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Advanced models of quality function deployment: a literature review

K. Sivasamy[1] · C. Arumugam[1] · S. R. Devadasan[2] · R. Murugesh[3] · V. M. M. Thilak[2]

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Abstract In this paper, a literature review conducted to study the characteristics of advanced models of quality function deployment (QFD) that have appeared in the literature arena is reported. QFD technique emerged in Japan in the 1970s. QFD has been proving to be a powerful tool that can be used for translating the voice of customers into technical languages. Yet from the beginning of this century, researchers began to point out the need to refine, modify and improve the features of QFD technique. In order to fulfil this need, few researchers brought out several advanced models of QFD. While conducting the literature review reported in this paper, six types of such advanced models of QFD were identified in the literature arena and their characteristics were studied. The result of this study revealed that the procedural and computational complexities are least in the case of an advanced model called total quality function deployment (TQFD). TQFD technique replaces the complex computations involved in applying conventional QFD technique with simple ratings. Besides the formation of teams to translate the voice of customers into work instructions ensures the quick reactions to the customers' desires in the actual field of implementation. In this background, at end of this paper, it is suggested to adopt TQFD for implementation in traditional organizations in which the prevalence of adequate education for adopting complex procedures is found to be least.

Keywords Quality function deployment · Voice of customer · Total quality management · Fuzzy logic · Analytical network process · Analytical hierarchy process

✉ K. Sivasamy
sivamechcit@gmail.com

1 Coimbatore Institute of Technology, Coimbatore, Tamil Nadu, India

2 PSG College of Technology, Coimbatore, Tamil Nadu, India

3 Darshan Institute of Engineering and Technology, Rajkot, Gujarat 363650, India

1 Introduction

Right from the middle part of twentieth century, the world began to experience the intensification of global competition (Shaik et al. 2014).In order to face this intensified competition, manufacturers and service providers were required to translate customer preferences into technical parameters and values. In order to carry out this translation accurately, quality function deployment (QFD) technique emerged in Japan during 1970s (Akao and Mazur 2003; Wolniak and Sedek 2009; Buyukozkan and Cifci 2013; John et al. 2014; Liu et al. 2014; Politis 2005; Vinayak and Kodali 2013; Rajiv et al. 2010). The developers of QFD named the 'customer preferences' as 'voice of customers' (Aytac and Deniz 2005; Vinodh and Chintha 2011). The core part of QFD is the construction of a matrix called house of quality (HoQ) (Raharjo 2013), which is the composition of four matrices (Wu and Shieh 2008; Kuo et al. 2009). In a HoQ matrix, customer voice is fed as the input and technical parameters with values are derived as the output. While developing a HoQ matrix, besides considering customer voice, competitors' position and interrelationships among the technical parameters are considered (Li et al. 2014).

After about two decades from its emergence, QFD was adopted by the companies situated in many parts of the world (Zhang et al. 2014). It was applied while carrying out many activities like, product design, quality management, decision making and team building (Wolniak and Sedek 2009). QFD was also applied in various industries like, manufacturing, transportation, electronics, construction, education and service (Aytac and Deniz 2005; Vinayak and Kodali 2013). From the year 1980, several researchers began to publish the outcome of QFD when it was applied in practice (Politis 2005; Zaim et al. 2014). Most of them reported several benefits of applying QFD (Andronikidis et al. 2009; Gremyr and Raharjo 2013; Kamvysi et al. 2014; Liao and Kao 2014; Raharjo 2013). According to these researchers, QFD aids in designing customer friendly products, reducing the product development lead time and improving product quality and reliability.

As a result of the appearance of abundant papers reporting researches on QFD, during the beginning part of this century, a few authors began to publish review papers on QFD. For example, Chan and Wu (2002) have reviewed as many as 650 papers and presented the highlights of the contents of these papers (Vinayak and Kodali 2013). Likewise, Gremyr and Raharjo (2013) reviewed 45 papers on QFD. The appearance of these papers on QFD till the beginning of this century reveals its widespread adoption throughout the world (Prasad et al. 2013). Despite its wider adoption, some researchers began to point out the drawbacks of applying HoQ in practice (Andronikidis et al. 2009; Iqbal et al. 2014). As a result, during the recent years, some researchers have been contributing advanced models of QFD to overcome the drawbacks pointed out by these researchers (Buyukozkan and Berkol 2011; Kamvysi et al. 2014; Raharjo et al. 2010; Vinayak and Kodali 2013). The practitioners have also begun to examine the practical feasibility of these advanced models of QFD (Mehrjerdi 2010a, b). Yet the practitioners are yet to identify the appropriate advanced model of QFD that would suit their applications in specific cases. This situation reveals the need to review the characteristics and advanced models of QFD that have appeared in literature arena. The research question of such review should be, 'What is the practically viable and powerful advanced QFD model?'. The result of such review should aid to identify an advanced QFD model which should be highly practically viable and powerful in translating 'customer voice' into technical parameters and values. In order to fulfil this need, the literature review being reported in this paper was carried out to answer to the above research question.

2 Drawbacks of QFD and emergence of advanced models

The literature review being reported here was begun by identifying the drawbacks of QFD which have been reported by the researchers in the literature arena. These drawbacks are enumerated in Table 1. As shown in Table 1, four distinct drawbacks of QFD have so far been cited in the literature arena. From the beginning part of this century, a significant number of researchers have brought out advanced models that would overcome these drawbacks of conventional QFD (Kamvysi et al. 2014). This development leads to derive an inference that the world has moved towards applying advanced models of QFD. This situation warrants the need to review the literature on the development and application of advanced models of QFD. On realising this need, the literature review being reported in this paper was carried out. In the first phase of this literature review, leading database namely, Emeraldinsight, Science direct, EPSCO and Springer-Link were searched to gather papers reporting researches on advanced models of QFD. This search resulted in the identification of 24 papers. Subsequently, the theory and practice of developing and applying the advanced models of QFD that have been reported in these papers were studied. The information and knowledge gathered by carrying out this exercise are presented in the following sections of this paper.

