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Use of ANP weighted crisp and fuzzy QFD for product development

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ABSTRACT

Quality Function Deployment (QFD) is a popular planning method often used to transform customer demands/requirements into the technical characteristics of a new or improved product or service. In order to better capture (and represent) the multifarious relationships between customer requirements and technical characteristics, and the relative weights among customer requirements, in this study a hybrid analytic network process (ANP)-weighted fuzzy methodology is proposed. The goal is to synthesize renowned capabilities of ANP and fuzzy logic to better rank technical characteristics of a product (or a service) while implementing QFD. To demonstrate the viability of the proposed methodology a real-world scenario, where a new equipment to squeeze the polyethylene pipes to stop the gas flow without damaging the pipes, is developed. The ranking of technical characteristics of the product is calculated using both crisp and fuzzy weights for illustration and comparison purposes.

1. Introduction

Successful and innovative product (or service) development is highly correlated with the company's success and reason for existence. It is imperative that a company's main purpose for existing is to provide goods and/or services to meet and even exceed the expectations of their customers. In order to be successful, companies must choose goods and/or services in which to establish a competitive advantage, and by doing so, differentiate themselves from their competitors (Smith, 2011). Product quality improvements are crucial factors for companies to gain and sustain competitive advantage. The Profit Impact of Marketing Strategy (PIMS) claims that improvements in product quality go along with customer loyalty, higher market share and higher profits (Lemmink & Kasper, 1994). Innovation and New Product Development (NPD) are considered important ingredients for economic development (Schumpeter, 1934) corporate growth and survival (Drucker, 1985).

There are many manufacturing and design techniques and strategies companies utilize to develop new products (Biswas & Sarker, 2008; Browning & Heath, 2009; Cavaleri, 2008; Chan & Kumar, 2009; Grewal, 2008). Some businesses may organize product development teams that are responsible for new product from conceptualization to getting the final product in store shelves (Smith & Offodile, 2008). While developing new products or improving existing products companies can choose to use one or more of the design methods, such as robust design (Boylan & Cho, 2013), modular design (Chang, Wang, & Wang, 2013), Computer Aided Design (CAD) (Naranje & Kumar, 2014), 3-D object modeling (Alves & Bártolo, 2008), Computer-Aided Manufacturing (CAM) (Kimura, 2013), virtual reality (Ore, Wiktorsson, Hanson, & Eriksson, 2014), value analysis (Smals & Smits, 2012) and Quality Function Deployment (QFD) (Chen, Chen, & Lın, 2004; Graner & Mißler-Behr, 2013; Li, 2013). According to the study conducted by Li et al. (2011), companies use a variety of methods to determine the final importance rating of customer requirements; these methods include point scoring scale (Hauser & Clausing, 1988), conjoint analysis (Griffin & Hauser, 1993), Analytic Hierarchy Process (AHP) (Armacost, Componation, Mullens, & Swart, 1994; Govers, 1996; Ho, 2008; Lu, Madu, Kuei, & Winokur, 1994; Wasserman, 1993), fuzzy AHP (Chan, Kao, Ng, & Wu, 1999; Kwong & Bai, 2002; Kwong & Bai, 2003; Wang, 1999), analytic network process (ANP)

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(Ertay, Kahraman, & Ruand, 2005; Karsak, Sozer, & Alpteki, 2002; Partovi, 2006; Partovi, 2007; Partovi & Corredoira, 2002; Raharjo, Brombacher, & Xie, 2008), fuzzy ANP (Buyukozkan, Feyzioğlu, & Ruan, 2004; Kahraman, Ertay, & Buyukozkan, 2006; Liu & Wang, 2010), fuzzy weighted average (Chen, Fung, & Tang, 2006; Khoo & Ho, 1996), gray model (Wu, 2006), evidential reasoning based approach (Chin, Wang, Yang, & Poon, 2008), rough set based approach (Li, Tang, Luo, & Xu, 2009; Zhai, Khoo, & Zhong, 2007; Zhai, Khoo, & Zhong, 2009), rough set enhanced fuzzy approach (Zhai, Khoo, & Zhong, 2008) and group decision- making approach (Ho, Lai, & Chang, 1999; Liu & Wu, 2007; Liu & Wu, 2008). Li et al. (2011) also added that in most of the QFD research studies, relationships and correlations among/between the features and specifications are determined using simple scaling methods. In order to more accurately capture and represent these relationships and correlations, several researchers have proposed the use advanced ranking/scaling methods, such as swing method (Park & Kim, 1998), Design Of Experiment (DOE) (Dawson & Askin, 1999), Taguchi method (Kumar, Barua, & Gaindhar, 2000), linear partial ordering approach (Han, Kim, & Choi, 2004), fuzzy regression (Fung, Chen, & Tang, 2006; Kim, Moskowitz, Dhingra, & Evans, 2000), evidential reasoning based approach (Chin et al., 2008) and ANP (Abbasi, Hosnavi, & Tabrizi, 2013; Horenbeek & Pintelon, 2014; Lee, Wu, Hu, & Flyn, 2013).

A popular and proven way to determine what customers want and how to channel their wants into a product design is through the QFD. According to Heizer and Render (2008), QFD helps to translate customer needs into engineering specifications for a product by prioritizing each product attribute/feature while simultaneously setting development targets for the same product. The House of Quality (HOQ), for example, is a popular tool used by QFD wherein visually appealing graphical illustrations are used to define the relationships between customer desires and the product features (Smith, 2011). The use of QFD has gained extensive international support for helping decision-makers (DMs') in product planning and improvement (Akao & Mazur, 2003; Chan & Wu, 2002; Chien, Chen, & Peng, 2010; Hajji, Mhada, Gharbi, Pellerin, & Malhame, 2011; Karipidis, 2011; Lin, Cheng, Tseng, & Tsai, 2010b; Lin, Yang, Chan, & Sheu, 2010a; Wong & Lai, 2011; Xie, Tan, & Goh, 2003). AHP has been used as the quantitative tool to augment QFD (Cheng & Lin, 2002). An integrated QFD–AHP approach can be successfully used in identifying and prioritizing customer requirements, dealing with complex situations, and rank ordering product features (Fiorenzo, 2001).

