach for analysing CAs and projecting them into the relevant design, engineering and product attributes in order to facilitate decision-making and to guide downstream manufacturing planning and control activities. The proposed hybrid system incorporates the principles of QFD, AHP and fuzzy set theory to tackle the complex and often imprecise problem domain encountered in customer requirement management. The documentation above, which consider combined fuzzy and entropy method (Chan), fuzzy sets (Lin), fuzzy multi-criteria decision making (Wang), fuzzy optimal target setting (Vanegas and Labib), fuzzy interference technique [85], combined QFD and lifecycle analysis (Bovea and Wang) and fuzzy AHP [87] omit some important elements. There appears to be omission of cost elements also, which is critical in driving customer satisfaction modelling. Again, the issue of incorporating feedback from customers is completely absent in these models. Also, considerable knowledge could have been gained from the powerful tool of neural network but its integration in the various QFD models developed is missing.

#### 2.3.2 Goal Programming based QFD

Han *et al.* [88] proposed a new comprehensive hierarchical framework for QFD planning process and a zero-one goal programming model for the selection of design requirements to enhance the effectiveness and efficiency of QFD as a means to transfer the VOC into design and production. The hierarchical framework contributes to the strategic guidance and provides clear direction for QFD teams during the construction of the HOQ. An illustrative example is also provided to demonstrate the practical usage of the design selection model. Dagersten *et al.*, [89] proposed an intuitive method for providing decision support of production control activities in which qualitative management information is represented by way of QFD matrices, while quantitative information is collected in the form of a simulation model of the plant. The quantitative-to-qualitative transform is provided by way of goal programming and fuzzy decision rules-where the latter naturally complements the symbolic method of representing information. In addition, Chen and Weng [90] proposed fuzzy goal programming models for the determination of design requirements (DRs) fulfillment levels incorporating business competition by specifying the minimum fulfillment levels of DRs and the pre-emptive priorities between goals. The growing aspect of QFD that applies knowledge of goal programming has omitted the issues of cost, feedback from customers and neural networks in their model development.

### 2.4. QFD in Manufacturing Industries

There are several studies in the literature, which fall under application of QFD in manufacturing industries. These are discussed here. The article by Zairi and Youssef [91] examined several case studies of companies based in the UK in their attempt to introduce QFD for new product development and reported benefits and how QFD starts to challenge existing cultures of developing new products. Vattharakul *et al.* [18] investigated on leather products. Lee *et al.* [92] proposed a set of criteria based on Sun Tzu's philosophy for evaluation of business management strategies against the world class business excellence models. The TQM models of the European Quality Award and the Malcolm Baldrige National Quality Award were used to compare with Sun Tzu's business management strategy model developed under the QFD methodology. The results of the QFD methodology can be used as performance indicators showing organisations' improvement priorities for self-assessment. Barad and Gien [93] developed a supporting methodology for determining the improvement priorities of Small Manufacturing Enterprises (SMEs) QFD methodology that applies a contingency oriented approach to improvement priorities. The essence of the QFD method is to extract the customer needs or desires and then to translate them into technical product quality characteristics. Cluster analysis identified several generic improvement models of the sampled enterprises.

In another study, Politis [94] conducted a survey of 104 middle level managers from wide variety of United Arab Emirate's industries who are engaged in quality management programs to investigate the relationship between different leadership style dimensions and a number of QFD methodologies. The results indicated that the leadership styles that involve human interaction and encourage participative decision making are supportive of open and collaborative QFD methodologies. Yet in another work, Crowe [95] described an effort to extend the use of QFD to manufacturing strategy development. The author described how the traditional QFD concepts and methods could be used in the formulation of manufacturing strategy to ensure alignment with business strategy. They studied powdered metals manufacturers to show how the QFD methodology can be adapted for use in manufacturing strategy formulation. Furthermore, Scheurell [96] focused on steps beyond the HOQ's the process planning and the production planning matrixes, and emphasizes the practical application of QFD to new product development. The author described the formulation of the QFD team at Kimberley Clarke Corporation, the strategies used to get around the barriers that existed, the results of the effort of the programme, and the transformation in the use of QFD from a *tool* to *the culture* by which business gets done on this programme. The above reviewed papers on manufacturing have omitted cost elements, customer feedback and neural networks in model development.