3 Advanced models of QFD

Time and again, QFD has been extended or modified by the researchers and practitioners to overcome the drawbacks mentioned in the previous section (Akao and Mazur 2003; Chan and Wu 2002; Kamvysi et al. 2010; Raharjo 2013). Due to their distinct prominence in the literature arena, the following six main advanced models of QFD fell within the scope of the literature review being reported in this paper.

Table 1 Drawbacks of QFD

Serial number	Drawbacks of QFD as reported in the literature arena	Paper
1.	Conventional QFD cannot be used when multi—criteria are required to be considered	Vinodh and Chintha (2011)
2.	The usage of customer language is leading to ambiguity and derivation of imprecise characteristics. These deficiencies result in questioning the effective outcome of QFD	Sener and Karsak (2011), Andronikidis et al. (2009)
3.	QFD is mainly useful for developing new products. It is seldom employed for developing improved products from the existing products	Akao and Mazur (2003), Devadasan et al. (2006)
4.	QFD is a complex process. Developing QFD chart is very difficult. Analysis of the data is carried out in subjective manner, leading to the inconsistencies of the outcome. The relationships between 'WHATs' and 'HOWs' are not accurately indicated	Bouchereau and Rowlands (2000), Andronikidis et al. (2009), Kamvysi et al. (2014), Wu and Shieh (2008)

(1) Fuzzy QFD.
(2) Kano based QFD.
(3) Analytic hierarchy process (AHP) integrated QFD.
(4) Analytic network process (ANP) integrated QFD.
(5) Project QFD.
(6) TQFD.

The researches reported about the above advanced models of QFD are described in the following subsections.

3.1 Researches on fuzzy QFD

During the conduct of the literature review being reported here, 13 papers reporting the researches on fuzzy logic integrated QFD could be identified. The researches reported in these papers are described in this subsection.

Kim et al. (2000) have stated that QFD is one of the techniques that the companies can adopt to develop new products. As the target values derived as the output by the HOQ of QFD technique are vague, it is suggested to employ fuzzy concept to quantify the same. In this regard, these authors have explained the method of formulating models and obtaining solutions using fuzzy logic integrated QFD process. In line to this information, Liu (2009) has mentioned that, Khoo and Ho (1996) had first proposed the methodology of integrating fuzzy logic with QFD. After that, many researchers have proposed several models of fuzzy integrated QFD. This author claims that these models give rise to the results which are not accurate. In order to overcome this deficiency, this author has proposed a model called extended fuzzy quality function deployment (E-QFD). This approach focuses the practical implementation of the results. After describing the theoretical aspects of E-QFD, this author has explained the application of E-QFD in a company located in Taiwan. This application consisted of seven steps. This author has mentioned that E-QFD enables the decision makers to recognize the problems faced during the product development phase. On the whole, E-QFD model enhances the practically of solutions obtained by applying the QFD approach. Similar to this research, few researchers brought out generalised advanced fuzzy integrated QFD models. For example, Ramasamy and Selladurai (2004) proposed a model named by them as fuzzy logic quality function deployment (FL-QFD). It is claimed that, FL-QFD is an innovative method of determining optimum rating of engineering characteristics (ECs) by simulating the QFD matrix. The FL-QFD approach provides better ratings for the ECs when compared with the FQFD model proposed by Khoo and Ho (1996). Few other authors have reported the application of fuzzy logic integrated QFD in specific cases and situations. The researches reported by these authors are briefly described in the following paragraphs of this subsection.

Ding (2009) has reported a research in which fuzzy QFD approach was applied to translate customers' requirements into technical parameters in the case of serving customers in a port. While conducting this case study, the largest international port of Taiwan namely port of Kaohsiung was considered for applying fuzzy QFD approach. To begin with, appropriate data from sixty users of ports of Kaohsiung were gathered by supplying a questionnaire. Using this data, the fuzzy QFD was applied. At the end of this application, eight key solutions were obtained. Some of the solutions include carrier retention in the port, carrier total satisfaction and quick efficiency customer response. Further, ten key factors were found to be playing major roles in improving the quality of service in the port. Some of them include 'berth dispatching and deployment,' 'port marketing,' and 'applied capability of IT'. It is on anticipated that the application of these eight solutions and top ten key factors in practice will improve the performance of the port.

Liang (2010) has enumerated seven steps for applying fuzzy QFD approach in service management arena. This author has illustrated the methodology of applying these steps by considering customers relationship management (CRM) of 'airlines cargo business'. This author has considered three customer quality needs under the titles 'value added', 'customer interaction', and 'customer profiling'. On applying fuzzy QFD, the importance of the customers' preferences could be ranked. The first rank of customer quality parameter was 'value added'. The second rank of customer quality was 'customer ranking'. The third rank of customer quality requirement was 'customer requirements'. Thus, this author has described in this paper the way of ranking customer priorities by applying seven steps of fuzzy QFD approach. While concluding this paper, this author has mentioned that this approach can be applied in any situation wherein management decisions are required to be made.