Research on fuzzy QFD has received a considerable amount of attention in the last couple of dacades (Harding, Popplewell, Fung, & Omar, 2001; Temponi, Yen, & Tiao, 1999), and made substantial progress. Khoo and Ho (1996) proposed an approach centred on the application of possibility theory and fuzzy arithmetic to address the ambiguity in QFD operations (Bevilacqua, Ciarapicab, & Giacchettab, 2006). Fuzzy approaches can be applied to formulate the relationships between customer requirements and engineering design requirements, and among design requirements (Cheng & Weng, 2006; Shen, Tan, & Xie, 2001). Ramasamy and Selladurai (2004) developed a fuzzy QFD for translating the Voice of Customer (VOC) into engineering characteristics. Yang, Wang, Dulaimi, and Low (2003) have proposed a fuzzy QFD system for buildable designs based on mechanisms of the conventional QFD methodology. The differences between the fuzzy QFD system and the traditional QFD methodology is that the QFD relevant data are expressed and represented as linguistic terms rather than crisp numbers, and the linguistic data is processed by algorithms embedded in the system's internal environment (Mehrjerdi, 2010).

In addition to AHP, the ANP technique, also developed by Saaty, is a generic form of the AHP that allows for more complex, interdependent, relationships, and feedback among elements in the hierarchy (Saaty, 2001). The ANP has been proposed as a suitable Multi Criteria Decision Analysis (MCDA) tool to evaluate multiple alternatives during the conceptual planning and design of remedial countermeasures (Promentilla, Furuichi, Ishii, & Tanikawa, 2006; Promentilla, Furuichi, Ishii, & Tanikawa, 2005). Due large to its late arrival, and not being recognized as a competitive tool, the ANP technique is not nearly as prominent and widely used in the MCDA literature as the AHP technique (Partovi, 2001). According to Shee, Tzeng, and Tang (2003), most of the traditional Multi Attribute Decision Making methods (MADM) are based on the additive concept along with the independence assumptions, but each individual criterion is not always completely independent. Even though AHP has a number of benefits it still has some inherent limitations due to its hierarchical representation (Anand & Kodali, 2009). Sarkis and Talluri (2002) have listed the limitations of AHP such as; each element in the hierarchy is supposed to be independent and a relative ratio scale of measurement is derived from pair-wise comparisons of the elements in a level of the hierarchy with respect to an element of the preceding level. However, in many cases, there is interdependence among criteria and alternatives (Sarkis & Talluri, 2002). The second limitation Sarkis and Talluri (2002) mentioned was that AHP employs a unidirectional hierarchical relationship among decision levels, which implies no influence of lower levels on the upper levels. But it may be possible for the components of the two levels to influence each other. These relationships cannot be evaluated using AHP (Sarkis & Talluri, 2002). To overcome these problems, Anand and Kodali (2009) suggested to use ANP in solving the complex decision problem for their case.

The local priorities in ANP are established in the same manner as they are in AHP using pair wise comparisons and judgments (Promentilla, Furuichi, Ishii, & Tanikawa, 2008). However, the super matrix approach, which became popularly known as the ANP approach, is becoming an attractive tool to understand more of the complex decision problem as it overcomes the limitation of the AHP's linear hierarchy structure (Saaty, 1996; Saaty, 2001). ANP also allows for the consideration of the interdependencies among and between the levels of attributes and alternatives (Partovi, 2001). To strengthen its capabilities, Partovi (2001) added that ANP does involve relationships hierarchically but does not require a strict hierarchical structure as AHP. Buyukozkan et al. (2004) used fuzzy ANP to prioritize design requirements by taking into account the degree of the interdependence between the customer needs and design requirements and the inner dependence among them. Mikhailov and Singh (2003) used fuzzy ANP and its application to the development of decision support systems. The aim of fuzzy ANP is to capture the 'fuzziness' or the vagueness-type uncertainties in the evaluation of remedial countermeasures particularly at the initial phase of remediation planning. (Promentilla et al., 2008).

AHP and ANP are often used in combination with other methods. For instance, Karsak et al. (2002) combined goal programming approach with ANP for product planning in QFD. Bevilacqua et al. (2006) indicated that in traditional QFD, most of the input variables are assumed to be precise and are treated as crisp numerical data. However, linguistic variables expressed in fuzzy numbers seem more appropriate for describing those inputs in QFD (Bevilacqua et al., 2006). Hisdal (1988) study indicated that in the context of rank-ordering requirements and specifications, fuzzy logic can handle inexact information and verbal variables in a mathematically well-defined way which simulates the processing of information in natural-language communication. Some researchers (Buyukozkan et al., 2004; Kahraman et al., 2006, 2004b) applied a fuzzy ANP approach to QFD problems. Their method is an extension of fuzzy AHP (FAHP) approach proposed by Chang (1996), which derives crisp local priorities from fuzzy comparison matrix using the extent analysis method and possibility theory (Promentilla et al., 2008). Liu and Tsai's study is proposed a fuzzy risk assessment method to provide a prevention and improvement technique against occupational hazards in the construction industry. This method used two-stage QFD tables to represent the relationships among construction items, hazard types and hazard causes. A fuzzy ANP method was developed to identify important hazard types and hazard causes (Liu & Tsai, 2012). Lin et al. (2010a), Lin et al. (2010b) is applied fuzzy QFD model with interdependence relations of Environmental Production Requirements (EPRs) aspects and Sustainable Production Indicators (SPIs) criteria or Original Equipment Manufacturing (OEM) firm in Taiwan. In conjunction with fuzzy sets theory and ANP, they proposed the systematic analytical procedures.