In a study by Fung *et al.* [87], the authors proposed a novel approach for analyzing customers attributes and projecting them into the relevant design, engineering and product attributes in order to facilitate decision-making and to guide downstream manufacturing planning and control activities. The proposed hybrid system incorporates the principles of QFD, AHP and fuzzy set theory to tackle the complex and often imprecise problem domain encountered in customer requirement management. It offers an analytical and intelligent tool for decoding prioritizing and inferring the qualitative, sometimes vague and imprecise voice of customer. As a result, the appropriate product attributes can be mapped out and their relevant design targets can be determined quantitatively and consistently. Franceschini and Rupil [97] worked on the use of rating scales in QFD, focusing the critical aspects and consequences resulting from an incorrect use of rating scales. The paper illustrated how the priority rank of design characteristics can change depending on the type of scale used. Practical effects of these issues were finally shown on a real case concerning the design of a climatic control system for commercial vehicles.

Another significant application of QFD is in ergonomics. Guedez *et al.* [98], who improved the ergonomics design of containers, which is used in flexible manufacturing systems (FMS), championed this. QFD was used to analyse the customer desires and to generate high quality and competitive ergonomic products and processes. Prasad [99] introduced a set of JIT house of matrices and a matrix-based procedure to analyse the results of strategic planning and implementation. The rating system is derived from the same principles on which QFD was based. This enables the planning team to sustain a series of successful planning activities throughout the strategic implementation process and the manufacturing and strategic teams from unknowingly making any possible implementation mistakes. Olhager and West [100] used the methodology from QFD for linking manufacturing flexibility to market requirements. This approach creates a framework for modelling the deployment of the need for flexibility from the customers' viewpoints into manufacturing flexibility at various hierarchical levels. The paper presented an application of the methodology in a firm where a manufacturing system was being redesigned for the manufacture of a new and wider range of products than previously, based on a new product platform. The studies on hybrid QFD, rating scale QFD, ergonomic-based QFD, hybrid JIT-QFD and the manufacturing flexibility-based QFD omitted cost elements. They also omitted feedback from customers as well as did not include neural networks in their model building.

Shen *et al.* [101] studied the procedures and methods for successful benchmarking in QFD for QI and proposed the use of hierarchical benchmarks for strategic competitor selection and decision making in small to medium-sized enterprises or companies in developing countries. Fogliatto *et al.* [102] proposed a customization index to estimate the viability of implementing mass customization systems. The index establishes a ranking of customizability for different characteristics of a product, which is based on three variables: customer requirements, supplier delivery flexibility and production flexibility. The index is implemented through an original application of the QFD matrix. Lockamy and Khurana [103] demonstrated how QFD can be used as a mechanism for incorporating TQM into the product design process and provided a case study illustrating the use of QFD by the Chrysler Motors Corporation, as well as preliminary conclusions on the use of QFD to facilitate TQM in new product development. Ramos da Silva *et al.* [104] evaluated the integrated use of the QFD and VA tools by employing a survey that was carried out which intended to reveal the young male consumers' requirements concerning a sports bicycle. Rahim and Baksh [105] utilized QFD for a pultrusion machine. Boubekri *et al.* [106] developed a technique for integrating the functions of engineering design and manufacturing in a production environment. The purpose of this methodology was to alleviate the problem of uni-directional flow of information and to eliminate the subjective decision making of the QFD approach. It should be noted that the methodology by Tan and Pawitra [107] could greatly enhance Boubekri *et al.* [106]'s article. The article by Yamashina *et al.* [58] described the Innovative Product Development Process (IPDP) method, which systematically integrates QFD with TRIZ (a Russian acronym for Theory of Inventive Problem Solving) and enables the effective and systematic creation of technical innovation for new products. The effectiveness of IPDP was confirmed by applying it to the technical innovation of a washing machine. The studies above seem not to have considered cost elements in building up the structures of the papers. In addition, the issue of cost, feedback was not addressed. Finally, no consideration has been given to the utilization of neural networks in building the structures of the papers.

