Application of Analytical Network Process in Quality Function Deployment

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ABSTRACT
A combined two established techniques, namely the Quality Function Deployment (QFD) and the Analytic Network Process (ANP) use in product development process. In this paper shows the how to use ANP decision making tool in QFD matrix. Combine the QFD and ANP method to determine the overall priorities of ECs. The ANP is a multi criteria decision-making method used to derive relative priority from individual judgments, which can deal with all kinds of dependences systematically. The ANP helps in the QFD matrixes which derives the pairwise comparison matrix and check the consistency ration for the customer degree of importance, interrelationship between Customer Requirements (CRs) and Engineering Characteristics (ECs) and the inner dependency among CRs and ECs. Finally, determine the overall priorities of ECs and focuses on those ECs which are highly assign weights and improve the customers' satisfaction.

Keywords
QFD, ANP, House of Quality

1. INTRODUCTION
In recent times, due to increased global competitions are become biggest issue in the manufacturing industries scenario. This keen challenge companies 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 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 process. Conflicting 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 revenues, 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.

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 Customer Requirements (CRs) and Engineering Characteristics (ECs). ANP is a good methodology to consider such inner dependencies in the QFD analysis [4]. The combining the QFD – ANP approach in product development phase to help the designer take a decisions about the product according the customers' requirements. QFD is marketing tool and ANP is decision making tool are combining together to optimize the product and better structure to solving a problem. The advantage of combining two different techniques is a greater scientific precision in the allocation of weights at the level of "WHATs" and "HOWs" while maintaining the simple and intuitive scheme of HOQ.

The rest of paper is organized in the following order. In Section 2, present a QFD and its structure. Section 3, describes the basics of ANP. Section 4, combined the QFD – ANP method procedure. In section 5, provides the concluding remarks.

2. QUALITY FUNCTION DEPLOYMENT
QFD originally developed in Japan and introduced by Dr. Yoji Akao in early 1970. Who first realized the value of this approach in 1969 and wanted to utilize its power during the product design stage so that the product design characteristics could be converted into precise quality control points in the manufacturing quality controls points chart. Akao wrote a paper on this new approach in 1972 and called"hinshitsu tenkai" (quality deployment) [5].

The QFD is a disciplined approach for translating the CRs into ECs and quality assurance point to be used through the production phase. It adopts a customer driven approach and provides a structured way to ensure that the final product meets customer requirements [6]. QFD analysis identifies the relative important of each CR and develops interrelationship between CRs and ECs to assign weights between them. Correlation matrix in QFD helps to measure the relationship of each engineering characteristics and how much they affect each other. Importance ratings for ECs, is calculated using customer requirements importance ratings and weights assigned to the relationships between customer requirements and engineering characteristics. The final relative weights of each engineering characteristics are determine and focus on it which is highly rated by customers.

QFD enables the design phase to concentrate on the customer requirements, thereby spending less time on redesign and modifications. The saved time has been estimated at one-third to one-half of the time taken for redesign and modification using traditional means. This saving means reduced development cost and also additional income because the product enters the market earlier [7].

2.1 QFD Structure

A typical QFD system usually has four interlinked phases where four matrices that integrate the customer requirements, design specifications, product or part characteristics, manufacturing processes, and operations conditions or control are used [8]. QFD model is usually used in product planning problems where more than one translation is required; in this study the HOQ method is applied.

2.2 Construction of House of Quality

House of quality (HOQ) is the first phase of the QFD system. The purpose of HOQ is to transform customer needs into product design specifications (referred to in QFD terms as "Engineering Characteristics"). HOQ shows what customer wants and how designer fulfils the requirements in product development phase. It provides a framework and guides the designer to set the target to improve their product quality.

QFD analysis, a matrix of HOQ is used to display the relationship between the Customer Requirement (referred to as 'WHATs') and the Engineering Characteristics (referred to as 'HOWs'). It identifies the interrelationship matrix between CRs and ECs. This matrix summarizes information about ECs and their associated customer ranking and the correlation between the ECs parameter. Six HOQ steps are following in Figure 2.

