Product development through QFD analysis using Analytical Network Process

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Abstract: This research suggest for the product development process in a manufacturing company, aiming at systematic approach of Quality Function Deployment (QFD) apply in the product design phase and using the decision making tool Analytic Network Process (ANP) in product development phase. Combining QFD and ANP approaches to provide an effective decision model in optimize product design issues. QFD is a customer-oriented design tool with cross-functional team members reaching a consensus in developing an existing product to increase customer satisfaction. QFD starts with the House of Quality (HOQ), which is a planning matrix translating the Customer Requirements (CRs), into measurable Engineering Characteristics (ECs). ANP is a strong valuation method should consider the interrelationship between ECs and CRs and inner dependency among them while determining the importance levels of ECs in the HOQ. The proposed model helps to effectively select the decision of product design and focuses on those product parts which are highly rated by customers and also revised the existing design of product that should give them a better kind of opportunity to reach customer desires. A case study was carried out of Indian manufacturing company product stainless steel submersible pump for a design process demonstrates how to use ANP in QFD matrixes.

Keywords: Quality function deployment; Analytic Network Process; House of Quality; Customer Requirements; Engineering Characteristics; Product Design

I. INTRODUCTION

In recent times, due to increased global competitions are become biggest issue in the manufacturing industries point of view. These keen challenge industries are facing quick moved by technological innovations and changing the customer demand periodically. The manufactures recognize that receiving high quality products to customer in a timely manner is a key for their survive in such an intense competitive market environment and continuous improvement to keep up rapid rate of product development phase. Product development process is an intricate managerial process that involves cross functional teams with different standpoint. To achieve above objective QFD analysis is used in initial phase of product development cycle along with cross functional team.

QFD is a team-based management tool in which the customer expectations are used to drive the product development cycle process. Inconsistent characteristics or requirements are identified early in the QFD process and can be resolved before production. QFD helps a company to attain greater control over its product development process through systematized transformations of customer requirements into product and manufacturing information [1]. Also it helps the companies to maintain their competitiveness using three strategies: decreasing costs, increasing returns, and reducing the time to produce new products (cycle time reduction) [2]. During the QFD planning process, product design team needs to know how to make a selection of design features. Due to the complexity of decision process, the design team will often rely upon unprepared procedures to assist in this product development [3]. As many researchers have pointed out, more convenient methodology is needed to get information from design team and provide an unforced evaluation of the QFD tables.

The starting point of QFD analysis is the Customer Requirements (CRs) that are then converted into Engineering Characteristics (ECs). The translation uses the matrix called the House of Quality (HOQ) which is used for identifying CRs and establishing priorities of ECs to satisfy the CRs [4]. As the four-phase based QFD model is usually used in process planning problems where more than one translation is required, in this study the HOQ method is applied [5]. It means that building a HOQ which links the CRs and ECs of an initial phase of product development it is sufficient for this study.

In the present study, a popular decision making tool is Analytic Network Process (ANP) is integrate with QFD. The reason behind the use of ANP is because there are inner dependence among CRs and ECs [6]. ANP is a good methodology to consider such inner dependencies in the QFD analysis [7]. The combining the QFD – ANP approach in product development phase to help the designer take a decisions about the product according the customers' requirements.

The rest of paper is organized in the following order. In Section 2, present the literature review on QFD and ANP approaches in product development. Section 3, we present a brief description of the HOQ. Section 4, combined the QFD – ANP method procedure. In Section 5, proposed methodology. In section 6, illustrative example, In Section 7, provides the concluding remarks.

II. LITERATURE REVIEW

QFD was conceived in the Japan in late 1960s, post-World War II. This was the time when most of the product development was happening through imitation and copying mode. In 1970s, it was the time QFD was first introduced by Dr Yoji Akao at the Kobe Dockyard of Mitsubishi heavy Industries began to apply the ideas of QFD in 1971. Following Akao's suggestion Nishimura at Kobe produced a quality table that showed the correlation between the customers required quality functions and the counterpart engineering characteristics. It has been successfully applied in many organizations to improve processes and build competitive advantages. Being one of these quality tools, QFD has been define by its originator Akao, 1992 as 'a method for developing a design quality aimed at satisfying the customer and then translating the customer demands into design targets and major quality assurance points to be used throughout the production phase'. According to *Sharma et al.* [4] the functional field of QFD can be grouped in three categories, which are:

a) Primary functional field including QFD usage in product development, customer requirement analysis and quality management system.

b) Secondary functional field including QFD usage in concurrent engineering, management sciences, planning, operation research, education, software and expert systems.

c) Tertiary functional field including QFD functions such as construction, cost, food, the environment and decision making.

QFD still has some limitations, how to deal with large amounts of subjective data and how to reduce the weight of a large dimensional evaluation is required to implement QFD efficiently and accurately. QFD is a cross functional team based tool, group decision making process, and how to generalize the opinions of multiple decision makers is a tough issue that needs to be tackled [7]. To solve this problem using decision making tools such as Analytical Hierarchy Process (AHP), ANP and Fuzzy set theory. The AHP has been applied extensively in QFD analysis [8-10]. It generalizes form ANP is used because some limitation of AHP is using in QFD matrix. Partovi (2001) [11] proposed a systematic method that combined QFD, AHP, ANP and benefit–cost analysis to determine the best process for a new facility. Partovi and Corredoira (2002) [12] used crisp AHP and ANP in QFD. Karsak et al. (2002) [2] employed ANP approach to incorporate CRs and ECs systematically into the product design phase in QFD. ANP is applied to consider the inner dependencies inherent in the QFD process. Partovi (2006) [13] presented a framework, based on QFD, AHP, and ANP and incorporated both external and internal criteria, to generate a strategic solution to the facility location problem. Partovi (2007) [14] developed an analytical technique, also based on QFD, AHP, and ANP, for process selection and evaluation of manufacturing systems in the chemical industry. Pal et al. (2007) [15] presented a combined approach of QFD and ANP to priorities ECs of a cast part for selecting and evaluating an appropriate Rapid Prototyping (RP) based route for tooling fabrication. Raharjo et al. (2008) [16] constructed a generic network model, based on QFD and ANP and incorporated new product development risk, competitors' benchmarking information, and feedback information, to enhance the accuracy of the QFD results. The authors' knowledge, in a simple or complex problem the ANP is incorporated with QFD has provided better results in product development cycle.