From the pool of research documentation in QFD is another application by Orth [108]. The author introduced an integrated framework that integrates market research with operations management for the purpose of providing information for planning production, allocating resources, and changing market strategies based on the mechanism of QFD. The approach employs a causal model. Ferguson [109] examined the role of QFD and barometer design using Taguchi methods in designing quality processes. Xavier and Hunt [110] studied a typical bricks and mortar company that had successfully applied strategy development and deployment methodologies such as Hoshin and QFD to their transformation process. Lyu and Gunasekaran [111] describe how a shipbuilding company in Taiwan can apply these positive concepts to improve its performance with several practical examples to illustrate these concepts. Ramaswamy *et al.* [112] reported on a study performed in SMEs to select and prioritize various techniques for the implementation of JIT in a seasonal order-manufacturing environment through the QFD technique. The paper by Parkin *et al.* [113] analysed the activities that are taking place to introduce QFD into an original equipment manufacturer (OEM). Delano *et al.* [114] presented and compared two techniques for making multiobjective product design decisions: QFD and decision analysis (DA) for a new cargo/passenger aircraft. DA improves the quality of decisions by providing the decision maker with a better understanding of his values, insights into value trade-offs, an understanding of major uncertainties, and the value of additional information. Walker [115] applied QFD in achieving breakthrough improvements for planning industry research and development in the Australian beef industry. In a survey by Sim and Curatola [116], the experience of management in dealing with time-based performance from 83 electronic plants located in the USA was reported. The general finding is that by managing time effectively, a firm is able to enjoy reductions in manufacturing cost, warranty cost, and more importantly increased market shares. Also, despite some prominent features offered by some of the more advanced quality related techniques, such as QFD technique and the Taguchi methods, the survey showed that very few electronic firms in the sample have actually adopted either of these two techniques. Yet consistent with the robustness of these theories, results indicate that those firms embracing these methods experienced a greater reduction in product development time. Thus, the study has important implications for manufacturing firms, particularly those that are still searching for better ways to improve their product development time.

## 3. Results and Discussion

From the review of the literature as demonstrated in previous sections, curious researchers may ask such questions as (i) what do we have to learn from colleagues who have investigated into QFD? (ii) Do we have some approaches that have been developed but could be extended? (iii) What new areas do we have? To answer these questions, we may start by probing details of some studies. A summary is provided below, which shows distilled ideas from reflections on the past works showing future promising areas. It may be interesting for scholars to embark on such QFD studies since they are fertile areas to explore. Information concerning promising research areas is presented in Table 1 (see appendix). Table 1 clearly reveals several issues about the weaknesses of existing studies reported in the literature. Of significance is the need to actualise proposals in studies with real –life cases to validate these proposals. The case of future validations of wind turbine example given by Schmidt [125] should follow real-life demonstrations in future. Real-life cases should also be extended to the work by Karsak *et al.* [119] with a focus on analytical network process in the development of an evaluation method for product planning. Also, based on the current author's research experience, some new tools are proposed to enhance certain studies as evident in Myint [126] where neural networks are suggested.

The study initiated by Bernner *et al.* [117] challenged the direct application of traditional QFD models to the food industry without model adjustments. Strong arguments were advanced for the large differences between changing food ingredients and non-changing components in heavy industries. Such an argument for tailoring QFD to food industries could be adapted to chemical and allied industries, which is characterized by changing product composition with time. It will thus enhance the quality of decision making in such a sector. The linear partial information methodology [118] and similar studies [15, 119] provide a good foundation for the integration of operations research (OR) principles to QFD. However, full advantage of the established knowledge pool in OR need to be taken such that all possible areas that have been explored in OR could be tested in the QFD-OR integration. For instance, aspects of sensitivity analysis need investigations.