Previous studies showed that the ANP approach is capable of capturing and representing the interrelationship between and within QFD components. Furthermore, the fuzzy logic is successfully used to represent imprecise logic in rankling and ordering of factors. To enhance the design process, this study takes in to account the ANP and Fuzzy Logic to augment the process of QFD in developing a product to be used for squeezing polyethylene (PE) pipes to stop the gas flow. Traditionally, the gas flow in the PE pipes is stopped using a conventional valve structure; in addition to its extra cost it is a process that sometimes damage the pipes causing disruption to the gas flow throughout the region. To overcome this problem a new PE pipe squeezing equipment, which is capable of stopping the gas flow in PE pipes without damaging the PE pipes, is proposed to be developed. As a part of the study, the design specifications of the new PE pipe squeezing tool are identified and prioritized using both crisp- and fuzzy-weighted ANP to augment QFD technique.

The rest of the paper is organized as follows. The next section (Section 2) briefly describes the foundations of QFD, Fuzzy Logic and the ANP methods provide a comprehensive coverage of the related literature. Section 3, presents the proposed ANP weighted crisp and fuzzy QFD methodology. Section 4, lists and discusses the findings of the study and Section 5, concludes the paper with final remarks.

2. Background information on QFD, fuzzy logic and ANP methods

To establish the foundation for the proposed methodology, this section aims to briefly describe the QFD, Fuzzy Theory, Fuzzy Numbers and ANP methods.

2.1. Quality Function Deployment (QFD) technique

QFD was found in 1966 by Akao (1990) and is successfully applied in both production and service sectors. The goal in QFD technique is to identify what customers' demands and complaints are about a certain product, service, or process; and then to determine what technical specifications should be developed in order to meet those needs of the customers. QFD also provides interrelationships and other prominent information about DOE and Statistical Process Control (SPC), both of which may be executed after the product development process. QFD is often applied using participation of people from variety of departments and backgrounds. QFD not only considers the "needs of customers", but also regulates the processes according to "capabilities of the firm".

QFD can be used for design of complex service systems, investments portfolios, and management of processes (Chan & Wu, 2004). Main advantages of QFD can be summarized as determining the correct wants of the customers (and hence improving customer satisfaction), improving production of reliable and quality products, optimizing design specifications, decreasing costs, increasing efficiency and revenue, and significantly reducing the design time. Among the most pronounces hurtles of QFD are the need for a nurturing corporate culture and highly skilled and committed managers and engineers (Akao, 1990).

HOQ, Facilitator, QFD team, VOC, and Gemba Analysis are some of the important concepts which are often associated with QFD approach. HOQ is a set of matrixes which include the comparison of customers' wants and characteristics of quality, comparisons of features of products and comparisons of characteristics of quality. Facilitator is a person who can facilitate process by leading that QFD projects. QFD team must consist of at least people who attend in a conference about QFD. Gemba analysis is a popular method used to better identify and consider the wants of the customers. The word Gemba means the place where the product is used. (Yenginol, 2000). Therefore, Gemba analysis is the procedure that involves direct observation of customers in their place of use (i.e. Gemba). Including the VOC is very important concept in the QFD methodology. Simply put, it is used to determine what to improve in the product or service design. This technique helps to integrate demands of the customers with R&D and production departments, so that the firm can successfully execute its processes (Almannai, Greenough, & Kay, 2008). In addition to accurately identifying customer demands, QFD can optimize product design, increase reliability and quality while decreasing costs (Al-Mashari, Zairi, & Ginn, 2005).

2.2. Fuzzy Theory and Fuzzy Numbers

Fuzzy sets were first introduced by Zadeh in 1965 as a means of representing and working with data that was neither precise nor complete; rather vague and incomplete (Dagdeviren & Yuksel, 2010). Fuzzy logic uses human linguistics (word or sentences) to express the knowledge of a system. This knowledge consists of facts, concepts, theories, procedures, and relationships and is expressed in the form of IF-THEN rules. Linguistic variables are characterized by ambiguity and multiplicity of meaning (Nguyen & Walker, 1999).

Kahraman, Ruan, and Dogan (2003) stated that the most critical contribution of fuzzy set theory is its capability of representing imprecise or vague data. A fuzzy set theory is defined to be a class of objects with a continuum of grades of membership. Such a set is specified by a membership (characteristic) function, which assigns a level of membership to each object, ranging between zero and one (Kahraman et al., 2003).

A triangular fuzzy number (TFN) is represented by $(l/m, m/u)$ or (l, m, u). The parameters l, m, and u refer to the smallest possible value, the most promising value, and the largest possible value, respectively. Each TFN is denoted by linear representations on its right and left sides such that its membership function μ can be defined as in Eq. (1).

$$\mu\left(\frac{x}{\widetilde{M}}\right) = \begin{cases} 0 & x < l \\ \frac{x-l}{m-l}, & l \le x \le m \\ \frac{u-x}{u-m}, & m \le x \le u \\ 0, & u \end{cases} \tag{1}$$

A fuzzy number can always be written by its corresponding left and right representation if each degree of membership as in Eq. (2)

$$\widetilde{M} = \left(M^{l(y)}, M^{r(y)}\right) = (l + (m-l)y, u + (m-u)y), \quad y \in [0,1] \tag{2}$$

where, $l(y)$ and $r(y)$ refer to the left side and right side representation of a fuzzy number, respectively. Fuzzy logic exhibits some useful features for exploitation in QFD, including (Fung et al., 2006):

- It uses human linguistic understanding to express the knowledge of the system.

- It allows decision making with estimated values under incomplete or uncertain information.
- It is suitable for uncertain or appropriate reasoning.
- Interpretation of its rules is simple and easy to understand.
- It deals with multi input and multi output system.