III. CONSTRUCTION OF HOUSE OF QUALITY (HOQ)

The HOQ is a visual chart that provides interfunctional planning and communication of CRs and ECs (Hauser and Clausing, 1988) [17]. HOQ contains in the body section a matrix which shows the relationship between CRs in rows and ECs in columns. The inner dependence among ECs are shown at the top or roof of the matrix and the inner dependencies of CRs are located at the left hand side of the HOQ and customer competitive analysis are shown on the right hand side column of the matrix and overall priorities of ECs are shown the bottom of the relationship matrix (Partovi, 2007) [14]. The basic construction of HOQ is shown in Figure 1.

The seven steps are involving for building the HOQ are listed below

Step I: Customers requirements (WHATs)

They are also known as customers need, demand quality, customer's attributes and Voice of Customers (VOC). QFD starts with a list of goals/objectives. This list is often named as the WHATs are the customer requirements or expects in a particular product. CR identifies individual customer's survey, group survey, telephonic interviews etc and at least 20 – 30 customers should be interviewed to obtain 90–95% of all the possible customer needs (Griffin and Hauser 1993) [18]. Step III: Inner dependences among CRs

The inner dependencies of CRs are located in left hand side of matrix that effect of each C R to other CRs.

Step II: Degree of importance

After CRs were identifies the next step is identifying the degree or relative importance of each CRs. Identified CRs are giving weights based on the degree of importance. Scale is using 1 – 9 (1 - extremely disagree to 9 - extremely agree) to identify the each CR relative weights and obtain each relative weights by the marketing survey.

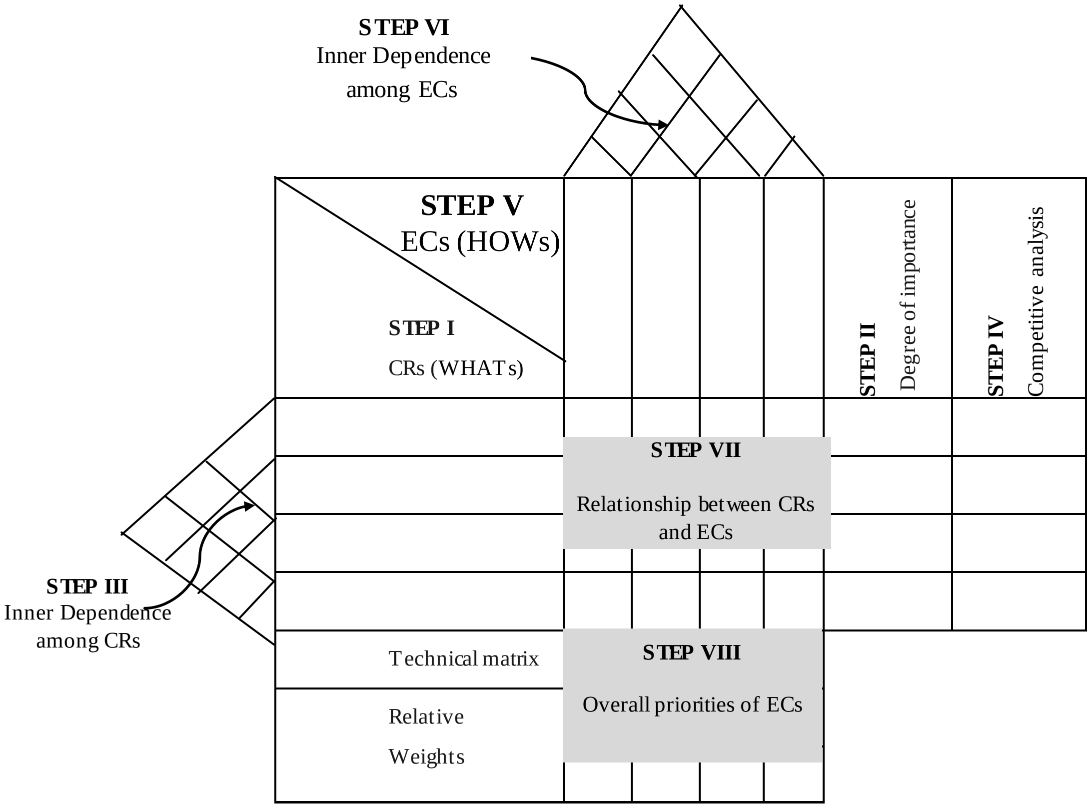

Figure 1: The HOQ

Step III: Inner dependences among CRs

The inner dependencies of CRs are located in left hand side of matrix that effect of each CR to other CRs.

Step IV: Customer competitive analysis

Competitors who manufacturers the similar products should be identified by the customer competitive analysis. Knowing the company's strengths and constraints in all aspects of a product and in comparison with its main competitors is essential for a company if it wishes to improve its competitiveness in the relevant markets. This kind of information can be obtained by asking the customers to rate the relative performance of the company and its competitors on each WHAT and then to aggregate the customers' ratings 1 to 5 (1 worse – 5 best). Useful ways of conducting this kind of comparison analysis are also via mailed surveys and individual interviews.

Step V: Engineering characteristics (HOWs)

EC is also known as design requirements, technical descriptors, and product technical ratings. The ECs are used to determine HOW well the company satisfies the customer requirements. The product development team should develop a set of HOWs to obtain the customer needs in measurable and operable technical terms. Customer requirements tell the company 'what to do' while the ECs tell 'how to do it'.