Furthermore, a principal focus of many studies in the QFD literature is the application of fuzzy tools (i.e. fuzzy logics, fuzzy sets, etc) to enhance customer satisfaction [120, 121]. While these studies have successfully monitored uncertainties in the QFD models, there seems to be a wide array of principles in the matured fuzzy field not yet integrated with QFD. For example, the fuzzy c-mean algorithms based on entropy or entropy-regularised methods could be suitable applications to QFD models. Also, considering optimization, there should be additional investment of research efforts to apply extensive OR techniques to the injection process optimization by Yeung and Lan [122]. This has to be complemented with adequate statistical tests such as ANOVAS, as demonstrated in the research. It should be noted that though QFD is data based, adequate statistical analysis of previously developed models have not been carried out. This is a limitation which other researchers need to overcome.

## 4. Conclusions, Future Directions and Implications

This research focuses on evaluating the past QFD methodologies and applications with a view to providing readers with an overall vision on the development of QFD. Specifically the results obtained in the current study points out to the follow conclusions: (i) that the dynamic nature of QFD through enrichment with other concepts has not been affected by cost; (ii) neural networks have not been fully explored to the advantage of QFD area; (iii) other phases of QFD, vis-à-vis process planning and product planning processes need more studies; and (iv) QFD is customer focused and how the feedback system from customer complaints could be integrated to the existing frameworks on QFD is missing.

An "added value" of the current work for our scientific community and the industry relates to time savings in conducting preliminary investigations on QFD on choice of research topic for studies and the enrichment that the new ideas proposed here will give towards improved customer satisfaction. For example, research students, particularly researchers (students of B.Sc, M.Sc., M.Phil. and Ph.D programmes as well as faculty members) spend enormous time seeking to understand the QFD area as a first step towards solving a significant problem that merits a degree and/or publishing an article. This wasted time could be saved by studying the current paper, and particularly, by understanding the existing problems to be solved in the QFD literature as suggested in this paper. Further work will then be done by the student in approaching specific papers for detailed analysis. In this way, the current paper contributes to the QFD literature. Articles are reviewed with the aim of understanding the profile of the literature in terms of the mixture of subjects, varieties of methodologies, approaches, and models. Hence, the goal of the article is to advance and sharpen our understanding of QFD research. The motivation behind this research was the fact that previous literature reviews have left a wide gap by not covering enough number of articles in the analysis in view of the fact that many of these reviews were carried out a long time ago and an enormous number of articles on QFD which were not included in their papers have been added to the literature. This is therefore the need to bring the common though or researchers together in an article so as to advance the knowledge frontier in this highly promising field. From the findings of this study it is recommended that future studies should be more focused toward integration of some existing tools in the QFD literature. These are mainly neurofuzzy, fuzzy concept, mathematical programming tools decision sciences tools such as AHP. Others are optimization tools and some soft computing tools like genetic algorithm, artificial intelligence, etc. It is surprising to note that the QFD literature has not benefited significantly for the knowledge base on design of experiments (DOE). Being dependent on a large pool of data, great enhancements to QFD research results would be done if the scientific approaches of this well-established field of DOE could be integrated to QFD. This will make QFD research results more reliable, scientific, acceptable, precise and of a wider interest to all members of the QFD community and beyond. This is also true of the need to incorporate cost into the existing QFD frameworks. A limitation of the current study and an area of future work is that it could be more focused – may be "QFD in service quality literature" or "QFD methodologies" could be the areas of focus. This will enhance coherence of the theme of the work, which could further be improved if attempt to critically categorise the literature using tables is made. Apart from the future directions suggested in this section, readers may consult the articles by Akao and Mazur [7] and Jiang *et al.* [123], which provide additional pointers for research in the QFD field.

Since potential readers of this article are researchers and practitioners, the work has implications for both readers: research implications for researchers and managerial implications for practitioners. For researchers, discussions have been made concerning how the research would lead to improved research productivity. However, for the practitioners, the managerial implications are stated as follows. From the viewpoint of resource conservation, financial resources that are usually channelled to research could be conserved if knowledge and direction of research to be prosecuted is known. For example, the current paper gives a clearer understanding of the various gaps of specific studies in the literature thereby leading the researcher to a good starting point for research.

