Part Deployment Model using Combined Quality Function Deployment and Cybernetic Fuzzy Analytic Network Process

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Abstract

Quality Function Deployment (QFD) is a customer oriented design tool used to ensure that customer expectations are satisfied in the early design stage. Customers directly and companies indirectly enjoy the benefits of implementing such methodology. Many extensions have been proposed in order to extend QFD’s application or improve limitation of traditional QFD; among which incorporation of Multi–Criteria Decision Making (MCDM) theories into QFD, in particular Analytic Network Process (ANP) is noteworthy. This paper proposes a new extension of QFD called Fuzzy Cybernetic ANP (FCANP) which is able to model QFD tables, especially when company’s experts deal with a large number of customer demands, while subjectivity of judgments are handled.

Keywords: Fuzzy Cybernetic Analytic Network Process (FCANP), Part Deployment, Quality Function Deployment (QFD)

1. Introduction

Global competitiveness in today’s world is an undeniable necessity of every industrial firm. This fact is not limited to industry and goods production; indeed, it includes all customer-oriented organizations where the customers play a vital role to identify organizational positive and negative aspects¹. They try to achieve better quality and less cost for the products. For this reason, many companies meet the challenges, which are related to various customer demands, and its rapid changes; they must be able to respond quickly to stay in the competitive market. With the emergence of competition, customer satisfaction was considered as the most important issue, and the concept of customer demands (WHATs) produced.

WHAT is a term used broadly in business, it is used to illustrate the identification process of customer’s needs and aversions, and consider these in designing the product.

By focusing on WHATs, QFD has been utilized as a powerful approach to meet customer demands, especially at the product design phase. It systematically translates WHATs into proper company requirements in all stages from product development to engineering and manufacturing stage, marketing and sales, and also distribution².

Conventional QFD, however, has its limitations. Many customized QFD models have been proposed among which integration of Goal Programming, Analytic Hierarchy Process (AHP), Fuzzy logic, Expert
There are two main QFD types; the first one is the Four–Phase model. It consists of four interconnected tables, which start with House of Quality (HoQ) or product planning, followed by part deployment, process planning, and production planning phase. The complete Four–Phase model has been described and illustrated\(^5\). The second deployment is based on Akao’s Matrix\(^6\). Although, these models differ in term of deployment style, they are similar in concept. However, the Four–Phase model is more popular\(^7\). While Four–Phase model represents a complete QFD process, most research only put focus on product planning, the first phase of QFD\(^8\).

Traditionally, customer demands are collected through survey, and then customers are asked to prioritise their needs. Important customer demands are, then, entered into HoQ. Since, the customer needs are usually vague, they should be meaningfully translated into technical measures. Technical measures or HOWs are the way in which WHATs are technically answered. One HOW may answer to only a WHAT. On the other side, it is either possible, one HOW satisfies a number of WHATs. There is also correlation between WHATs, which should be taken into account during the quantification process of HoQ. In order to optimally satisfy customer needs, correlation between HOWs should also be seen. This is because; answering to one customer need may negatively affect other customer needs. The first stage of QFD like an engine derives priority to HOWs through a systematic process. The HoQ is the predecessor of part development table, where technical measures are translated into essential part characteristics. Similar to HoQ, part deployment table derives priority of Part Characteristics (PCs). Figure 1 shows both HoQ and part deployment stages along with their elements.

The paper has been organized as follows: Section 2 briefly reviews existing literature on QFD, ANP–QFD and highlights the gap when ANP is incorporated into QFD. Section 3 describes proposed model of FCANP–QFD. Section 4 illustrates a methodology of this paper on a case study, and finally Section 5 concludes this paper and made some recommendations.