Step VI: Correlation matrix of ECs

The HOQ's roof matrix is used to specify the each EC that have effect to other ECs, providing a basis to what extent a change in one feature will affect other features. A desirable change in one feature may result in a negative effect on another feature. This correlation facilitates the necessary engineering impacts and trade-offs.

Step VII: Relationship matrix between CRs and ECs

The relationship matrix of WHATs versus HOWs is a systematic means for identifying the degree of relationship between each WHAT and each HOW. Completing this relationship matrix, which is done carefully by the designer, is a vital step in the HOQ/QFD process. Usually there are four relationship levels, i.e., no relationship, weak/possible relationship, medium/moderate relationship, and strong relationship (Chan and Wu, 2002) [19]. 9 strong relationships, 3 medium relationships, 1 weak relationship

Step VIII: Overall priorities of ECS

ECs with higher final technical ratings, implying greater importance for the company's product to be successful in the competitive markets, are transferred into the second phase of QFD, parts deployment, which translates important ECs (new WHATs) into parts characteristics (new HOWs). These metrics help in determining overall priorities and directions for improvement, as well as providing an objective means of assuring that requirements have been met.

IV. COMBINE QFD AND ANP

QFD is a method for structured product development. It enables a development team to specify clearly the customer's wants and needs, and then evaluates each proposed product systematically in terms of its impact on meeting those needs [17]. In the QFD process, a matrix called the House of Quality (HOQ) is used to display the relationship between the Customers' Requirements (CRs) is refer as WHATs and the Engineering Characteristics (ECs) refer as HOWs. During the QFD transformation, the HOQ is developed to demonstrate how the ECs satisfy the CRs. The traditional QFD approach uses absolute importance to identify the degree of importance for each customer requirement and relationship matrix between WHATs and HOWs uses the fix scale 9-strong relation, 3-medium and 1-weak. This assumes that accurate and representative data in an absolute scale is available [20]. In the HOQ matrix, the calculation performed only between degree of importance and relationship matrix not included the inner dependency matrixes of ECs and CRs. This matrix only shows the relation among of each criterion means the impact of one criterion over the other criterion uses indications. So, these matrixes do not contribute much in helping QFD developers to prioritize ECs responses. To avoid this problem, the ANP helps in QFD matrix to identify the overall priorities of ECs with the contribution of inner dependence and interrelationship matrix of CRs and ECs.

The ANP is a decision making tool, which aid to incorporate the dependency issues in the analysis [21]. Hence it enables to take into account the degree of the interrelationship between the CRs and ECs, and the inner dependence among them [22, 23]. ANP treats as decision support tool to help for making a better decision for product design evolution process. The advantages of ANP in product development are reducing complex decisions to a network of pairwise comparisons and decision makers of company arrive at the best decision. [24] Therefore, in our study, ANP has been integrated with QFD for product development phase and ANP is used to assist the construction of HOQ matrix. In this chapter we propose a mathematical model of ANP combined with QFD matrix to determine the overall priorities of ECs. A modified QFD network presentation is shown in Figure 2.

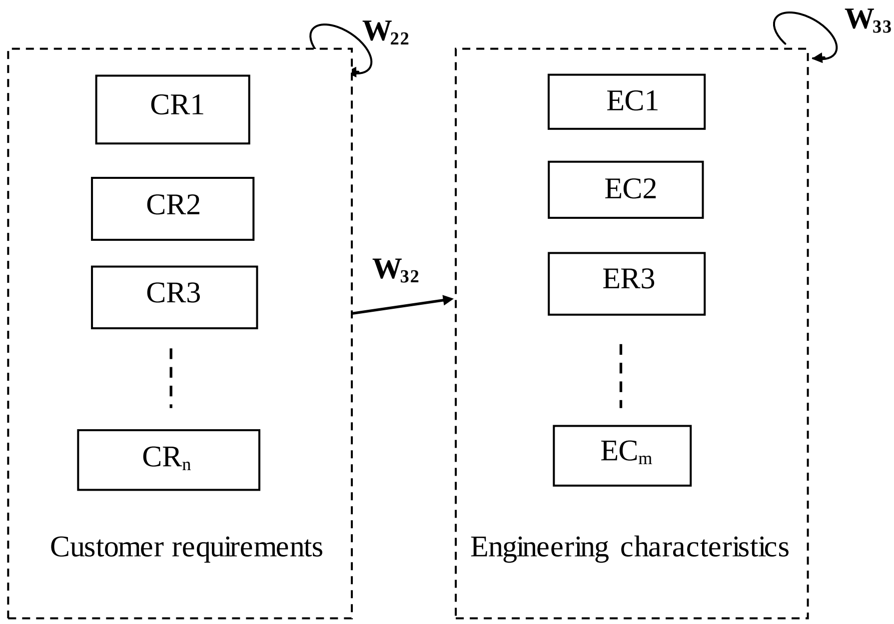

Figure 2: A modify QFD network structure

Here, $\mathbf{W}_{22}$ is the inner dependency among CRs, $\mathbf{W}_{33}$ is the inner dependency among ECs and $\mathbf{W}_{32}$ is the interrelationship of ECs with respect to each CR.

V. METHODOLOGY

The proposed methodology combine ANP and QFD are shown in Figure 3.