Wu (2011) explored an intelligent method to evaluate the product design time (PDT). At the early development stage, designers do not have appropriate facilities to access sufficient product information and have difficulty in determining PDT by subjective evaluation. In order to overcome these deficiencies, a model named as 'fuzzy measurable house of quality' (FM-HOQ) is proposed in this paper to provide measurable engineering information. In this model, QFD is combined with a mapping pattern of 'function, principle and structure' to extract product characteristics from customer demands. Vinodh and Chintha (2011) have reported a research in which a fuzzy integrated QFD approach has been used for enhancing agility of a traditional manufacturing organization. The primary objective of this research was to improve the strategic agile position of an organization by prioritizing of agile performance measures (APMs), agile attributes (AAs) and agile enablers (AEs) by applying this fuzzy integrated QFD approach. Agile decision domains (ADD) is the agile manufacturing (AM) criteria and AAs are the ways through which the criteria could be met. In order to prioritize the ADDs, AEs and AAs, this fuzzy integrated QFD was applied for enhancing the agility of the case organization. Sener and Karsak (2011) have made use of fuzzy linear regression model to develop a fuzzy multiple objective decision making framework for considering fuzzy nature of design problems and making precise the vague representation of the voice of the customers in the execution of QFD technique. These authors have described the application of this framework by considering the case of developing a washing machine.

Yang et al. (2003) have applied fuzzy integrated QFD while carrying out the building design. These authors have created a matrix named by them as 'HoQ for buildable design' (HoQBD) to make the conventional HoQ compatible for making decisions while carrying out the building design. These authors have illustrated the application of HoQBD by describing a hypothetical case study. While concluding, these authors have stated that, integration of fuzzy logic in QFD results in the identification of precise solutions that would be useful for making good decisions while carrying out building design. Lin (2010) has presented a research work in which fuzzy QFD was applied to determine the expectation of the customers who visit trade shows. The attributes of trade shows were obtained by building HoQ. Subsequently, fuzzy integrated QFD was employed to study the functional relationship between attributes of trade shows and indicate the values of trade shows using fuzzy and crisp numbers. Entropy methods were employed to rate the trade shows from the view point of the different clusters of visitors. A fuzzy decision support system was also developed by incorporating this approach and entropy methods.

Chen and Ko (2009) have claimed that so far researchers have not addressed the method of integrating QFD with FMEA. Furthermore, the uncertainty aspects of developing new products have also not been addressed by the researchers. In order to overcome this deficient situation, these authors have contributed a fuzzy logic integrated QFD approach. In this approach, these authors have integrated FMEA with QFD by constructing fuzzy nonlinear mathematical programming models. This model was used to obtain the interrelationship between the several phases of QFD. These authors have considered Kano's concept and proposed this fuzzy nonlinear model to achieve better satisfaction of customers.

Kuo et al. (2009) have proposed a model named as fuzzy based Eco-QFD model. This model would aid a design team to choose the target levels of technical attributes based on environmental concerns. In order to apply this model, ecological based design product development problem is to be formulated as a fuzzy multi-objective model. The HoQ is applied based on the importance ratings that are assigned by the customers against each product. These authors have concluded that, this model is useful in integrating environmental attributes with quality, cost and customer requirements. Also the vagueness and uncertainty faced in group decision making process can be eradicated by employing this Eco-QFD model. Sen and Baracli (2010) have categorized non-functional requirements of software into three criteria under the titles 'quality characteristics', 'technology factors', and 'socio economic factors'. In order to support the non-functional requirements that are considered while developing software packages, these authors have proposed a fuzzy QFD based method. This fuzzy QFD based method, which consists of seven steps, has been illustrated by applying it to audio electronics. In the conclusion section, these authors have mentioned that, in the proposed fuzzy integrated QFD method, large volume of computations is required to be carried out. These authors have suggested to the future researchers to develop expert systems or decision support systems for supporting these voluminous computations.

The review of the papers described above has indicated that in total, fuzzy based QFD models have been applied in several fields. However, the complex computations presented in the above papers indicate that the practical application feasibility of fuzzy QFD models is weak.

3.2 Researches on Kano QFD

While conducting the literature review being reported here, three papers reporting the researches on integrating Kano model with QFD were encountered. The researches reported in these papers are briefly reported in this section.

Kuo et al. (2012) have described about the increasing usage of health foods in developing countries. These authors have considered a case of buying black beans as a health food by the customers in Taiwan. Because of the higher sales of black beans in Taiwan, the black bean manufacturers are required to identify the customer requirements through the translation of customers' vague languages. In order to carry out this task, these authors have used Kano integrated QFD model. This research was conducted in seven steps. In the first step, the questionnaires were designed and supplied to 20 years old customers in Taiwan. After gathering the filled in questionnaire and drawing relevant data from them, Kano model was applied to identify quality factors of health food. During the pursuance of this research, 15 attributes of black beans were considered. Out of them, five attributes were considered to be important form the customers' point of view. Subsequently, QFD was applied to identify the important techniques that are required to be applied for improving the quality of black beans. Some of the techniques identified were 'market positioning,' 'competitive product analysis' and 'trend review'. By gathering this information through the application of Kano QFD model, these authors have listed suggestions for improving the selling of health products and the titles of products, prices, promotions and channels. For example, under the title prices, these authors have suggested the manufacturers to identify the ways of reducing the cost of manufacturing ingredients and lowering the prices of health products.