Even customer satisfaction which QFD aims at is achieved when researchers are quickly able to identify areas of interest to them from a source. To those who utilize QFD information such as organizations in manufacturing, the issue of not incorporating cost into models developed is similar to prosecuting a project without knowing its profitability or whether it is cost effective or not. Thus, the incorporation of cost into model development gives clearance as to how certain alterables lead to increased/decreased cost of project. Another serious implication of the work relates to feedback from customers. When a project is already implemented, and feedbacks are not obtained from customers, dissatisfied customers have no avenue of making their complaints known to the producer and as such, feedbacks to improve their satisfaction is absent, which may lead to low patronage. Thus, valuable information would impact on the product competitiveness. Prediction of outcomes is a necessary output of customer's satisfaction elements in QFD model development. When outputs are to be simulated, neural networks become an effective tool. If this tool is not linked to the QFD model, a great loss of information occurs. Other implications of not incorporating the elements discussed in this paper include weaknesses relating to competitiveness (through absence of cost information), patronage and inability to predict possible liquidity and cash flow problems.

## Nomenclature

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| CAs | Customer Attributes |
| BSC | Balance Scorecard |
| QFD | Quality Function Deployment |
| JUSE | Japanese Union of Scientists and Engineers |
| CE | Concurrent Engineering |
| ECs | Engineering Characteristics |
| VOC | Voice of the Customer |
| CQFD | Continuous Quality Function Deployment |
| QI | Quality Improvement |
| CIRs | Customer Improvement Ratings |
| TIRs | Technical Importance Rating |
| MCDM | Multiple Criteria Decision Making |
| PDM | Product Data Management |
| PDT | Product Development Teams |
| CFD | Concurrent Function Deployment |
| FMEA | Failure Mode Effect Analysis |
| TQM | Total Quality Management |
| IPDP | Innovative Product Development Process |
| ANP | Analytical Network Process |
| NBI | Normal Boundary Intersection |
| IPDP | Innovative Product Development Process |

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| TRIZ | Theory of Inventive Problem Solving |
| ANN | Artificial Neural Network |
| AHP | Analytic(al) Hierarchy Process |
| GQFD-II | Green Quality Function Deployment-II |
| LCC | Life Cycle Costing |
| LCA | Life Cycle Assessment |
| IQFD | Intelligent Quality Function Deployment |
| ICoDe | Integrated Concept Development |
| IRSEs | Improvement Ratios of Satisfactory Estimations |
| HSIM | Hybrid Structural Interaction Matrix |
| QSD | Quality System Deployment |

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Table 1. Promising Investigative Areas on QFD for Future Researchers

| S/No. | Reference(s) | Research Overview | Promising Investigative Areas |
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| 1. | Sarkis and Liles [124] | QFD and IDEF0 functional modelling are integrated to determine requirements and processes for the justification methodology. | The work needs be extended to pursue some form of automation of the IDEF0 procedure using documentation in the IDEF0 form which fits in with a number of other IDEF tools that exist to help in the automation of functional models. |
| 2. | Yeung and Lan [122] | The author constructed an $L_{27}$ orthogonal array and tested 7 injection process parameters for a circular plate. ANOVAs were carried out and different settings for optimization were generated. | Further research incorporating a quality evaluation and enhancement element into CAE are of high potential and promise high returns. |
| 3. | Schmidt [125] | The author proposed a process model of "Integrated Concept Development (ICoDe) to fill the gap between marketing science and engineering by consequently relating market oriented concept development and testing to the House of Quality concept of QFD. | Conjoint analysis has been applied in the paper. However, the high potential of combining conjoint analysis and QFD is still restricted because of methodological shortcomings. For example, as used in the work, conjoint analysis is still not able to handle the 28 secondary Need attributes of a wind turbine. More research is yet to be conducted to realize the potential and benefits of linking conjoint analysis to QFD. Furthermore, restrictions of the positive results of the ICoDe application described in Schmidt's work are evident. Up to now, ICoDe application has not been applied to a real world example and development process. The restriction of only taking one product feature into account means, that the coordination of different product features has not been analysed in Schmidt's article, and need to be focused on by future investigations. Also, further studies have to be undertaken to test ICoDe under "real world conditions" using different product categories. As Schmidt pointed out, in the case of positive results the ICoDe process may be improved by linking it to Target Cost, Rapid Prototyping, and the development of product related services. Furthermore, Schmidt's article does not solve all the problems related to product concept development. Nevertheless it contributes to the guidance of the project team within the implementation of Simultaneous Engineering and future work should further this for improvement. |
| 4. | Bode and Fung [1] | The authors integrates design costs into QFD framework, which aids optimization of product development resources towards customer satisfaction and performed conduct analytical investigations to facilitate decision making in product design and development. | Future research efforts should be directed toward the refinement of the model by investigating the relationship between resource requirement and the degree of attainment of the technical attributes. Efforts to understand inter-dependencies such as those between the technical attributes and the customer requirements, as well as the correlations among various technical attributes should be made. |