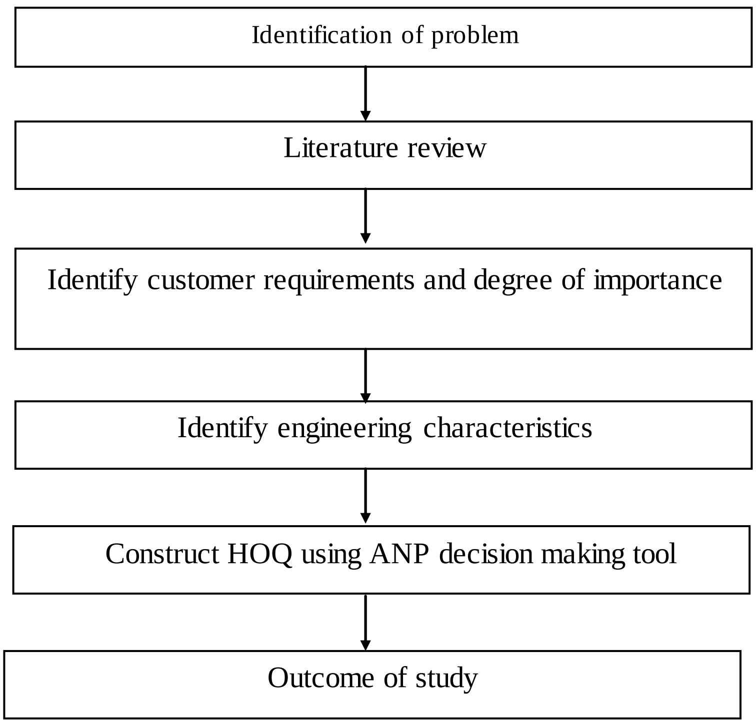

Figure 3: Proposed methodology

VI. A CASE STUDY

A case study of an Indian manufacturing company which manufactures the various types stainless steel submersible pumps (name not disclosed). This pump is used for agriculture, water supply, pressure boosting etc. The XYZ Company has a manufacturing as well as assembly industry. The company manufactures and assembles the products. The company improves the existing product design using QFD analysis to identify the CRs and translating in terms of ECs and focuses on those ECs which are highly rated by the customers. In the current study investigation was done on the company product and its competitors' which manufactures similar type product. An intensive marketing survey was conducted for identifying customers' requirements and how company fulfills the customer's requirements as shown in figure 4.

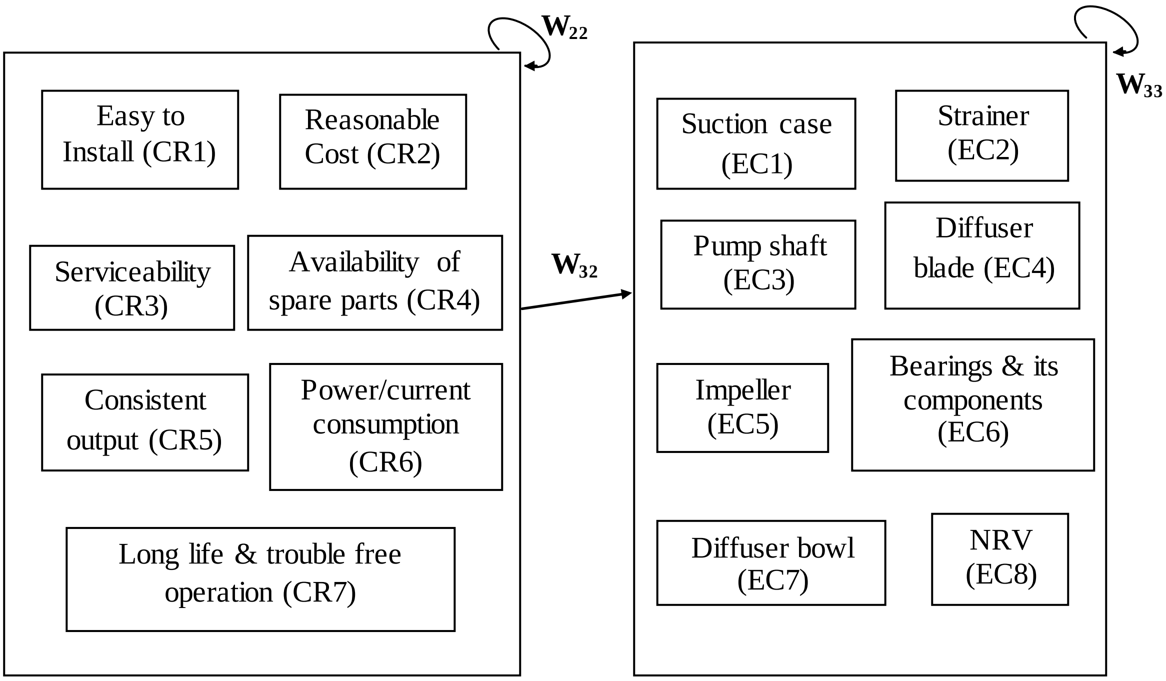

Figure 4: modified QFD network presentation (stainless steel submersible pump)

Here, the QFD-ANP methodology was very useful in such situations because ANP is determines the relative weight by the pairwise comparisons and these weight are used in QFD matrix helps to focuses on those product components which are highly rated by the customers. The application of the methodology is demonstrated in next section.

QFD – ANP calculation

Step I – Identifies CRs and degree of importance of each CR

A marketing survey was conducted for a product and many discussions were held with the manufacturer of the submersible pump and its end users. The following seven customer requirements were identified:

- Easy to install
- Reasonable cost
- Serviceability
- Availability of spare parts
- Consistent output

- Power/current consumption
- Long life & trouble free operation.

Questionnaire was sent to the many customers that are using the submersible pumps for evaluating the each customer's requirements. Twenty such filled forms were received in which customers rated each of the indentified requirements using likert scale 1 to 9 (1 means extremely disagree – 9 means extremely agree). The CRs and degree of importance is shown in Table I.

Table I Customer Requirements and Degree of importance (**W_1**)

	Customer Requirements	*Degree of importance* (**W_1**)
CR1	Easy to install	6.65
CR2	Reasonable cost	6.7
CR3	Serviceability	7.65
CR4	Availability of spare parts	8.15
CR5	Consistent output	6.4
CR6	Power/current consumption	6
CR7	Long life & trouble free operation	7.4

Step II - Determine inner dependencies matrix of CRs with respect to each CR (calculation for $\boldsymbol{W_{22}}$)

The inner dependence among the customer requirements is determined through analyzing the impact of each CR on other CRs by using pairwise comparisons. Experts are asked to pairwise compare the elements using Saaty scale 1 to 9. The inner dependence among the CRs is shown in figure 5.