Lee et al. (2008) have reported a research in which QFD was incorporated in product life cycle management (PLM) to capture the voice of customers. The requirements of customers which form the input of PLM are derived from customer complaints. Since the customer complaints do not lead to the identification of customer requirements exactly, it is suggested to apply QFD in PLM. Further, the usage of Kano model has been suggested to indicate customer requirements under the titles 'basic quality element', 'attractive quality element' and 'reverse quality element'. In order to convert these customer requirements which are indicated using linguistic elements in Kano model, these authors have suggested the employment of fuzzy concept. After theoretically describing its steps, the practical application of this QFD integrated PLM model, has been described by presenting a case study. While carrying out this case study, first the data were gathered by using the questionnaires. Then, these data were analyzed using fuzzy Kano model. The method of calculating the weights and the method of identifying the most influential ones are presented. These authors have listed as many as eight major benefits of PLM which include achievement of higher product quality and better business results. These authors have claimed that these benefits can be reaped significantly if QFD, Kano model and fuzzy logic concept are incorporated in PLM by employing the integrated model proposed by them. These authors have suggested the employment of AHP in the proposed integrated model as the future scope of research.

Shen et al. (2000) have proposed a process which is named by them as innovative product development process. It is pointed out that in order to face the competition, more than satisfying the customers, it is required to delight them by providing innovative products. In order achieve this goal, it is suggested to use Kano model which classifies the different customer desires into categories like 'must be', 'attractive' and 'desirable' characteristics. The attributes derived by applying Kano model which basically involve the data collection using a questionnaire are to be input into the QFD process. The QFD process converts these attributes into technical languages. This process facilitates to develop innovative products for delighting the customers. After describing this process, the method of designing the web page for increasing the efficiency of innovative product development is described. While concluding, these authors have suggested investigating the integration of TRIZ with this proposed process for enhancing the efficiency of producing innovative products to delight the customers.

On the whole, in order to improve the accuracy of 'voice of customer', the method of integrating Kano model with QFD model is suggested in the above papers. The drawback of this integration is that it increases the steps of translating the voice of customer into technical parameters. Hence, the lead time of developing the innovative products will be increased which is intolerable given the intensified competition prevailing in the markets.

3.3 Researches on analytic hierarchy process integrated QFD

While conducting the literature review being reported here, two papers reporting a research on integrated analytical hierarchy process (AHP) with QFD were encountered. The researches reported in these papers are briefly described in this section.

Ho et al. (2011) have reported a research in which an integrated approach involving QFD and AHP approach was developed for selecting the supplier to meet the strategic objectives of the organization. This integrated approach has to be carried out by applying 13 steps to achieve effective supplier selection. While implementing these steps, three houses of quality need to be developed. The practical implementation of this integrated approach has been demonstrated by reporting a case study in a UK based multinational automobile manufacturing company. In this case study, the performance of the current supplier with three other suppliers has been evaluated. At the end of this case study, these suppliers were ranked. Subsequently, the results were further analysed. The result of this analysis suggested the replacement of the current supplier with either one or two other suppliers. In the conclusion section of this paper, these authors have described five advantages of applying this integrated approach in practice. Particularly, the advantage of facilitating active involvement of all concerned members while evaluating these suppliers is noteworthy.

Ho et al. (2012) applied an approach involving the integration of QFD, fuzzy set theory and AHP for selecting third party logistics (3PL) service providers. According to this approach, fuzzy and AHP are applied to rate and weigh the 3PL service providers. Application of fuzzy and AHP reduces the inconsistencies in ranking the 3PL providers. The objectives of applying this approach were, the reduction of total logistics costs, reduction of cycle time, assurance of quality in distribution, providing customized logistics services, increasing customer satisfaction, possessing state-of-the art hardware and software, providing guidance on time and resolving problems effectively. The constraints considered in this approach are, finance, 'logistics and transportation', manufacturing and marketing. Appropriate selection of 3PL will enhance the competition between the companies providing a particular production process. Thus, this fuzzy and AHP integrated QFD approach ensures that the stakeholders' requirements are met and the business objectives of 3PL providers are achieved. A significant merit of this approach is that, several teams of personnel are triggered to involve in the selection of 3PL service providers, which lead to the balanced consideration of the requirements at each stage of the business process. The conventional approaches on the strategic logistic outsourcing are outranked by this new approach.

On the whole, the researches reported in the above papers indicate that, it is beneficial to integrate fuzzy logic concept and AHP with QFD for effectively translating 'voice of the customers' desires into technical parameters and their values. However, the complex steps and computations involved in this integration weaken its practical feasibility.

3.4 Researches on analytic network process integrated QFD

While conducting the literature review being reported here, three papers reporting the research on analytic network process (ANP) integrated QFD were encountered. The researches reported in these papers are briefly described in this section.

Lin et al. (2010) have mentioned that very little studies have been conducted to determine the factors that would improve both environmental production requirements (EPRs) and sustainable production indicators (SPIs). These authors have conducted studies among original equipment manufacturers (OEMs). It is a difficult process to link environmental aspects while designing products and processes employed in OEMs. These authors have proposed an approach that makes use of QFD and ANP integration. In this approach, fuzzy principles have been used. An empirical study was conducted to study the practical feasibility of this approach. The results of this empirical study have suggested that the firm considered under the case study shall listen to EPRs to improve the values of SPIs.

Like Kim et al. (2000), Liu and Wang (2010) have proposed an advanced QFD model which is incorporated with fuzzy logic system and ANP. In order to apply this model, six steps are to be followed. Constructing the network diagram, fuzzy ranking and fuzzy clustering are the major hallmarks of these steps. The application of this model in real time situation has been explained by presenting a case study. While concluding the article, these authors have pointed out the positive features of this model. These authors have also pointed out the drawbacks of this model. One of these drawbacks is that during the application of this model, several computations are required to be carried out which will be tiresome in practice. In order to overcome this difficulty, these authors have suggested the development of decision support systems to assist managers for implementing this fuzzy and ANP integrated advanced QFD model.