2.3. Analytical network process (ANP)

The AHP method is one of the most popular Multiple Criteria Decision Making (MCDM) tools for formulating and analyzing decisions. AHP, since its invention, has been a tool at the hands of DMs' and researchers (Ertugrul & Karakasoglu, 2009; Subramanian & Ramanathan, 2012).

The ANP is a general form of the AHP. Both the AHP and the ANP were introduced by Saaty (Yang, Chuang, & Huang, 2009). The ANP is a more accurate method than many other complicated models which use criteria feedback and interrelationship. The method provides a tool to evaluate all the relationships systematically by adding all interactions, interdependences, and feedbacks in Decision Making (DM) system. The powerful side of this model is to represent the DM problem that involves many complicated relationships easily. This technique is not only enabling the pair-wise comparisons of the sub-criteria under main criteria, but also is providing independent comparisons for all interacted sub-criteria. A comparison of AHP and ANP methods is presented in Fig. 1.

Problems occurred from DM cannot be explained only by a hierarchical structure. There may be an interaction between criteria and alternatives of the problem.

All interactions and feedbacks within the clusters are called inner dependencies whereas interactions and feedbacks between the clusters are called outer dependencies (Saaty, 2001). In such circumstances a complicated analysis is necessary to figure out the weights of all components. The ANP technique is used for this kind of problems which are also based on pair-wise comparisons as it is in AHP. For pairwise comparisons the 1–9 scale of Saaty (1980) is used. The ANP model defines all components and relationships which are then determined as two way interactions. The model uses a network structure and encounters the relationship of the sub-criteria with its parent cluster; in addition to this the network also considers the relationship among each cluster. The ANP method is useful for getting more accurate and effective results in such complex and crucial DM problems, due to involving relationships among sub-criteria under each cluster and interactions among different criteria.

There are four basic steps when using ANP: (1) deconstructing a problem into a complete set of hierarchical or network model; (2) generating pairwise comparisons to estimate the relative importance of various elements at each level; (3) building a super matrix to represent the influence priority of elements; and, (4) making decisions based on the super matrix (Yang et al., 2003). The ANP method includes three matrix analyses such as super matrix, weighted super matrix and limit matrix. The super matrix provides relative importance of all components, weighted super matrix is the normalized of the super matrix values and the value of each cluster. The limit matrix is the desired priorities of the criteria of the decision network with respect to the cluster. The limit matrix is obtained by raising the weighted super matrix to the power $2k + 1$ is an arbitrarily large number, allows convergence of the interdependent relationship. The results of the DM problem are gained from the limit matrix scores (Boran, Göztepe, & Yavuz, 2008). It is important to evaluate the criteria and the alternatives using experts and experienced people in order to obtain more accurate, consistent and reliable results.

In this study, ANP method is used to evaluate the alternatives according to qualitative and quantitative criteria that are evaluated by experts using direct interviews and the pair-wise comparison method.

3. The proposed ANP weighted crisp and fuzzy QFD methodology

In this study, two different approaches were used: crisp and fuzzy. In the first approach (the crisp approach), the ANP weighed QFD methodology was used to design and develop the product. In the second approach, fuzzy logic was incorporated within ANP weighed QFD. After identifying quality characteristics that pertain to the development of the new product, both crisp- and fuzzy logic-based ANP weighed QFD methods are utilized, and the results of both methods were compared and interpreted.

At the core of this study, we employed the QFD methodology for translating customer needs/wants into the quality characteristics to improve the pipe squeezing tool. The mechanism of the PE pipe squeeze-off is a rather complicated phenomenon itself (Yayla & Bilgin, 2007) and to best of our knowledge, this is one of the studies

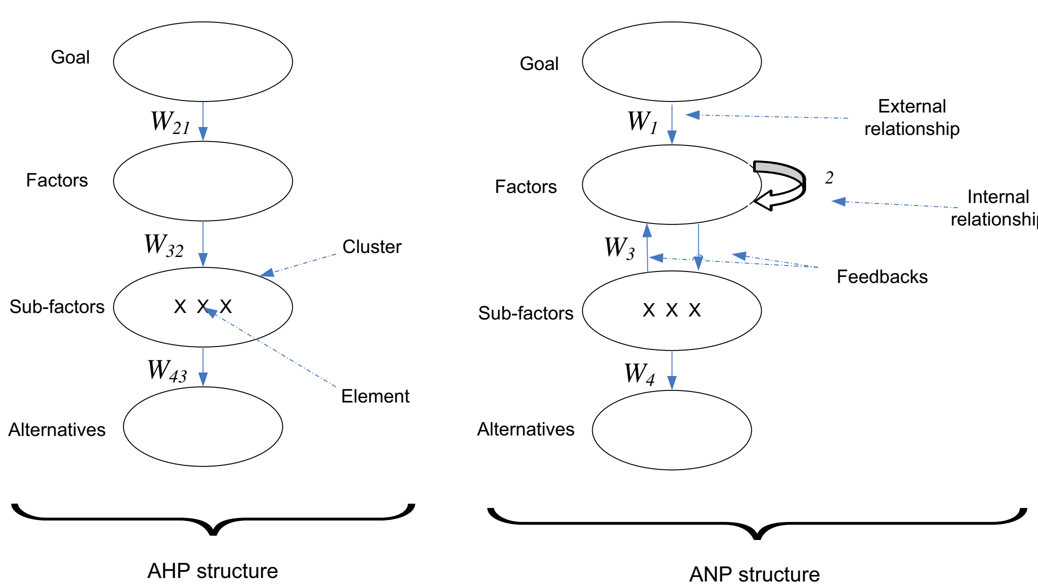

Fig. 1. AHP vs. ANP.

in the literature that employs the ANP weighted QFD technique to improve a tool of this sort for the natural gas sector. QFD is also known, and often referred to as the HOQ. QFD uses a matrix format to capture a number of issues pertinent and vital to the planning process. The QFD matrix consists of six steps. *The first step* starts with constructing a list of product demands as voiced by the customer. *The second step* of the HOQ is customers' competitive evaluations. *The next step* is to determine the quality characteristics. These quality characteristics determined for this step are measurable and controllable that impacts on one or more customer demands. *The forth step* is the correlation matrix to identify the interrelationship of each quality characteristic. *The fifth st*ep is an evaluation of the strength of the relationship between the customer demand and the technical requirements. *The last* step is the technical assessment. The output of the HOQ is not a product design but merely the requirements of the end product (Vonderembse & Raghunathan, 1997).