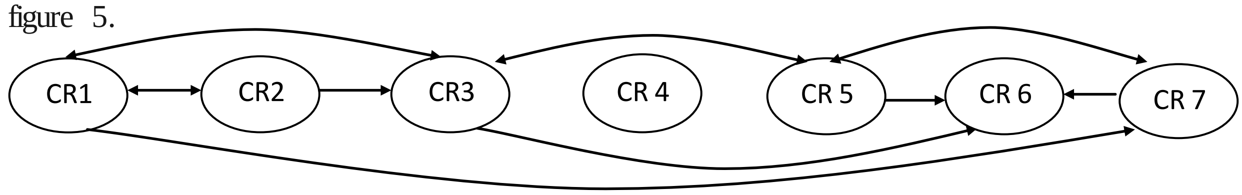

Figure 5: Inner dependence among the CRs

The calculation of pairwise comparison for determines the relative weight of CRs. The sample of calculation for relative weight is shown below: For example the pairwise comparison matrix of CRs with respect to easy to install (CR1).

$$A = \begin{array}{c} \\ CR1 \\ CR2 \\ \vdots \\ CRm \end{array} \begin{array}{c} \begin{array}{cccc} CR1 & CR2 & \dots & CR_m \end{array} \\ \begin{bmatrix} 1 & a_{12} & \dots & a_{1m} \\ \frac{1}{a_{12}} & 1 & \dots & a_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ a_{m1} & a_{m2} & \dots & a_{mm} \end{bmatrix} \end{array} = \begin{array}{c} \\ CR1 \\ CR2 \\ CR3 \\ CR7 \end{array} \begin{array}{c} \begin{array}{cccc} CR1 & CR2 & CR3 & CR7 \end{array} \\ \begin{bmatrix} 1 & 1/4 & 1/5 & 1/6 \\ 4 & 1 & 1/3 & 1 \\ 5 & 3 & 1 & 3 \\ 6 & 1 & 1/3 & 1 \end{bmatrix} \end{array}$$

Where, m is number of CRs and a_{ij} = ith element is how much more important jth element. For all i and j, it is necessary that $a_{ii} = 1$ and $a_{ij} = 1/a_{ji}$.

Next, divide each entry (a_{ij}) in each column of matrix A by its column total. The matrix now becomes a normalized pairwise comparison matrix,

$$A' = \begin{bmatrix} \frac{a_{11}}{\sum_{i=1}^{m} a_{i1}} & \frac{a_{12}}{\sum_{i=1}^{m} a_{i2}} & \cdots & \frac{a_{1m}}{\sum_{i=1}^{m} a_{im}} \\ \vdots & \vdots & \cdots & \vdots \\ \vdots & \vdots & \ddots & \vdots \\ \frac{a_{m1}}{\sum_{i=1}^{m} a_{i1}} & \frac{a_{m2}}{\sum_{i=1}^{m} a_{i2}} & \cdots & \frac{a_{mm}}{\sum_{i=1}^{m} a_{im}} \end{bmatrix} = \begin{bmatrix} .062 & .047 & .107 & .032 \\ .250 & .190 & .177 & .193 \\ .312 & .571 & .537 & .580 \\ .375 & .190 & .177 & .193 \end{bmatrix}$$

Next, compute C_i as the average of the entries in row ith of A' to yield column vector C.

$$C = \begin{bmatrix} \frac{\frac{a_{11}}{\sum_{i=1}^{m} a_{i1}} + \frac{a_{12}}{\sum_{i=1}^{m} a_{i2}} + \ldots + \frac{a_{1m}}{\sum_{i=1}^{m} a_{im}}}{m} \\ \vdots \\ \vdots \\ \frac{\frac{a_{m1}}{\sum_{i=1}^{m} a_{i1}} + \frac{a_{m2}}{\sum_{i=1}^{m} a_{i2}} + \ldots + \frac{a_{mm}}{\sum_{i=1}^{m} a_{im}}}{m} \end{bmatrix} = \begin{bmatrix} 0.060 \\ 0.202 \\ 0.506 \\ 0.242 \end{bmatrix}$$

Where, C_i represents the relative weights for the ith customer requirement in the column vector of importance weighting of each customer requirement. Similarly, rest of the pairwise comparisons calculation was done using super decision software (trial version).

A possible question is as follows: 'What is the relative importance of Serviceability when compared to Reasonable cost on Easy to install' gives rating 3, it means Serviceability is moderately important then reasonable cost as shown in Table II.

Table II The inner dependence matrix of CRs with respect to Easy to Install (CR1) (other customer needs which do not have an impact on Easy to Install are not included in comparison matrix)

Easy to Install (CR1)	*CR1*	*Reasonable cost (CR2)*	*Serviceability (CR3)*	*Long life & trouble free operation (CR7)*	*Relative weights (RW)*
CR1	1	1/4	1/5	1/6	0.060
CR2	4	1	1/3	1	0.202
CR3	5	3	1	3	0.506
CR7	6	1	1/3	1	0.232
					consistency ratio = 0.060

After relative weights of CR1 is identified. Next to checking the consistency of pairwise comparison matrix, the subsets are performed as follows:

(i) Compute **(CR1 × RW)**

$$(\mathbf{CR1 \times RW}) = \begin{bmatrix} 1 & .25 & .20 & .166 \\ 4 & 1 & .33 & 1 \\ 5 & 3 & 1 & 3 \\ 6 & 1 & .33 & 1 \end{bmatrix} \times \begin{bmatrix} .060 \\ .202 \\ .506 \\ .232 \end{bmatrix} = \begin{bmatrix} .251872 \\ .85098 \\ 2.1800 \\ .97098 \end{bmatrix}$$

(ii) Compute the average value of the maximum Eigen value $(\boldsymbol{\lambda_{\max}})$

$$\boldsymbol{\lambda_{\max}} = \frac{1}{m} \sum_{i=1}^{m} \left(\frac{CR1 \times RW}{RW} \right)$$

$$\boldsymbol{\lambda_{\max}} = \frac{1}{4} \left(\frac{.251872}{.060} + \frac{.85098}{.202} + \frac{2.1800}{.506} + \frac{.97098}{.232} \right) = \mathbf{4.162062}$$

(iii) Compute the consistency index (CI)

$CI = \frac{\lambda_{\max} - n}{n-1} = \frac{4.162062 - 4}{4-1} = .054$, Random Index (RI) for n=4 is .90

Consistency Ratio (CR) = $\frac{CI}{RI}$

CR = $\frac{.054}{.90}$ = .060 < .10

Since CR is less than 0.1, the experts' judgment is consistent. If the consistency test fails, the experts are required to fill out the specific part of the questionnaire again until a consensus is met. Similarly, rest of the consistency ratios of all paiwise comparison matrixes was determined.