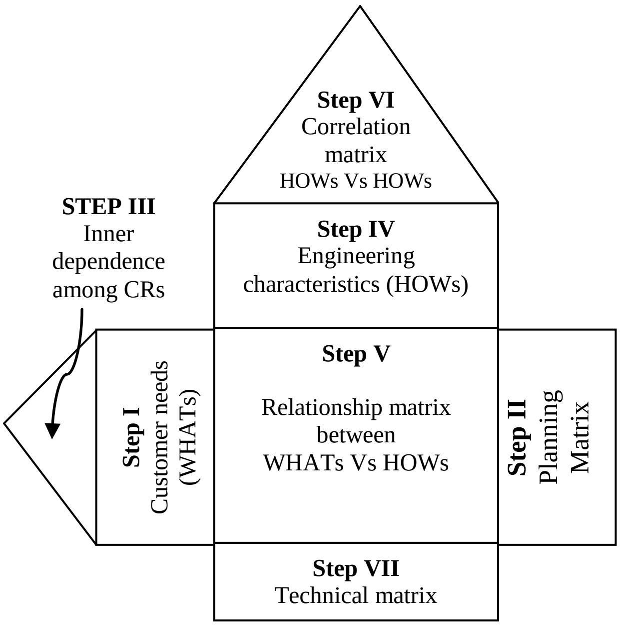

Fig 1: HOQ, description [5]

Step I has a list of customer needs and identify the degree of importance of each customer needs; **Step II** contains market data, strategic goal setting for the new product and computations for prioritizing the customer needs; **Step III** contains inner dependence among CRs means each CR affect to other CRs; **Step IV** includes information to translate the customer needs into the organization's technical description or engineering characteristics; **Step V** contains the relationship matrix between each customer need and each engineering characteristics; **Step VI** the "roof" of HOQ assesses the correlation matrix between each engineering characteristics; **Step VII** contains the prioritization of the engineering characteristics and technical targets.

3. ANALYTICAL NETWORK PROCESS

The Analytical Network Process **(**ANP) generalizes a widely used multi-criteria decision making tool, the Analytical Hierarchical Process (AHP), by replacing hierarchies with networks. The AHP is a well-known technique that decomposes a problem into several levels in such a way that they form a hierarchy [9]. 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. The ANP can be used as an effective tool in those cases where the interactions among the elements of a system form a network structure [10].

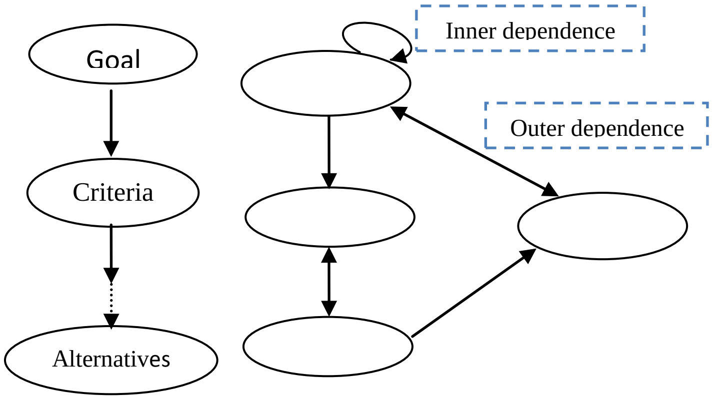

Fig 2: (A) AHP (B) ANP

While AHP employs a unidirectional hierarchical relationship among decision levels, ANP enables interrelationships among the decision levels and attributes to be taken into consideration in a more general form. ANP uses ratio scale measurements based on pair wise comparisons; however, it does not impose a strict hierarchical structure as in AHP, and models a decision problem using a systems with feedback approach. Figure 2 A and B shows the structural difference between the hierarchy and network. Nodes of the network represent components of the system, and arcs denote interactions between them. The directions of the arcs represent dependence, whereas loops signify inner dependence of the elements in a cluster [11].

In ANP, the relative importance values are determined similar to AHP using pair wise comparisons with a scale of 1–9, where a score of 1 indicates equal importance between the two elements and 9 represents the extreme importance of one element compared to the other one. The relations $a_{ji} = 1/a_{ij}$; where a_{ij} denotes the importance of the *i*th element compared to the *j*th element, and $a_{ii} = 1$ are preserved in the pair wise comparison matrix to improve the consistency of the judgments. To check the consistency of each pairwise comparison matrix should be less than .10, if value more than 10 revised the pairwise comparison matrix.