Zaim et al. (2014) stated that researchers have been evolving advanced models of QFD which are augmented by the concepts like AHP and ANP. In the research reported in this paper, two techniques namely ‘ANP weighted QFD’ and ‘fuzzy analytical network process weighted QFD’ were employed. The quality characteristics of the product were evaluated according to qualitative and quantitative criteria by employing both these techniques. The results obtained by crisp based ANP and fuzzy logic based ANP were compared and interpreted. A new tool called ‘polyethylene squeeze off tool’ was developed using this methodology to fulfil the need of the customers.

The researches reported in the above papers have indicated the practicality of improving the preciseness of the outcomes of QFD by integrating fuzzy and ANP principles with it. However, the long steps and complex computations tend to desist the practitioners from employing the above fuzzy and ANP integrated QFD approaches reported in these researches in real time situations.

3.5 Researches on project QFD

During the conduct of the literature review being reported have, a paper reporting the research on applying project QFD technique was encountered. The research presented in this paper is briefly described here. Chao and Ishii (2004) have pointed out that 46 % of the projects that were started by the companies worldwide to develop new products fail. Many researchers have examined the causes of failures of these projects. The main cause identified is the failure to define the product requirements. Another cause identified is the failure to address the risks associated with the execution of the projects. These two failures can be prevented in case project QFD is adopted in companies while executing the projects. The HoQ of project QFD consists of two houses. In the first house, the project requirements are mapped against the development matrix. In the second house, the project matrix is mapped. After constructing these houses, cost worth analysis (CWA) is analyzed by considering the tools for developing new product and the cost of implementation. In total, the three stages of project QFD indicate the tools to be applied to successfully define the product for minimizing the risk and utilizing the resources meticulously. These authors have described the working of project QFD by reporting a case study in an alternating current (AC) drive controller project. While conducting this case study, it was realised that the effort must be made to define a project and overcome risks of carrying out this project. The pursuance of this case study has revealed that project QFD is one of the powerful project definition tools. In the conclusion section, these authors have mentioned that companies like General Electric, Asea Brown Boreri (ABB) and National Aeronautics and

Space Administration (NASA) have recognized project QFD as a powerful product definition tool. These authors have also mentioned that project QFD is known as “boss or business” QFD as this tool facilitates a company to achieve business results. Despite this benefit, the limited scope of applying to improve the success rate of projects prevents the widespread application of project QFD in organizations. Presumably due to this reason, except the above paper, no other paper reporting the application of Project QFD could be encountered in the literature arena.

3.6 Researches on TQFD

During the conduct of the literature review being reported here, two papers reporting the theory and application of the TQFD technique were found. The information and knowledge derived by reviewing these papers are briefly described in this section.

Devadasan et al. (2006) have described the roles played by QFD in implementing the TQM in companies. These authors have pointed out that several benefits of implementing QFD have been reported in the literature arena. Yet QFD suffers from certain limitations which impede its implementation to a great extent. As many as nine deficiencies of QFD as reported in few other papers found in the literature arena are listed in this paper. Among these, the notable deficiency is the complexity of developing HoQ while implementing the QFD and drawing the outcomes from HoQ. In order to overcome this complexity, these authors have proposed the TQFD technique. TQFD stipulates the development of five different matrices in stages. In each stage, the total involvement of the cross-functional team members in translating customers’ vague languages into technical languages is ensured. The first matrix is customer reaction matrix and the fifth matrix is planning and control chart. From the planning and control chart, the work instructions are drawn which need to be implemented after obtaining the endorsement of the top management. The unique features of TQFD technique is that, the personnel with no or little literacy can participate in TQFD project and supply solutions. Another unique feature of this technique is that, the solution is practically implemented through the development and execution of work instructions. These authors have explained the application of TQFD in a pump manufacturing company. It has been pointed out that all matrices and work instructions are useful to the users at different levels. For example, the component deployment matrix is useful for gathering about the changes to be made technically in the components to both senior level managerial and non-managerial personnel. Likewise, work instructions are useful to the operators for knowing the exact actions to be taken against the customer language. Altogether, TQFD is prone to be a highly practically compatible and powerful technique in translating ‘voice of customers’ into technical parameters and values, and also executing the same in practice.

Kathiravan et al. (2008) reported a study on implementing TQFD in a rubber manufacturing company by name The Indiar Block Rubber Factory (hereafter, shortly referred to as Indiar). Indiar is situated in the Kerala state of India. The beginning of this study was marked by the gathering of information about the steps carried out at Indiar to process rubber. In continuation to this information gathering exercise, the complaints and grievances that reflected the ‘voice of the customers’ were gathered. This exercise resulted in the identification of ten voices of customer. These voices of customer were entered into customer requirement matrix. In this matrix, the importance of each voice of the customer was indicated using a scale of range 0–10. In this scale, ‘0’ meant ‘not at all important’ and ‘10’ meant ‘most important’. Subsequently, product deployment/modification matrix, component deployment matrix, planning and control chart and work instructions were

Table 2 Quantitative and qualitative assessments on the complexities of implementing six advanced models of QFD