Similarly, after completing all the pair-wise comparisons, the resulting eigenvectors obtained from pairwise comparisons are presented in Table III.

Table III Eigen vectors obtained from pairwise comparisons for CRs

W_{22}	**CR1**	**CR2**	**CR3**	**CR4**	**CR5**	**CR6**	**CR7**
CR1	0.06015	0.12196	0	0	0	0	0
CR2	0.20241	0.31962	0	0	0	0	0
CR3	0.50614	0.55842	0.41494	0	0.32510	0.52614	0.51231
CR4	0	0	0	1	0	0	0
CR5	0	0	0.22860	0	0.12879	0.16830	0.13342
CR6	0	0	0.28026	0	0.47685	0.24747	0.28379
CR7	0.23130	0	0.07620	0	0.06926	0.05809	0.07078

Step III - Identify Engineering Characteristics

After the CRs were identified and considering that product part is highly intricate, the ECs is likely to affect these requirements are identified as suction case, strainer, pump shaft, diffuser blade, impeller, bearings, diffuser bowl and NRV. The ECs are used to determine how well the company satisfies the customer requirements. ECs are shown in Table IV.

Table IV Engineering Characteristics

EC1	**Suction Case**
EC2	Strainer
EC3	Pump Shaft
EC4	Diffuser Blade
EC5	Impeller
EC6	Bearings
EC7	Diffuser Bowl
EC8	NRV

Step IV - Determine the inner dependency matrix of the ECs with respect to each EC (calculation for $\boldsymbol{W_{33}}$)

The inner dependence among the ECs is determined through analyzing the impact of each EC on other EC by using pairwise comparisons are performed by the experts. The inner dependence among ECs is shown in Figure 6.

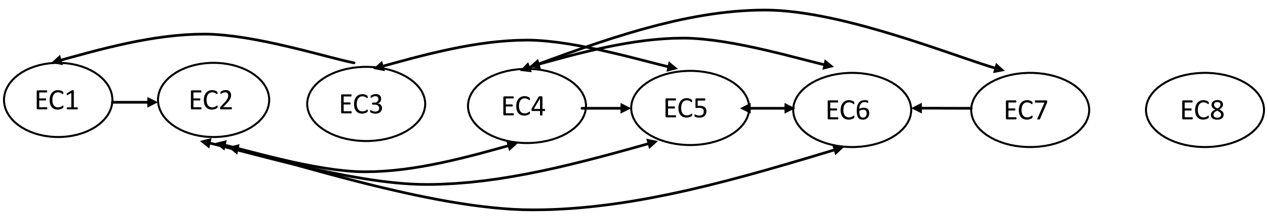

Figure 6: Inner dependence among the ECs

We utilize questions such as 'What is the relative importance of Impeller when compared to Bearings on Strainer' gives rating 5; it means impeller is strongly more important than Bearings & its components as shown in Table V. The resulting eigenvectors obtained from pairwise comparisons are presented in Table VI.

Table V The inner dependence matrix of ECs with respect to strainer (EC2) (other ECs which do not have an impact on Strainer are not included in comparison matrix)

Strainer (EC2)	EC2	EC4	EC5	EC6	Relative weight
EC2	1	4	3	5	0.52153
EC4	1/4	1	1/3	4	0.14206
EC5	1/3	3	1	5	0.27646
EC6	1/5	¼	1/5	1	0.05995
		Consistency ratio			0.09535

Table VI Eigen vectors obtained from pairwise comparison for ECs

W_{33}	Suction case (EC1)	Strainer (EC2)	Pump shaft (EC3)	Diffuser blade (EC4)	Impeller (EC5)	Bearing (EC6)	Diffuser bowl (EC7)	NRV (EC8)
EC1	0.83333	0	0.536825	0	0	0	0	0
EC2	0.166667	0.52151	0	0.444099	0.512315	0.457509	0	0
EC3	0	0	0.098884	0	0.070475	0	0	0
EC4	0	0.142057	0	0.055315	0	0.106644	0.157964	0
EC5	0	0.276462	0.364292	0.255942	0.283794	0.075688	0.197466	0
EC6	0	0.059950	0	0.137708	0.133416	0.360059	0.090190	0
EC7	0	0	0	0.106935	0	0	0.554381	0
EC8	0	0	0	0	0	0	0	1

Step V - Determine the inter relationship of ECs with respect to each CR by assuming that there is no dependence among the ECs (calculation of $\boldsymbol{W_{23}}$*).*

Assuming that there is no dependence among the ECs, they are compared with respect to each CR yielding the column eigenvectors regarding each customer need. For example, one of the possible questions for determining the degree of relative importance of the ECs for consistent output can be as follows: "What is the relative importance of Strainer (EC2) when compared to Impeller (EC5) with respect to the consistent output (CR5)" gives rating 3 as shown in Table VII. The transpose of this data shown in Table 8 will be placed in the body of the HOQ. The degree of relative importance of the ECs for the remaining CRs are calculated in a similar way and presented in Table VIII. This interrelationship matrix placed in the center of HOQ matrix.