The following step to identify the relative weights of each comparison matrix and check the consistency ratio:

STEP I: construct the parwise comparison matrix A

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1m} \\ a_{21} & 1 & \cdots & a_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mm} \end{bmatrix}$$

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

STEP II: 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'.

$$A' = \begin{bmatrix} \frac{a_{11}}{\sum_{i=1}^{m} a_{i1}} & \frac{a_{12}}{\sum_{i=1}^{m} a_{i2}} & \cdots & \frac{a_{1m}}{\sum_{i=1}^{m} a_{im}} \\ \vdots & \vdots & \cdots & \vdots \\ \vdots & \vdots & \ddots & \vdots \\ \frac{a_{m1}}{\sum_{i=1}^{m} a_{i1}} & \frac{a_{m2}}{\sum_{i=1}^{m} a_{i2}} & \cdots & \frac{a_{mm}}{\sum_{i=1}^{m} a_{im}} \end{bmatrix}$$

STEP III: Next, compute C_i as the average of the entries in row ith of A' to yield column matrix C

$$C = \begin{bmatrix} \dfrac{\frac{a_{11}}{\sum_{i=1}^{m} a_{i1}} + \frac{a_{12}}{\sum_{i=1}^{m} a_{i2}} + \ldots + \frac{a_{1m}}{\sum_{i=1}^{m} a_{im}}}{m} \\ \vdots \\ \vdots \\ \dfrac{\frac{a_{m1}}{\sum_{i=1}^{m} a_{i1}} + \frac{a_{m2}}{\sum_{i=1}^{m} a_{i2}} + \ldots + \frac{a_{mm}}{\sum_{i=1}^{m} a_{im}}}{m} \end{bmatrix} = \begin{bmatrix} C_1 \\ C_2 \\ \vdots \\ C_i \end{bmatrix}$$

Where, C_i represents the relative weights for the ith customer requirement in the column matrix.

STEP IV: relatives weights of comparison matrix were identify next to checking the consistency of paiwise comparison matrix, the subset are performed as follows.

a. Compute A . C

$$A \cdot C = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1m} \\ a_{21} & 1 & \cdots & a_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mm} \end{bmatrix} \begin{bmatrix} C_1 \\ C_2 \\ C_3 \\ \vdots \\ C_i \end{bmatrix} = \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ \vdots \\ i_i \end{bmatrix}$$

b. Compute maximum Eigen value (λ_{max})

$$\lambda_{max} = \frac{1}{m} \sum_{i=1}^{m} \left(\frac{\text{ith entry in A.C}}{\text{ith entry in C}} \right) = \frac{1}{m} \sum_{i=1}^{m} \left(\frac{x_i}{C_i} \right)$$

c. Compute the Consistency Index (CI)

$$CI = \frac{\lambda_{max} - m}{m - 1}$$

Compare CI to the Random Index (RI) for the appropriate value of m to determine if the degree of consistency is satisfactory. If CI is sufficiently small, the decision maker's comparisons are probably consistent enough to give useful estimates of the weights for the objective function. If CI/RI < 0.10, the degree of consistency is satisfactory, but if CI/RI > 0.10, serious inconsistencies may exist, and the AHP may not yield meaningful results [14]. The reference values of the RI for different numbers of m is shown Table 1.

Table 1 Random Index [11]

m	1	2	3	4	5	6	7	8	9	10	11	12
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.58

4. COMBINE QFD - ANP METHOD

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 [11]. In the QFD process, a matrix called the House of Quality (HOQ) is used to display the relationship between the CRs and ECs. 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 [12]. 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 [13].

The ANP is a decision making tool, which aid to incorporate the dependency issues in the analysis. Hence it enables to take into account the degree of the interrelationship between the CRs and ECs, and the inner dependence among them. ANP treats as decision support tool to help for making a better decision for product design or 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. The dependencies of customer needs inbuilt 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 product designing [15]. 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 3.1.

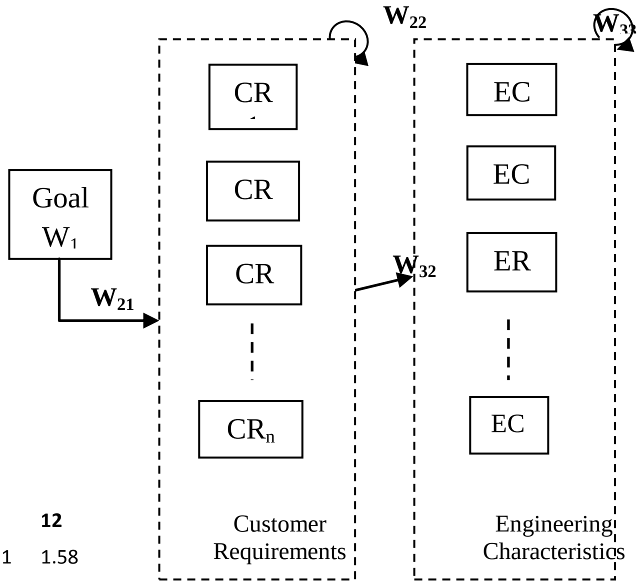

Fig 3: Network representation of QFD matrix

Here,

W_{21} = determine degree of importance for each CRs with respect to goal
W_{22}= Inner dependence among CRs
W_{33}= Inner dependence among ECs
W_{32}= Interrelationship between ECs and CRs means the relation of ECs with respect to each CRs