Advanced models of QFD	Concept	Paper	Number of steps (quantitative assessment)	Qualitative assessments on procedural and computational complexities
Fuzzy QFD	This advanced model of QFD is integrated with fuzzy concepts, for quantifying vague statements using crisp values	Chen and Ko (2009)	7	High
		Kuo et al. (2009)	6	
		Lin (2010)	5	
		Liu (2009)	7	
		Ramasamy and Selladurai (2004)	7	
		Sen and Baracli (2010)	7	
		Sener and Karsak (2011)	7	
Kano based QFD	Customers' perceptions are categorised by employing Kano model in the QFD process	Lee et al. (2008)	9	Medium
AHP integrated QFD models	AHP technique is linked with the HoQ of QFD	Ho et al. (2011)	13	Very high
		Ho et al. (2012)	13	
ANP integrated QFD models	ANP is linked with the HoQ of QFD	Liu and Wang (2010)	6	High
		Zaim et al. (2014)	6	
PQFD	Using the 'Requirements matrices' and 'resources matrices', HoQ is developed. Then cost benefit analysis is carried out. The results are finally derived	Chao and Ishii (2004)	4	Moderate
TQFD	Simplest form of QFD. The collected data are used directly. Work instructions are developed by referring to planning and control matrix. Work instructions clearly point out the activities to be carried out in practice to fulfil the desires of customers	Devadasan et al. (2006)	6	Simple

developed. In the work instructions, the actions to be taken at the work place by the operators were indicated. This study revealed the practical feasibility of implementing TQFD in a rubber processing company. Also, the conduct of this study revealed that TQFD can be used as a vehicle to unearth the voices of the customer and identify the actions to be taken by the operators through the spontaneous formation of teams. As the actual implementation of the actions specified in the work instructions could not be implemented at Indiar, the overall opinions of the executives on the implementation of TQFD were gathered. As the opinions of these executives were encouraging, it was construed that TQFD is a simple and practically feasible technique that can be used to translate the 'voice of customers' into technical parameters and values, and put them into practice.

Altogether, the researches reported in the above two papers have indicated that TQFD is a simple and practically compatible technique. Particularly, its capability in enabling the participation of all kinds of employees possessing or not possessing educational qualifications is highly noteworthy.

4 Complexities of implementing advanced models of QFD

After studying the features of the six advanced models of QFD, the requirements for applying them in practice were studied. These studies were made from the point of view of the complexity of the procedures and computations involved while implementing these advanced models of QFD in real time scenario. This perspective was chosen based on a deficiency of QFD which has been apprised by many researchers. According this deficiency, the procedure and computation involved in developing HoQ in practice are complex enough to prevent the successful implementation of QFD. This appraisal suggests that it is preferable to employ an advanced model of QFD which requires following least complex procedure and carry out simple computations. Hence, at the end of conducting the literature review being presented here, the complexities of implementing the six advanced models of QFD were quantitatively and qualitatively assessed. These assessments of advanced models of QFD from the perspective of procedural and computational complexities involved in applying them in practice are summarised in Table 2.

As shown in Table 2, except TQFD and PQFD, other advanced QFD models stipulate the conversion of the gathered data using concepts like fuzzy and AHP, and then to identify the technical parameters and values. Though the adoption of fuzzy and AHP concept is not stipulated in PQFD, its implementation requires the construction of two houses of quality. This aspect increases the complexity of applying PQFD in real time practice. Though these advanced models enhance the accuracy of the data gathered, these advanced models of QFD fail to indicate the exact activities to be carried out in real time scenario in response to the voice of customers. In the case of TQFD, not only the procedure stipulated is simple enough to use the gathered data directly, it also facilitates the implementation of technical parameters and their values in the real time scenario through the evolving of work instructions. These work instructions are required to be endorsed by the competent authorities. This endorsement ensures that the voice of customers is not only translated but also is executed in practice. In the context of drawing this inference, it is suggested to a adopt TQFD in practical scenario to achieve the goals of applying QFD technique. Particularly, the application of TQFD would be highly beneficial in companies wherein adequate literacy among the management and employees is absent to follow complex procedures and carry out complex computations for achieving the goals of QFD.

5 Conclusion

QFD emerged in Japan in 1970s (Liu and Wang 2010). Thereafter it was applied in many companies situated in many parts of the world (Zaim et al. 2014). In the initial period of its development, QFD was largely applied in manufacturing companies. Later on, QFD was applied in several other fields like healthcare, finance and services (Chan and Wu 2002; Gremyr and Raharjo 2013). Several benefits reaped by implementing QFD in real time practice have been reported by both researchers and practitioners. Yet, from 1980s, these professionals began to point out the need for evolving advanced models of QFD. One reason for this appraisal is that QFD is highly biased towards its application in manufacturing engineering scenario and hence, when it is required to implement in non-manufacturing engineering fields, its framework needs to be modified to suit such applications. The second reason is that it was found that integration of QFD with other techniques like FMEA would produce benefits which are manifold in comparison to that are reaped by implementing QFD and other techniques separately. Third reason is that the researchers have identified certain drawbacks of QFD which are required to be overcome by evolving appropriate advanced models. Due to these three reasons, researchers have evolved numerous advanced models of QFD.

Out of the three reasons mentioned, the third reason is very sensitive, as the primary objective of QFD is to initiate action in practical scenario that would meet the customer requirements. Particularly, the computational complexity involved in developing the HoQ of QFD as pointed by the researchers deserves special attention. In this background, it is necessary to examine the capability of the advanced models in overcoming the drawbacks of QFD as appraised by the researchers. From this perspective, the literature review reported in this paper was carried out. While carrying out this literature review, it was found that many researchers have been incorporating fuzzy logic principles with QFD. In continuation to this kind of research, a few more researchers began to integrate ANP and AHP with QFD and fuzzy logic principles (Zaim et al. 2014). In this direction, Wu and Shieh (2008) have reported a research in which Markov chain model was used while applying of QFD to improve the accuracy of the relationships between 'WHATs' and HOWs' of HoQ. A critical study of these advanced models has indicated that the researchers who have been developing these models strive to enhance the precision and accuracy of the outcomes of QFD technique.