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| 5. | Sohn [125] | The paper utilizes cluster analysis and Poisson regression to relate accident variation to local driving environmental characteristics in a local traffic accident reduction drive. | The work used cluster analysis and centroid method as a criterion for grouping. However, other criteria for clustering could be used and their results can be compared with those reported in Sohn. Also, Poisson regression, which is used in the study is a fixed effects model which assumes that the average number of accidents is the same as the variance and when the condition of covariates are the same. However, this situation may not be true always, thus, a random effects Poisson model might be a better choice than a fixed effect model. It could not be noted that the choice of a model between the two (random and fixed effects models) would not have much effect on the point estimate of each indicator variable but significance test result may change. In addition, cross product terms of several factors could be added to the Poisson regression model when the data available are sufficient enough to fit the model. These extensions are left for further study topics. |
| 6. | Karsak *et al.* [119] | Analytic network process is employed to develop an evaluation method that considers the interrelationships among customer needs and product technical requirements, taking into account the multi-objective nature of the problem which incorporates other goals such as cost, extendibility and manufacturability. | The decision approach presented can be easily extended to real world applications of QFD by considering additional resource limitations and design metrics. |
| 7. | Myint [126] | The work develops a methodology of an intelligent quality function deployment (IQFD) application in the discrete parts, assembly environment. | There is need to consider customer needs using neural network and the application of sensitivity analysis principles to justify the possible changing of the weights of needs. |
| 8. | Bernner *et al.* [117] | The study investigates whether it is possible to apply QFD method originating from heavy industries without changes to the food industry. The work answers the question whether it is necessary to tailor the QFD method to account for the large differences between the often still metabolically active and thus changing, food ingredients instead of the exactly specified and not changing components used in the electronic and mechanical industries. | The focus of future studies should include (i) the development of a framework that could incorporate feedback from customers into the QFD system as apposed to customer involvement only at the initial phase of the development (ii) computerization of activities that could capture all the WHATS' and HOWS' of the customer since very diverse information would lead to high quality model development (iii) the development of an analytical framework that would successfully take care of the fact that the functional properties of food products cannot be detached from each other and that food products cannot be divided into parts (except into packing and content of the packing) (iv) rigorous research that extensively treat QFD beyond the HOQ. There are many publications that only give an example of the HOQ (v) interactions between the actors in the food industry expressed in quantified terms (vi) an adjustment to the QFD method such that the target |