2. **Relevant Studies on QFD and ANP–QFD**

Benefits of QFD are not limited to customer satisfaction, rather QFD enables the company to assign their resources and organize skills based on customer requirements, and, therefore, it would lead to lower production costs by ignoring features with low priority from the customer’s perspective. Its organized environment also evaluates the essential choices from alters and expansion at the starting point of the design process and decreasing the mid project modifications. QFD attracts customers, which result in more selling rates resulting in higher revenues. In this manner, QFD utilizes the whole expansion procedure, minimizing the modifications and waste throughout this stage, and as a result, time optimization is needed for presenting a new product and/or service to the marketplace\(^9\).
Interestingly, if the elements in the roof and porch of QFD tables are respectively regarded as decision alternatives and criteria, QFD can be viewed as Multi–Criteria Decision Making (MCDM) tool since it derives priority to decision alternatives. On the other side, alternatives are prioritised against weighted criteria; therefore, MCDM has been combined with QFD for the purpose of prioritisation. Probably, AHP is the first MCDM theory integrated with QFD to prioritise customer needs, and decision alternatives. However, the concept behind AHP based decision–making is hierarchal modelling of decision problem in which dependence and feedback as an inherent nature of QFD tables were not considered. Later, the AHP generalized into ANP that was able to solve more complex decision problem. In addition, supermatrix approach was replaced with additive synthesis to derive final decision alternatives. The work of Karsak et al. was the pioneer research where ANP is used to model product planning table. However, since 2003, in contrast to other available QFD extensions, which is being widely used, very few studies adopted ANP and incorporated it into QFD. Review of aforementioned ANP in QFD works reveals researchers generally following either simple matrix manipulation or supermatrix approach to estimate final priority of decision alternatives. Meanwhile, fuzzy set theory in several works integrated with the ANP to handle subjectivity of human judgments.

Undoubtedly, there is nothing wrong with the logic behind ANP, however, when a decision problem with a large number of decision criteria, and alternatives is solved with the aid of ANP, this is the inability of the human brain that cannot precisely perform such a large number of pairwise comparisons. It is noteworthy to mention, all above, ANP in QFD models were demonstrated with a simple and small case studies whose number of customer needs and technical measures are less than six. However, in real world QFD cases, a team of experts usually faces with a large number of customer demands, and technical measures. As a result, an extension like conventional ANP that is based on pairwise comparison falls short to model such a QFD tables with large data. Therefore, the methodology of this study aims to propose a new extension that is compatible with real world QFD cases whose decision makers deal with large customer demands, technical measures, and subsequently, product characteristics.

### 3. Methodology

This section presents the modelling framework of implementing QFD up to part deployment phase based on the fuzzy cybernetic ANP model in which supermatrix approach is employed to estimate priority of decision alternatives. The model is based on three steps, namely, problem decomposition or depicting network of interactions, knowledge acquisition and analysis. The steps are demonstrated in Figure 2 and discussed in detail.

![Figure 2. Framework of FCANP–QFD.](image-url)
3.1 Problem Decomposition

Since the first two tables of QFD are considered as decision problem, the initial step is to identify effective components of model. In both tables, WHATs and HOWs, relationship matrix between HOWs and WHATs, and two separate correlation matrix for HOWs and WHATs are regarded as decision components. Then, a focus group is usually conducted, and participants who are company’s experts are asked to identify existent inner and outer-relationships between QFD components. When the dependences are identified, as shown in Figure 3, the decision network including goal, criteria (WHATs), sub–criteria (HOWs), Alternatives (PCs) together with their connections is illustrated.

3.2 Knowledge Acquisition

Following the network of interactions, judgments are elicited with the aid of questionnaire for the purpose of estimating local priority vectors. The pairwise comparison is the heart of ANP/AHP in which one compares two elements in terms of dominance\(^21,22\). In conventional pairwise comparison, respondents are asked to answer this question; given a pair of elements, with respect to the third element, which one of these two elements is more dominant? The response to the question is based on Saaty’s 1–9 scale where 1 and 9 indicate equally and the overwhelming dominance of element \(i\) over \(j\). However, in this study instead of pairwise comparison, pairwiser is employed.

The pairwiser\(^27\) was first introduced as a novel approach for data collection of ANP/AHP in response to the bottleneck problem of data collection work load and inconsistency of judgments when a large number of decision elements should be pairwise compared. His model is called Cybernetic Analytic Network Process (CANP) whereby, instead of comparison of influential elements in pair with respect to a common property, a set of questions are prepared, and experts are asked to score influential elements in term of dominance on the scale of 1–9 where 1 and 9 represent, not important and extremely important respectively.