The proposed methodology is implemented/applied using the following three main steps for the new product design problem, details of which are explained in the previous sections.

3.1. Step 1: determine the customer demands

The initial and most critical step of the QFD process is the identification of what customers want and expect from a consumer product. In this step, customers' demands, expectations, and complaints are determined. Identified data contain current customer expectations that are critical to success and potential expectations that would excite customers. Several methods can be used to establish the customers' requirements, including: customer panels; focused group discussions; structured or unstructured customer interviews; self-completing questionnaires; in-depth customer observation; customers' complaint and compliment database; customers' service inquiries database; front-line staff feedback.

The list of customer demand is identified with literature search, and focusing on group brainstorming in the company. In the brainstorming process, group considered the complaints that are received from customer as an input. In addition a small customer group is chosen for a pilot study. Finally an open question is asked to the respondent to gather data. After collecting data, the following list is obtained. The list of the customer demands is:

- Complete stoppage of gas-flow.
- Squeezing the pipe without damaging.
- Easy to adjust for multiple pipe sizes.
- Electrical grounding.
- No need to get into trench.
- Practical secure lock.
- Durability.
- Light weight.
- Convenient and practical.
- Small in size as possible.
- Cost-effective.

3.2. Step 2: weighting the customer demand using ANP

At any one time it is unlikely that an organization can satisfy all of its customers' requirements. Therefore it is necessary to prioritize the needs that are to be met within a planning cycle systematically. The rate of importance is a rating of the customer demands calculated based on the ANP approach (Yuksel & Dagdeviren, 2007). To determine the degree of importance of each customer demand factor (within a 1–9 scale), a focus group is developed (i.e. calculate w1). The pairwise comparisons used in this study are shown in Table 1. The focus group included experts in NPD, top management of IGDAŞ, and personnel using the squeeze off tool. The results of the focus group study, the pairwise comparison values are figured out as seen in Table 1.

After normalizing the pairwise comparison values in Table 1, the summation of normalized values of each criterion provided the weight of customer demand which assumes that there is no dependence among the criteria (see Table 2).

ANP Approach assumes that there may be dependence among the customer demand factors. Determination of the inner dependence matrix of each customer demand factor with respect to the other factors by using the schematic representation of inner dependence among the customer demand factors was performed (see Fig. 1 and Table 3). Fig. 1 also shows interdependency between customer demands criteria. The directions of the arrows show that some of the customer demands are influenced by the other customer demands. For example, light weight is influenced by two criteria which are named as "Convenient and practical" and "small in size as possible." In that way, all the relationships are formed.

Inner dependence among the customer demand factors are determined by analyzing the impact of each factor on every other factor using pair-wise comparisons. Based on the inner dependencies, pairwise comparison matrices are formed and the interdependent customer demands priorities are calculated. ANP weights of customer demand are calculated by multiplying inner and inter dependence matrix by weights of customer demand under assumption of no dependency. The calculated weight of customer demand using ANP is given in Table 4.

3.3. Step 3: developing fuzzy relationship matrix between customer demands and technical requirements

In this step, determined customer demands are translated into technical requirements. The objective is to translate each customer voice into one or more technical requirements. Each technical requirement should be measurable and global in nature and should satisfy the voice of the customer (Radharamanan & Godoy, 1996).

To build the relationship matrix between 'hows' and 'whats', it is necessary to establish relationships that exist between every 'what' and every 'how'. All relationships are categorized such as either strong, medium, or weak. The relative importance and the customer rating can be linguistic or crisp variable. As mentioned, linguistic variables such as *strong relation* (s) *moderate relation* (m) and *weak relation* (w) are used to describe the relative importance instead of 9, 3 and 1. The relationship matrix is shown in Table 5.

Table 1
Pairwise comparison values.

Criteria[a]	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
C1	1	2	4	1	6	5	8	3	7	8	9
C2	1/2	1	3	1/2	5	4	7	2	6	7	8
C3	1/4	1/3	1	1/4	3	2	5	1/2	4	5	7
C4	1	2	4	1	6	5	8	3	7	8	9
C5	1/6	1/5	1/3	1/6	1	1/2	3	1/4	5	3	7
C6	1/5	1/4	½	1/5	2	1	4	1/3	3	4	5
C7	1/8	1/7	1/5	1/8	1/3	1/4	1	1/6	1/2	1	2
C8	1/3	1/2	2	1/3	4	3	6	1	4	5	6
C9	1/7	1/6	¼	1/7	1/5	1/3	2	1/4	1	2	3
C10	1/8	1/7	1/5	1/8	1/3	1/4	1	1/5	1/2	1	2
C11	1/9	1/8	1/7	1/9	1/7	1/5	1/2	1/6	1/3	1/2	1

[a] C1: Complete stoppage of gas-flow; C2: Squeezing the pipe without damaging it; C3: Easy to adjust for multiple pipe sizes; C4: Electrical grounding; C5: No need to get into trench; C6: Practical secure lock; C7: Durability; C8: Light weight; C9: Convenient and practical; C10: Small in size as possible; C11: Cost-effective.

Table 2
AHP Weights of customer demand under assumption of no dependency.