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| | | | values (or HOW MUCHs) be replaced by target intervals (as indicated by Benner *et al.*, 2003). This is because food ingredients are still physiologically active materials that are subject to changes. |
| 9. | Han *et al.* [118] | The author proposed a linear partial information model in extracting weights of CAs and relationship values of CAs between ECs. This aimed at reducing the cognitive burden of designers and engineers of QFD planning team. | Two major drawbacks of the study are noted: solving a number of linear programming and computational complexity. Future investigators could focus on resolving these problems by extensive coding for software development. These decision support system developed would interest practitioners and researchers in applying the framework with ease while promoting performance improvement with ease. The application of the model developed could be made to real world problems such as healthcare, education, construction, hospital management, hotel system, manufacturing and service systems. Results of case studies could be compared and also with the traditional methodologies. |
| 10. | Chen *et al.* [120] | The paper proposed a method that uses fuzzy weighted average method in the fuzzy expected value operator in order to rank technical attributes in fuzzy QFD. | A possible fruitful research area relates to extending Chen *et al.*'s (2006) work by considering the correlations among multiple technical attributes, bench marking information compared to competitors, or other types of fuzzy number (e.g trapezoidal fuzzy number). |
| 11. | Chen and Weng [90] | The authors proposed fuzzy goal programming models to determine the fulfillment levels of the design requirements (DRs) while considering business competition by specifying the minimum fulfillment levels of DRs and the pre-emptive priorities between goals. | Future investigators are advised to perform more $\alpha$-cuts and the fuzzy fulfillment levels of the DRs can be defuzzified into real numbers, which can be done by designers. |
| 12. | Chin *et al.* [11] | The authors presented an evidential reasoning (ER) based methodology for synthesizing various types of assessments information provided by a group of customers and multiple QFD team members. | A drawback to use the ER-based QFD methodology is its complexity. However, such a draw back can be overcome when the interval ER Algorithm is implemented recursively on a Microsoft Excel worksheet. This challenge could be the subject of future investigations. |
| 13. | Delice and Gungor [15] | The authors proposed a new approach to QFD processes to obtain optimum solution from a limited number of design requirement alternatives, whose values are discrete MILP model and the Kano model that are integrated into the product development problem thus solving the problem of lack of solutions of integer and linear programming in the QFD optimization. | Delice and Gungor [15] accepted all values (i.e correlation, relationship, etc) as deterministic. However, further research needs to consider this as fuzzy numbers. Additionally, the fulfillment levels of design requirements are assumed to be in a linear relationship with cost. However, there is rarely a linear relationship in real world applications because of the constraints of technology and production (i.e the dimensions of computer monitors have changes such as 15", 17" and 19", but the price of these monitors changes sequentially as in \$140, \$150 and \$250). Consequently, in achieving greater |

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| | | | validity in further research, it is important to take account of this piece-wise linear while designing the model. This could be the subject of another research. Also, generally, the QFD process may be necessary to optimize more than one conflicting objectives simultaneously. Therefore, Delice and Gungor's model may be developed with multi-objective decision making approach. This may be the interest of future investigators. |
| 14. | Liu [16] | The author developed an extended fuzzy quality function deployment approach (E-QFD) with expanded research scope from product planning to part deployment. An advanced method in product planning ensures proper collection of customer requirements with an integrated competitive analysis system. In part deployment, an enhancement to the original part deployment table is made by incorporating importance of part characteristics (PCs) and the bottleneck level of PCs. A modified fuzzy k-means clustering method was proposed to classify various bottleneck or importance groups of PCs. The FMEA was then conditioned for high bottleneck (or high importance) groups of PCs. through fuzzy inference approach. | Several issues are opened up for investigations for the enhancement of the practicality of the fuzzy-QFD model developed. As the author suggested, a better clustering algorithm could be obtained but is lacking in the published paper. Also, no explanation is given concerning this. The current review work proposes extensive test of fuzzy c-means since it is a major technique of clustering in general. A family of algorithms under this fuzzy c-mean that utilizes entropy or entropy-regularized methods could be applied to the QFD model. It may be important to compare results produced by employing (i) the methodologically different Dunn and Bezdez traditional method (ii) entropy based method and (iii) the original method proposed by Liu [16]. Further exploration of the subsequent phases (process planning and production planning) of QFD would benefit the academic community. Detailed analytical frameworks concerning the stages of the planning process need be explored. This viewpoint is missing in the published work by Liu. Future investigators could find ways of defining the business numerically (i.e determination of the organization's mission and goals in quantitative forms), analyzing the current situation and developing strategies (formulation of strategy) and allocating resources and responsibilities achieve strategy (i.e. implementation of strategy). For the production planning phase of QFD, we suggest that interested researchers should clearly incorporate all the four steps of production planning (i.e planning, routing, scheduling and loading) into the analytical framework suggested by Liu. Measures to reflect the planning aspect include the quantity of material, manpower, machine and money required for producing a set of predetermined output in a time frame. Routing activities of the production planning process should include quantitative dimensions of (i) make/buy analysis (ii) determination of the quality and type of material (iii) manufacturing operations/ sequence analysis (iv) lot size determination (v) scrap estimation (vi) cost of the article; (vii) organization of production control forms. For scheduling, there is need to incorporate the following in the QFD framework proposed: (i) descriptions of personnel skills and to |