Table VII Relative importance of ECs with respect to **consistent output (CR5)**

CR5	EC2	EC4	EC5	EC6	EC8	Relative weight
EC2	1	4	3	3	2	0.36972
EC4	¼	1	1/5	1/3	1/5	0.05024
EC5	1/3	5	1	3	1/3	0.17111
EC6	1/3	3	1/3	1	1/5	0.08998
EC8	½	5	3	5	1	0.31894
					Consistency ratio	0.08647

Table VIII Degree of relative importance of the ECs with respect to CRs

W_{23}	CR1	CR2	CR3	CR4	CR5	CR6	CR7
EC1	0	0.06923	0.03226	0.04854	0	0	0.060844
EC2	0	0.07791	0.09062	0.06226	0.369724	0	0.030941
EC3	0	0.09224	0.13784	0.12236	0	0.166667	0.070235
EC4	0	0.13004	0.06712	0.11489	0.050243	0	0.125599
EC5	0	0.20569	0.19477	0.18148	0.171108	0.833333	0.169182
EC6	0	0.09575	0.16078	0.15160	0.089984	0	0.051721
EC7	0	0.11561	0.07130	0.11675	0	0	0.254732

EC8	1	0.21354	0.24533	0.19771	0.318941	0	0.236117

*Step VI - Determine the interdependent priorities of the CRs (calculation of **$Wc = W_{22} \times W_1$**)*

The interdependent priorities of the CRs is given as below

$$\begin{bmatrix} 0.06015 & 0.12196 & 0 & 0 & 0 & 0 & 0 \\ 0.20241 & 0.31962 & 0 & 0 & 0 & 0 & 0 \\ 0.50614 & 0.55842 & 0.41494 & 0 & 0.32510 & 0.52614 & 0.51231 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0.22860 & 0 & 0.12879 & 0.16830 & 0.13342 \\ 0 & 0 & 0.28026 & 0 & 0.47685 & 0.24747 & 0.28379 \\ 0 & 0 & 0.07620 & 0 & 0.06926 & 0.05809 & 0.07078 \end{bmatrix} \times \begin{bmatrix} 6.65 \\ 6.7 \\ 7.65 \\ 8.15 \\ 6.4 \\ 6 \\ 7.4 \end{bmatrix}$$

$$\mathbf{Wc} = \begin{bmatrix} 1.2171 \\ 3.4874 \\ 19.3101 \\ 8.15 \\ 4.57015 \\ 8.78069 \\ 3.4344 \end{bmatrix}$$

*Step VII - Determine the interdependent priorities of the ECs (calculation of **$W_A = W_{33} \times W_{23}$**)*

The interdependent priorities of the ECs, are calculated as

$$\begin{bmatrix} 0.83333 & 0 & 0.536825 & 0 & 0 & 0 & 0 & 0 \\ 0.166667 & 0.52151 & 0 & 0.444099 & 0.512315 & 0.457509 & 0 & 0 \\ 0 & 0 & 0.098884 & 0 & 0.070475 & 0 & 0 & 0 \\ 0 & 0.142057 & 0 & 0.055315 & 0 & 0.106644 & 0.157964 & 0 \\ 0 & 0.276462 & 0.364292 & 0.255942 & 0.283794 & 0.075688 & 0.197466 & 0 \\ 0 & 0.059950 & 0 & 0.137708 & 0.133416 & 0.360059 & 0.090190 & 0 \\ 0 & 0 & 0 & 0.106935 & 0 & 0 & 0.554381 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

$$\times$$

$$\begin{bmatrix} 0 & 0.06923 & 0.03226 & 0.04854 & 0 & 0 & 0.060844 \\ 0 & 0.07791 & 0.09002 & 0.06226 & 0.369724 & 0 & 0.030941 \\ 0 & 0.09224 & 0.13784 & 0.12236 & 0 & 0.166667 & 0.070235 \\ 0 & 0.13004 & 0.06712 & 0.11489 & 0.050243 & 0 & 0.125599 \\ 0 & 0.20569 & 0.19477 & 0.18148 & 0.171108 & 0.833333 & 0.169182 \\ 0 & 0.09575 & 0.16078 & 0.15160 & 0.089984 & 0 & 0.051721 \\ 0 & 0.11561 & 0.07130 & 0.11675 & 0 & 0 & 0.254732 \\ 1 & 0.21354 & 0.24533 & 0.19771 & 0.318941 & 0 & 0.236117 \end{bmatrix}$$

$$=$$

$$\mathbf{W_A} = \begin{bmatrix} 0 & 0.107208 & 0.1008 & 0.106135 & 0 & 0.089470 & 0.08840 \\ 0 & 0.259115 & 0.2554 & 0.253931 & 0.34397 & 0.42692 & 0.192720 \\ 0 & 0.023617 & 0.2735 & 0.024889 & 0.00354 & 0.07520 & 0.018912 \\ 0 & 0.046734 & 0.0449 & 0.049809 & 0.06489 & 0 & 0.057097 \\ 0 & 0.176873 & 0.1738 & 0.177223 & 0.202916 & 0.297209 & 0.168933 \\ 0 & 0.094923 & 0.1049 & 0.142470 & 0.084311 & 0.11117 & 0.083403 \\ 0 & 0.077997 & 0.04670 & 0.077000 & 0.0053727 & 0 & 0.154649 \\ 1 & 0.213540 & 0.24533 & 0.197710 & 0.318941 & 0 & 0.236117 \end{bmatrix}$$