Customer demands (criteria)		Weights
C1	Complete stoppage of gas-flow	0.224
C2	Squeezing the pipe without damaging	0.158
C3	Easy to adjust for multiple pipe sizes	0.085
C4	Electrical grounding	0.224
C5	No need to get into trench	0.054
C6	Practical secure lock	0.060
C7	Durability	0.021
C8	Light weight	0.109
C9	Convenient and practical	0.029
C10	Small in size as possible	0.021
C11	Cost-effective	0.015

[#] C1: Complete stoppage of gas-flow; C2: Squeezing the pipe without damaging it; C3: Easy to adjust for multiple pipe sizes; C4: Electrical grounding; C5: No need to get into trench; C6: Practical secure lock; C7: Durability; C8: Light weight; C9: Convenient and practical; C10: Small in size as possible; C11: Cost-effective.

Table 3
Inner and Inter dependency matrix.

Criteria[a]	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
C1	1	0.5	0	0	0	0	0	0	0	0	0
C2	0	0.5	0	0	0	0	0	0	0	0	0
C3	0	0	0.5	0	0	0	0	0	0	0	0
C4	0	0	0	1	0	0	0	0	0	0	0.5
C5	0	0	0	0	0.5	0	0	0	0	0	0
C6	0	0	0	0	0	0.5	0	0	0	0	0
C7	0	0	0	0	0	0	0.5	0	0	0	0
C8	0	0	0	0	0	0	0.5	0.5	0	0	0
C9	0	0	0.5	0	0.5	0.5	0	0.375	0.5	0	0
C10	0	0	0	0	0	0	0	0.125	0.5	1	0
C11	0	0	0	0	0	0	0	0	0	0	0.5

[a] C1: Complete stoppage of gas-flow; C2: Squeezing the pipe without damaging it; C3: Easy to adjust for multiple pipe sizes; C4: Electrical grounding; C5: No need to get into trench; C6: Practical secure lock; C7: Durability; C8: Light weight; C9: Convenient and practical; C10: Small in size as possible; C11: Cost-effective.

Table 4
ANP weights of customer demand.

Customer demands (criteria)	Weights	
C1	Complete stoppage of gas-flow	0.303
C2	Squeezing the pipe without damaging	0.079
C3	Easy to adjust for multiple pipe sizes	0.042
C4	Electrical grounding	0.232
C5	No need to get into trench	0.027
C6	Practical secure lock	0.030
C7	Durability	0.010
C8	Light weight	0.065
C9	Convenient and practical	0.155
C10	Small in size as possible	0.049
C11	Cost-effective	0.007

[#] C1: Complete stoppage of gas-flow; C2: Squeezing the pipe without damaging it; C3: Easy to adjust for multiple pipe sizes; C4: Electrical grounding; C5: No need to get into trench; C6: Practical secure lock; C7: Durability; C8: Light weight; C9: Convenient and practical; C10: Small in size as possible; C11: Cost-effective.

In crisp approach, individual ratings are calculated and then translated into normalized value. Calculation of individual ratings is given below:

Leaking rate:

$$\sum_{j}^{11} A_{1j}X_j = (0.303 \times 9) + (0.079 \times 0.0) + (0.042 \times 0.0) + (0.232 \times 0.0) + (0.027 \times 0.0) + (0.030 \times 0.0) + (0.010 \times 0.0) + (0.065 \times 0.0) + (0.155 \times 0.0) + (0.049 \times 0.0) + (0.007 \times 0.0) = 2.731$$

All of the other ratings shown in Table 6 are calculated using the same notation above.

Individual rating values are normalized by dividing individual values into the highest mean rating value.

In the fuzzy approach which is mentioned above, one needs to translate the linguistic variables such as strong relation (s) moderate relation (m) and weak relation (w) into the fuzzy numbers, which is shown in Table 7. The ranges of linguistic values for quantifying the relationship are determined by intuition of the focus group. The group also benefited from a preliminary literature survey during this translation phase.

Individual ratings are calculated and then translated into normalized individual ratings as follows:

Leaking rate

$$\begin{aligned}\sum_{j}^{11} A_{1j}X_j &= (0.303 \times 0.6; 0.303 \times 0.9; 0.303 \times 1.00)\\ &+ (0.079 \times 0.0; 0.079 \times 0.0; 0.079 \times 0.00)\\ &+ (0.042 \times 0.0; 0.042 \times 0.0; 0.042 \times 0.00)\\ &+ (0.232 \times 0.0; 0.232 \times 0.0; 0.232 \times 0.00)\\ &+ (0.027 \times 0.0; 0.027 \times 0.0; 0.027 \times 0.00)\\ &+ (0.030 \times 0.0; 0.030 \times 0.0; 0.030 \times 0.00)\\ &+ (0.010 \times 0.0; 0.010 \times 0.0; 0.010 \times 0.00)\\ &+ (0.065 \times 0.0; 0.065 \times 0.0; 0.065 \times 0.00)\\ &+ (0.155 \times 0.0; 0.155 \times 0.0; 0.155 \times 0.00)\\ &+ (0.049 \times 0.0; 0.049 \times 0.0; 0.049 \times 0.00)\\ &+ (0.007 \times 0.0; 0.007 \times 0.0; 0.007 \times 0.00)\\ &= (0.182; 0.273; 0.303)\end{aligned}$$

Converting Crisp value for *Leaking rate* = (0.182 + 2 × 0.273 + 0.303)/4 = 0.258.

All of the other ratings are calculated using the same notation above.

Maximum crisp value (after defuzzyfing) came out to be 0.258. Normalized Individual Rating for Leaking rate is: 0.258/0.258 = 1.000.

Other ratings are calculated using the same notation, and they are given in Table 8.

4. Results and discussion

The new PE pipe squeeze-off tool was successfully developed to stop the gas flow in PE pipes through squeezing without instigating any damage to the PE pipes. Before this product was developed, the gas flow in the PE pipes was stopped through valves, cutting all of the gas flow in the area. To overcome the problems and to improve the effectiveness and efficiency of the process, a PE pipe squeeze-off tool was developed using crisp and fuzzy analytic network process weighted quality function deployment technique. After implementing quality plan according to results of study, an improved version of the product was designed and produced, and performance of the developed product was found to be significantly better than the old one. A picture of the improved product itself is shown in Fig. 2.