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| | | | operate the equipment and perform the type of work involved (ii) quantitative descriptions of physical plant facilities, including the type required to process the material being scheduled (iii) quantitative values of necessary materials and purchased parts; (iv) numerically-described total load on each section (v) evaluation of the job status. While understanding loading as the execution of the schedule plan as per the route chalked out, which includes the assignment of the work to the operators at their machines or work places. (i.e who will do the work), information about this should be included in the new QFD framework. Another aspect of improvement is the development of a user-friendly and intelligent decision support system, which could be developed based on the Liu's model and the alternative proposals. |
| 19. | Li *et al.* [17] | An integrated model is proposed to obtain the final importance of customer requirements in product planning house of quality by combining rough set theory, Kano's model, AHP, and scale method. | Future research areas include using some related methods of the incomplete decision system in rough set theory to tackle the sample set. More accurate functions for determining the importance rating of achieving the improvement ratios of satisfactory estimations (IRSEs) of customer requirement may be developed to represent the results of the efficiency and risk analysis. |
| 20. | Bottani [19] | The work which links competitive bases, agile attributes and agile enablers, aims at identifying the most appropriate enablers to be implemented by companies based on QFD methodology. | A 3-step conceptual model that links competitive bases, agile attributes and agile enablers were presented in the work. Focusing on the methodological point of view, the work paid particular attention on showing application of the methodology, rather than on providing a precise description of competitive bases, agile attributes and enablers. Consequently, in developing the numerical example, such elements, as well as relationships and correlation matrixes, were derived from existing studies. Nonetheless, the applicability of the methodology to real cases would benefit from a precise taxonomy of attributes and enablers that companies perceive as relevant to achieve agility, as well as from exploratory studies attempting to describe possible relationships and correlations between them. Starting from suggestions provided in literature, future research could thus be focused on these topics. Also, the QFD approach proposed in the study is tailored for agility context. Thus, extending the approach developed for different paradigms is a viable future research direction. Specifically, the agile paradigm is frequently linked to the lean and "leagile" ones and similarly to the agility concept, attributes and enablers can be identified in literature for the lean paradigm. Hence, future studies could be addressed at developing a similar integrated approach suitable to be adopted to enhance leanness or leagility of companies. |

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| 15. | Wang [10] | A QFD model is constructed under a pure linguistic environment by assessing customer needs, evaluating the relationship between customer needs and situation schemes, and prioritizing the solution schemes. | A useful advantage of Wang's model over the traditional one is that the work further enhances the tolerance of the conclusion. However, the sensitivity of conclusions is decreased. This is a major challenge for researchers and practitioners. Reduction of this sensitivity should be an interesting topic of subsequent research. |
| 16. | Ramanathan and Yungfeng [2] | Data envelopment analysis was utilized for deriving the relative importance of design requirements when cost and environmental impact are considered. | There is need for consideration of multi-criteria decision analysis models and comparison with the current work. Differences in results could be studied for improvement in the eventual operations research model that may emerge if proper integration is made. |
| 17 | Chen and Ko [12] | The authors consider the close link between the four phases of QFD using the means-end chain (MEC) concept to build up a set of fuzzy linear programming models to determine the contribution levels of each "how" for customer satisfaction by incorporating risk analysis and fuzzy approaches to deal with the vague nature of product development processes. | Further efforts should be made in the NPD problem formulation. Besides the MEC concept, other considerations, such as Kano's concept, could be modeled in QFD problems in future research. |
| 18. | Li and Kuo [128] | The authors adopt the genetic chaotic neural network (GCNN) technique to identify each customer's needs and their priorities in the development of virtual items in massive multi-player online role playing games and also proposed the enhanced quality function deployment (EQFD). | Future investigators should search for more accurate equations of chaotic systems to improve on the study which only shows the possibility of orbital instability and could not generate the given orbital instability within given iterations. There is need to further look into the methods to generate the relationship matrix of HOQ since the foundation work by Li and Kuo (2007) only shows that these weights are acquired based on repeatedly interviewing domain experts, and these weights may include some subjective results. |

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