*Step VI- Determine the overall priorities of the ECs **$w = W_A \times W_c$***

The overall priorities of the ECs, reflecting the interrelationships within the HOQ, are obtained by

$$\mathbf{w} = \mathbf{W_A}\begin{bmatrix} 0 & 0.107208 & 0.1008 & 0.106135 & 0 & 0.08947 & 0.088400 \\ 0 & 0.259115 & 0.2554 & 0.253931 & 0.34397 & 0.42692 & 0.192720 \\ 0 & 0.023617 & 0.2735 & 0.024889 & 0.00354 & 0.07520 & 0.018912 \\ 0 & 0.046734 & 0.0449 & 0.049809 & 0.06489 & 0 & 0.057097 \\ 0 & 0.176873 & 0.1738 & 0.177223 & 0.202916 & 0.297209 & 0.168933 \\ 0 & 0.094923 & 0.1049 & 0.142470 & 0.084311 & 0.11117 & 0.083403 \\ 0 & 0.077997 & 0.0467 & 0.077000 & 0.0053727 & 0 & 0.154649 \\ 1 & 0.213540 & 0.2453 & 0.197710 & 0.318941 & 0 & 0.236117 \end{bmatrix} \times \mathbf{W_c}\begin{bmatrix} 1.2171 \\ 3.4874 \\ 19.310 \\ 8.15 \\ 4.5701 \\ 8.7806 \\ 3.4344 \end{bmatrix}$$

$$\mathbf{w} = \begin{bmatrix} EC1 & 4.2745 \\ EC2 & 13.887 \\ EC3 & 6.3079 \\ EC4 & 1.9285 \\ EC5 & 9.5345 \\ EC6 & 5.1656 \\ EC7 & 2.3570 \\ EC8 & 10.5784 \end{bmatrix}$$

The QFD-ANP analysis results shows that the most important engineering parameter is the Strainer with a relative value of 13.887, followed by NRV, impeller, Pump Shaft, Bearing & its components, Suction Case, diffuser bowl and Diffuser blade. We filled the body of HOQ by the weights obtained through comparing the ECs with respect to each CR (relationship matrix), and then, obtaining inner dependence among the each CR is shown upper left corner of the matrix and inner dependence among ECs are shown roof of the matrix. The competitive analysis is right hand side of the matrix and overall priorities is shown below the relationship matrix. The modify HOQ is shown in figure 7.

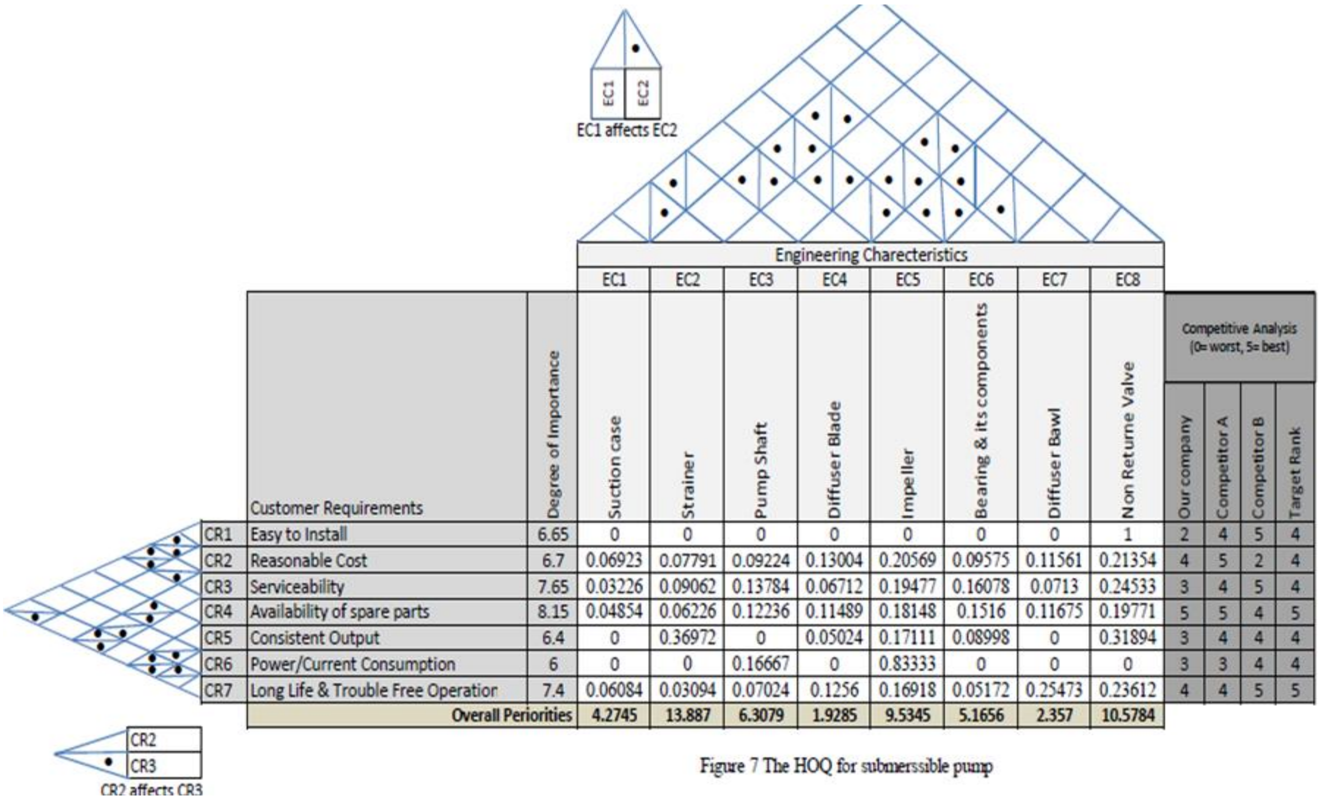

Figure 7 The HOQ for submerssible pump

VII. CONCLUSION

The QFD approach, which enables companies to translate customer needs to relevant product design requirements, is a design tool of vital importance. In this paper, we present a systematic decision making tool such as ANP to be used in QFD product planning, which has been usually based on expert opinions. The decision approach aims to consider the interdependence between the CRs and ECs, and the inner dependence within themselves, along with the customer degree of importance and customer competitive analysis. In this case study, the overall priorities of ECs were identified. Strainer, Non Return Valve and Impeller have a highest relative weights among all ECs focuses on those ECs to fulfill the customers desires. The designer keep in mind and improve the existing product quality at the most economical price should be take advantage from the customers preference.

The proposed methodology suggested to this company and also related manufacturing companies use this methodology to help in the decision taking and improve the customer satisfaction level.

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