After calculating weights of each technical requirement, it can be perceived which particular technical requirements are more important, and hence to be improve first, so that efforts and resources could be concentrated on them for better quality and much improved development process. Table 9 illustrates the order of importance of each technical requirement for crisp and fuzzy AHP and ANP weighted QFD approaches. In the AHP weighted QFD approach (both crisp and fuzzy), *crushing rate of pump* had the highest weight of importance. Therefore, based on this approach, it was determined as the most important technical

Table 5
The relationship matrix between customer demands and technical requirements.

Criteria[a]	Rating[b]	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15
C1	0,303	9			3											
C2	0,079		9	3	9											
C3	0,042					9										
C4	0,232						9									
C5	0,027							9								
C6	0,030									9						
C7	0,010								9		9					
C8	0,065											9				
C9	0,155												3	9		
C10	0,049														9	
C11	0,007															9

[a] C1: Complete stoppage of gas-flow; C2: Squeezing the pipe without damaging it; C3: Easy to adjust for multiple pipe sizes; C4: Electrical grounding; C5: No need to get into trench; C6: Practical secure lock; C7: Durability; C8: Light weight; C9: Convenient and practical; C10: Small in size as possible; C11: Cost-effective.
[b] T1: Leaking rate; T2: Jaw radius; T3: Squeezing speed; T4: Crushing rate of pipe; T5: Size adjusting time; T6: Grounding; T7: Distance of control squeezing; T8: Strength; T9: Set-up time for secure; T10: Product life; T11: Weight; T12: Preparation time of the equipment; T13: Positioning time onto the pipe; T14: Height; T15: Cost.

Table 6
Crisp rating scores.

Technical charactiritics	Mean (ANP) (ındividual rating)	Normalized Mean (ANP) (ındividual rating)	Mean (AHP) (ındividual rating) for AHP	Normalized Mean (AHP) (ındividual rating)
Leaking rate	2.731	1.000	2.0181	0.9618
Jaw radius	0.713	0.261	1.4255	0.6794
Squeezing speed	0.238	0.087	0.4752	0.2265
Crushing rate of pipe	1.623	0.594	2.0982	1.000
Size adjusting time	0.381	0.139	0.7611	0.3628
Grounding	2.084	0.763	2.0181	0.9618
Distance of control squeezing	0.245	0.090	0.4902	0.2336
Strength	0.093	0.034	0.1858	0.0886
Set-up time for secure	0.270	0.099	0.5391	0.2569
Product life	0.093	0.034	0.1858	0.0886
Weight	0.581	0.213	0.9768	0.4656
Preparation time of the equipment	0.465	0.170	0.0884	0.0421
Positioning time onto the pipe	1.394	0.511	0.2651	0.1263
Height	0.443	0.162	0.1883	0.0897
Cost	0.066	0.024	0.1319	0.0628

requirement to be improved first. In the quality improvement plan, after addressing the *crushing rate* of the pump problem, *leaking rate* and *grounding* were found as the next two most important technical requirements to be addressed. On the other hand, in the ANP approach, *leakage rate* was determined as the most important technical requirement for both crisp and fuzzy methodology. Since ANP takes into account both inner and inter-dependence relationships, and the previous research suggests that it is a more complete method, when there is a conflict, ANP is preferred over AHP. Inner and inter relationships for this product development is shown in Fig. 3. As explained earlier, *leakage rate* (which was weighted as the most important factor by ANP method) is deemed as very important by the domain experts to adequately meet the customer requirement of ‘‘complete stoppage of gas flow’’.

The second most important factor in the ANP approach was found to be *grounding* using the crisp methodology. However, in the fuzzy methodology, *crushing rate of pipe* was found to be the second most important factor. During the decision process, if there was a conflict between different methods (crisp vs. fuzzy), we decided to use another metric (a tiebreaker rule) to resolve the conflict and make a decision. In this study, based on the input from all parties, ‘‘difficulty of implementation of the criterion’’ was taken into consideration as the tiebreaking rule. After lengthy discussions, focus group in the new product development department concluded that implementation of *grounding* is easier than the *crushing rate of pipe*; therefore, *grounding* is selected as the second important criterion to be considered. *Crushing rate of pipe* was also found as the second most important criterion in the crisp and fuzzy AHP weighted QFD approaches. According to the QFD improvement plan, AHP and ANP approaches provide different criteria as the most important factors to be improved. These two criteria which are named *crushing rate of pipe* and *leakage rate* had a negative and strong correlation between them. Therefore, it was not easy to carry out both of them at the same time.

Table 7
Definition of linguistic variables.

Linguistic variables	Fuzzy Number
Strong relation (9)	[0.60; 0.90; 1.00]
Moderate relation (3)	[0.30; 0.55; 0.70]
Weak relation (1)	[0.00; 0.10; 0.40]

The finding indicates that *set up time for secure* was found to have more important effect on PE pipe squeeze-off tool performance in fuzzy approach as compared to crisp approach. It is also reasonable to argue that *set up time for secure* is more important than *preparation time of equipment* with respect to implementation difficulty.

There were no differences between crisp and fuzzy approaches in terms of cost criteria. The technical criteria of the PE pipe squeeze-off tool consisted of two general components, which are called cost oriented criteria and non-cost oriented criteria. All non-cost technical requirements were found to be more important than cost criteria in the new product development process, based

Table 8
Fuzzy rating scores.