The examination of the results of the literature review reported in this paper has revealed that despite enhancing the precision and accuracy of translating customer vague languages into practical languages, the advanced models of QFD evolved by the researchers are encompassed with computational complexity. In the context of this observation, at the end of conducting this literature review, the advanced models of QFD were critically studied from the point of view of the number of steps and complexity of procedural and computational steps involved in implementing them. The results of this examination facilitated to answer to the research question 'What is the practically viable and powerful advanced model that can be employed in an environment wherein educational level is insufficient to compute complex computations?'. The quest for getting answer to this question ended with the completion of the literature review reported in this paper by identifying the TQFD technique. In comparison to other five advanced models of QFD whose features were studied during the conduct of this literature review, it was found that TQFD technique involves minimum number of steps and very simple computations. In this background, the authors of this paper, suggest that instead of applying complex advanced models of QFD integrated with principles like fuzzy and AHP, it would be beneficial to adopt the simple, modified and refined model QFD namely TQFD in practical environments in which adequate literacy is not prevailing amongst many employees to carry out complex computations and steps. Through the several stages of its execution, TQFD is prone to facilitate the successful reaping of the benefits QFD which will be reflected in the form of 'work instructions'. These work instructions will in turn facilitate the implementation of technical parameters and values translated from the voice of the customers in the practical scenario.

References

Akao, Y., Mazur, G.H.: The leading edge in QFD: past, present and future. Int. J. Qual. Reliab. Manag. **20**(1), 20–35 (2003)

Andronikidis, A., Georgiou, A.C., Gotzamani, K., Kamvysi, K.: The application of quality function deployment in service quality management. TQM J. **21**(4), 319–333 (2009)

Aytac, A., Deniz, V.: Quality function deployment in education: a curriculum review. Qual. Quant. **39**, 507–514 (2005)

Bouchereau, V., Rowlands, H.: Methods and techniques to help quality function deployment (QFD). Benchmarking **7**(1), 8–19 (2000)

Buyukozkan, G., Berkol, C.: Designing a sustainable supply chain using an integrated analytic network process and goal programming approach in quality function deployment. Expert Syst. Appl. **38**, 13731–13748 (2011)

Buyukozkan, G., Cifci, G.: An integrated QFD framework with multiple formatted and incomplete preferences: a sustainable supply chain application Gülc. Appl. Soft Comput. **13**, 3931–3941 (2013)

Chan, L.-K., Wu, M.-L.: Quality function deployment: a literature review. Eur. J. Oper. Res. **143**, 463–497 (2002)

Chao, L.P., Ishii, K.: Project quality function deployment. Int. J. Qual. Reliab. Manag. **21**(9), 938–958 (2004)

Chen, L.-H., Ko, W.-C.: Fuzzy approaches to quality function deployment for new product design. Fuzzy Sets Syst. **160**(18), 2620–2639 (2009)

Devadasan, S.R., Kathiravan, N., Thirunavukkarasu, V.: Theory and practice of total quality function deployment: a perspective from a traditional pump-manufacturing environment. Total Qual. Funct. Deploy. **18**(2), 143–161 (2006)

Ding, J.-F.: Applying fuzzy quality function deployment (QFD) to identify solutions of service delivery system for port of Kaohsiung. Qual. Quant. **43**, 553–570 (2009)

Gremyr, I., Raharjo, H.: Quality function deployment in healthcare: a literature review and case study. Int. J. Health Care Qual. Assur. **26**(2), 135–146 (2013)

Ho, W., Dey, P.K., Lockstrom, M.: Strategic sourcing: a combined QFD and AHP approach in manufacturing. Supply Chain Manag. **16**(6), 446–461 (2011)

Ho, W., He, T., Lee, C.K.M., Emrouznejad, A.: Strategic logistics outsourcing: An integrated QFD and fuzzy AHP approach. Expert Syst. Appl. **39**(12), 10841–10850 (2012)

Iqbal, Z., Grigg, N.P., Govinderaju, K., Campbell-Allen, N.: Statistical comparison of final weight scores in quality function deployment (QFD) studies. Int. J. Qual. Reliab. Manag. **31**(2), 184–204 (2014)

John, R., Smith, A., Chotipanich, S., Pitt, M.: Awareness and effectiveness of quality function deployment (QFD) in design and build projects in Nigeria. J Facil. Manag. **12**(1), 72–88 (2014)

Kamvysi, K., Gotzamani, K., Andronikidis, A., Georgiou, A.C.: Capturing and prioritizing students' requirements for course design by embedding Fuzzy-AHP and linear programming in QFD. Eur. J. Oper. Res. **237**(3), 1083–1094 (2014)

Kamvysi, K., Gotzamani, K., Georgiou, A.C., Andronikidis, A.: Integrating DEAHP and DEANP into the quality function deployment. TQM J. **22**(3), 293–316 (2010)

Kathiravan, N., Devadasan, S.R., Michael, T.B., Goyal, S.K.: Total quality function deployment in a rubber processing company: a sample application study. Prod. Plan. Control **19**(1), 53–66 (2008)

Khoo, L.P., Ho, N.C.: Framework of a fuzzy quality function deployment system. Int. J. Prod. Res. **34**(2), 299–311 (1996)

Kim, K.-J., Moskowitz, H., Dhingra, A., Evans, G.: Fuzzy multicriteria models for quality function deployment. Eur. J. Oper. Res. **121**, 504–518 (2000)