The following steps are use in QFD-ANP approach [2]

1. Identify the Customer Requirements (CRs) and Engineering Characteristics (ECs)
2. Determine the degrees of importance CRs by assuming that there is no dependence among the CRs (calculation of W_1)
3. Determine the inner dependency matrix of the CRs with respect to each CRs (calculation of W_{22})
4. Determine the inner dependency matrix of the ECs with respect to each EC (calculation of W_{33})
5. Determine the importance degrees of ECs with respect to each CR by assuming that there is no dependence among the ECs (calculation of W_{32})
6. Determine the interdependent priorities of the CRs (calculation of $Wc = W_{22} \times W_1$)
7. Determine the interdependent priorities of the ECs (calculation of $W_A=W_{33} \times W_{32}$)
8. Determining the overall priorities of the ECs (calculation of $W^{ANP}=W_A \times W_c$)

The ANP outcomes were used to complete the HOQ. The HOQ matrix forms the basis for inserting the network model ANP. Representation of ANP in QFD matrix is shown in Figure 4.

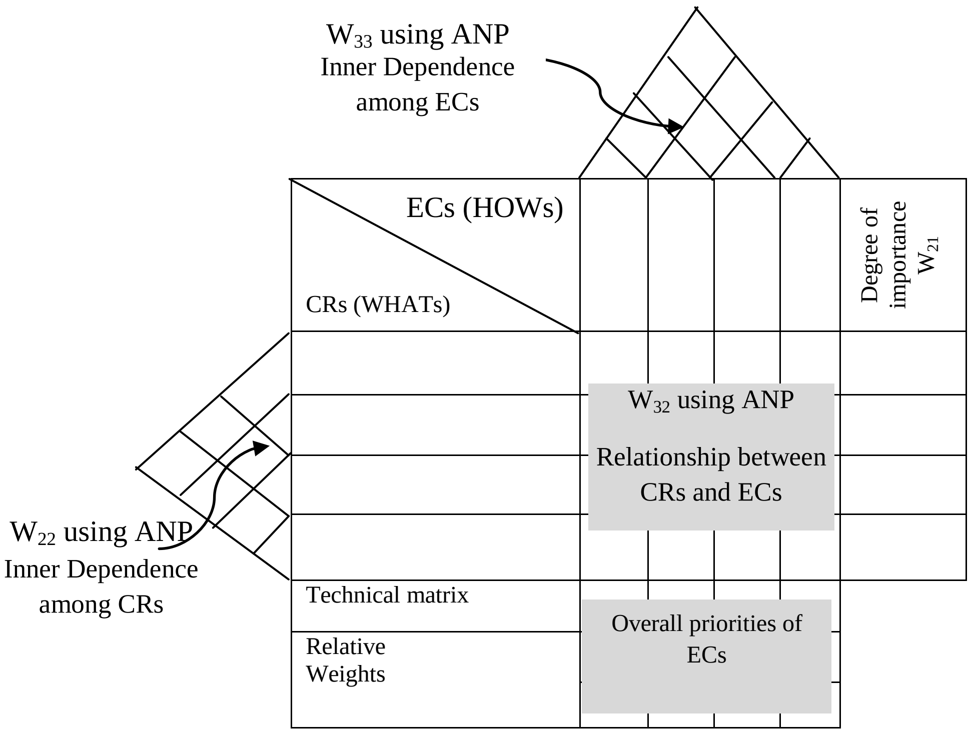

Fig 4: The representation of ANP in QFD matrix

5. CONCLUSION

The paper combined the use of two established methodologies, namely the Quality Function Deployment (QFD) and the Analytic Network Process (ANP), applied to a product development process. QFD matrix shows the visual chart called HOQ which developed the relationship among the CRs and ECs. The outcome of matrix focus on these ECs which is assigns high weight by the customers. This matrix the calculation is involved between degree of importance (CRs) and relationship matrix (CRs and ECs) not include the inner dependence matrix of CRs and ECs. Avoid this problem of QFD matrix include a multi criterion decision making tool such ANP to improve the decision efficiency of QFD matrix. The ANP application is used in QFD matrix to provide a better outcome of decision makers. This methodology helps to applied in decision related problem such as product development process, product selection and product parts selection etc. which are emphasis of these decision criterions to improve the customer satisfaction levels.

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