Technical Characteritics	Low	Medium	Top	Defuzzy	Rating
Leaking rate	0.182	0.273	0.303	0.258	1.000
Jaw radius	0.048	0.071	0.079	0.067	0.261
Squeezing speed	0.024	0.044	0.055	0.042	0.161
Crushing rate of pipe	0.139	0.238	0.292	0.227	0.879
Size adjusting time	0.025	0.038	0.042	0.036	0.139
Grounding	0.139	0.208	0.232	0.197	0.763
Distance of control squeezing	0.016	0.025	0.027	0.023	0.090
Strength	0.006	0.009	0.010	0.009	0.034
Set-up time for secure	0.018	0.027	0.030	0.025	0.099
Product life	0.006	0.009	0.010	0.009	0.034
Weight	0.039	0.058	0.065	0.055	0.213
Preparation time of the equipment	0.046	0.085	0.108	0.081	0.315
Positioning time onto the pipe	0.093	0.139	0.155	0.132	0.511
Height	0.030	0.044	0.049	0.042	0.162
Cost	0.004	0.007	0.007	0.006	0.024

Fig. 2. A picture of the improved product.

on the objective investigation and experimentation with the two approaches. In view of the fact that the non-cost oriented factors are theoretically more important than cost oriented factors, in the new product development process, they need to be taken into account accordingly. This however is not usually a common practice in the real-world applications, especially in the developing countries, where cost and cost related factors are given high importance. The empirical results obtained in this study constitutes that both techniques provide somewhat similar and hence confirmatory results in determining the most important and less important criteria in designing the best possible product, one that complies with a large collection of technical specifications and corresponding customer requirements.

5. Conclusions

Total quality management is a philosophical approach that suggests meeting or even exceeding the expectation, and by doing so satisfying customers, through increasing the quality and productivity of goods and services. Identifying, understanding and meeting the customer expectations are very important for firms to survive/strive in the global marketplace. Carefully and s successfully considering customer expectations, and accordingly improving products and services yields higher profit and competitive

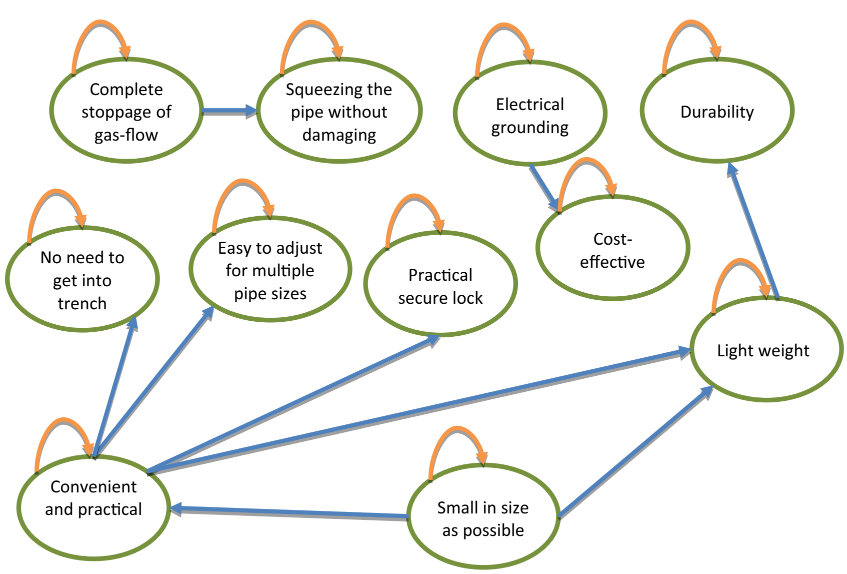

Fig. 3. Inner and inter dependence of customer demand.

Table 9
Results generated by the ANP and AHP weighted crisp and fuzzy QFD approach.

Technical characteristics	Crisp ANP	Fuzzy ANP	Crisp AHP	Fuzzy AHP
Leaking rate	1.000	1.000	0.755	0.962
Jaw radius	0.261	0.261	0.533	0.679
Squeezing speed	0.087	0.161	0.330	0.226
Crushing rate of pipe	0.594	0.879	1.000	1.000
Size adjusting time	0.139	0.139	0.285	0.363
Grounding	0.763	0.763	0.755	0.962
Distance of control squeezing	0.090	0.090	0.183	0.234
Strength	0.034	0.034	0.070	0.089
Set-up time for secure	0.099	0.099	0.202	0.257
Product life	0.034	0.034	0.070	0.089
Weight	0.213	0.213	0.366	0.466
Preparation time of the equipment	0.170	0.315	0.061	0.042
Positioning time onto the pipe	0.511	0.511	0.099	0.126
Height	0.162	0.162	0.070	0.090
Cost	0.024	0.024	0.049	0.063

advantages to companies. On the other hand, insufficient responses in meeting customer expectations cause variety of problems such as decreasing sales, diminishing profit and damaged company image. Combining new product development and quality approach, it has been demonstrated many times that one could determine customers‘ needs and wants by simply identifying the most important factor related to their products and services. An important and proven technique in quality approach is the QFT technique where one can determine customers' needs/wants and can convert these needs/wants into technical requirements for improved products and services.

In this paper we improve a pipe squeeze-off tool by using two approaches: the ANP weighted QFD and fuzzy ANP weighted QFD. The dependencies of customer needs inherent in the QFD process are taken into account using the ANP method. ANP method has been used in order to get more accurate and effective results for determining such weights of critical factors of designing the pipe squeeze-off tool. The reason of including the fuzzy logic was to better address the subjective evaluation of the experts. In fact, it has been shown that including fuzzy logic improved the representation of criteria and hence resulted in weights that better reflect on the customer requirements.

After defining the product quality characteristics of the tool to be developed using the proposed methods, the outcomes of these two methods were also compared with each other. It was shown that the use of ANP weighted QFD and fuzzy ANP weighted QFD methods provide rather effective quantitative precision to classify the product characteristics to be met, and prioritize these on the basis of customer expectations. The decision making approach presented in this work can be easily extended to other real-world applications of customer driven product development activities for making better decision of planning and evaluations of product characteristics.

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