Kuo, C.-M., Yuo, S.-H., Lu, C.Y.: Integration of the Kano and QFD model in health food development: using black beans as examples. Qual. Quant. (2012). doi:10.1007/s11135-012-9762-8
Kuo, T.-C., Wu, H.-H., Shieh, J.-I.: Integration of environmental considerations in quality function deployment by using fuzzy logic. Expert Syst. Appl. **36**(3), 7148–7156 (2009)
Lee, Y.-C., Sheu, L.-C., Tsou, Y.-G.: Quality function deployment implementation based on Fuzzy Kano model: an application in PLM system. Comput. Ind. Eng. **55**, 48–63 (2008)
Li, M., Jin, L., Wang, J.: A new MCDM method combining QFD with TOPSIS for knowledge management system selection from the user's perspective in intuitionistic fuzzy environment. Appl. Soft Comput. J. **21**, 28–37 (2014)
Liang, G.-S.: Applying fuzzy quality function deployment to identify service management requirements for customer quality needs. Qual. Quant. **44**, 47–57 (2010)
Liao, C.-N., Kao, H.-P.: An evaluation approach to logistics service using fuzzy theory, quality function development and goal programming. Comput. Ind. Eng. **68**, 54–64 (2014)
Lin, L.-Z.: A perceptual measure of trade shows using fuzzy quality deployment development. Expert Syst. Appl. **37**(5), 3921–3933 (2010)
Lin, Y., Cheng, H.-P., Tseng, M.-L., Tsai, J.C.C.: Using QFD and ANP to analyze the environmental production requirements in linguistic preferences. Expert Syst. Appl. **37**(3), 2186–2196 (2010)
Liu, H.-T., Wang, C.-H.: An advanced quality function deployment model using fuzzy analytic network process. Appl. Math. Model. **34**(11), 3333–3351 (2010)
Liu, H.-T.: The extension of fuzzy QFD: from product planning to part deployment. Expert Syst. Appl. **36**(8), 11131–11144 (2009)
Liu, Y., Zhou, J., Chen, Y.: Using fuzzy non-linear regression to identify the degree of compensation among customer requirements in QFD. Neurocomputing **142**, 115–124 (2014)
Mehrjerdi, Y.Z.: Applications and extensions of quality function deployment. Assem. Autom. **4**, 388–403 (2010a)
Mehrjerdi, Y.Z.: Quality function deployment and its extensions. Int. J. Qual. Reliab. Manag. **27**(6), 616–640 (2010b)
Politis, J.D.: QFD, organisational creativity and productivity. Int. J. Qual. Reliab. Manag. **22**(1), 59–71 (2005)
Prasad, K.G.D., Subbaiah, K.V., Rao, K.N.: Supply chain design through QFD based optimization. J. Manuf. Technol. Manag. **25**(5), 712–733 (2013)
Raharjo, H., Chai, K.H., Xie, M., Bramoacher, A.C.: Dynamic benchmarking methodology for quality function deployment. Benchmarking **17**(1), 27–43 (2010)
Raharjo, H.: On normalizing the relationship matrix in quality function deployment. Int. J. Qual. Reliab. Manag. **30**(6), 647–661 (2013)
Rajiv, P., Logesh, R., Vinodh, S., Rajanayagam, D.: Financial feasibility and value engineering principles integrated quality function deployment for a manufacturing organization: a case study. J. Eng. Design Technol. **12**(1), 71–88 (2010)
Ramasamy, N.R., Selladurai, V.: Fuzzy logic approach to prioritise engineering characteristics in quality function deployment (FL-QFD). Int. J. Qual. Reliab. Manag. **21**(9), 1012–1023 (2004)
Sen, C.G., Baracli, H.: Fuzzy quality function deployment based methodology for acquiring enterprise software selection requirements. Expert Syst. Appl. **37**, 3415–3426 (2010)
Sener, Z., Karsak, E.E.: A combined fuzzy linear regression and fuzzy multiple objective programming approach for setting target levels in quality function deployment. Expert Syst. Appl. **38**(4), 3015–3022 (2011)
Shaik, A.M., Rao, V.V.S.K., Rao, C.S.: Development of modular manufacturing systems: a review. Int. J. Adv. Manuf. Technol. **76**(5–8), 789–802 (2014)
Shen, X.X., Tan, K.C., Xie, M.: An integrated approach to innovative product development using Kano's model and QFD. Eur. J. Innov. Manag. **3**(2), 91–99 (2000)
Vinayak, K., Kodali, R.: Benchmarking the quality function deployment models. Benchmarking **20**(6), 825–854 (2013)
Vinodh, S., Chintha, S.K.: Application of fuzzy QFD for enabling agility in a manufacturing organization A case study. TQM J. **23**(3), 343–357 (2011)
Wolniak, E.R., Sedek, A.: Using QFD method for the ecological designing of products and services. Qual. Quant. **43**, 695–701 (2009)
Wu, H.-H., Shieh, J.-I.: Applying a markov chain model in quality function deployment. Qual. Quant. **42**, 665–678 (2008)
Wu, Q.: Fuzzy measurable house of quality and quality function deployment for fuzzy regression estimation problem. Expert Syst. Appl. **38**, 14398–14406 (2011)

Yang, Y.Q., Wang, S.Q., Dulaimi, M., Low, S.P.: A fuzzy quality function deployment system for buildable design. Autom. Constr. **12**, 381–393 (2003)
Zaim, S., Sevkli, M., Camgöz-Akdag, H., Demirel, O.F., Yayla, A.Y., Delen, D.: Use of ANP weighted crisp and fuzzy QFD for product development. Expert Syst. Appl. **41**, 4464–4474 (2014)
Zhang, F., Yang, M., Liu, W.: Using integrated quality function deployment and theory of innovation problem solving approach for ergonomic product design. Comput. Ind. Eng. **76**, 60–74 (2014)