The CANP was developed based on crisp judgments. However, no human judgment is perfect, and the subjectivity is the inherent part of human judgment, especially during deployment of QFD tables where group of experts are involved in decision making process. Therefore, this paper incorporates fuzzy set theory, and with the aid of triangular fuzzy numbers (TFNs) whose membership function is adopted from the work of Lee and Lin\(^23\), which proposes a new extension based on Fuzzy Cybernetic Analytic Network Process (FCANP).

The difference between FCANP and CANP model is the fuzzification step. Once the judgments on the scale of 1–9 are elicited, according to the defined rules shown in Table 1 judgments are transformed into fuzzy linguistic variables. Then pairwiser comparison matrixes are formed based on corresponding TFNs. Clearly, when a group of K experts are involved in decision making process, K fuzzy pairwiser comparison matrixes are obtained. In order to estimate priority vectors, K fuzzy matrixes are aggregated with the aid of geometric mean. In addition, since priority vectors are obtained by solving the Equation (1) which has been defined for crisp matrixes, aggregated fuzzy comparison matrix are defuzzified with Centre of Gravity (COG) method\(^24\). Reasonably after estimation of priority vectors, consistency test (CR) is conducted as proof of reliability of judgment\(^25\). Experts whose judgments are identified as inconsistent, should be asked to revise their judgments in order to improve consistency ratio.
### Table 1. Pairwiser rules

<table>
<thead>
<tr>
<th>Scores : i and j</th>
<th>Rules</th>
<th>TFN</th>
</tr>
</thead>
<tbody>
<tr>
<td>1=Not important</td>
<td>IF PC = i : j and i − j = 0 THEN LVij = Equal to moderately dominant</td>
<td>(1,1,1)</td>
</tr>
<tr>
<td>2=Not to Moderately important</td>
<td>IF PC = i : j and i − j = 1 THEN LVij = Equal to moderate dominant</td>
<td>(1,2,3)</td>
</tr>
<tr>
<td>3=Moderately important</td>
<td>IF PC = i : j and i − j = 2 THEN LVij = Moderately dominant</td>
<td>(2,3,4)</td>
</tr>
<tr>
<td>4=Moderately to Strongly important</td>
<td>IF PC = i : j and i − j = 3 THEN LVij = Moderately to strongly dominant</td>
<td>(3,4,5)</td>
</tr>
<tr>
<td>5=Strongly important</td>
<td>IF PC = i : j and i − j = 4 THEN LVij = Strong to very strong dominant</td>
<td>(4,5,6)</td>
</tr>
<tr>
<td>6=Strongly to very Strongly important</td>
<td>IF PC = i : j and i − j = 5 THEN LVij = Strong to very strong dominant</td>
<td>(5,6,7)</td>
</tr>
<tr>
<td>7=Very strongly important</td>
<td>IF PC = i : j and i − j = 6 THEN LVij = Very strong dominant</td>
<td>(6,7,8)</td>
</tr>
<tr>
<td>8=Very strongly to Extremely important</td>
<td>IF PC = i : j and i − j = 7 THEN LVij = Very strong to extremely dominant</td>
<td>(7,8,9)</td>
</tr>
<tr>
<td>9=Extremely important</td>
<td>IF PC = i : j and i − j = 8 THEN LVij = Extremely dominant</td>
<td>(9,9,9)</td>
</tr>
</tbody>
</table>

where LV and PC stand for linguistic variable and pairwise comparison respectively.

\[
A.W = \lambda_{\text{max}}W \tag{1}
\]

where, A is the crisp value comparison matrix, w is the eigenvector and \( \lambda_{\text{max}} \) is the largest Eigen Value of A.

### 3.3 Supermatrix Formation and Analysis

The supermatrix is a holistic approach which represents how much an element on the left side of matrix can have influence on an element on the top of matrix\(^2\). In this paper, the following supermatrix represents how two stage QFD tables are modelled in ANP.

\[
W = \begin{bmatrix}
    \text{Goal} & \text{Criteria} & \text{Sub-criteria} & \text{Alternatives} \\
    0 & 0 & 0 & 0 \\
    \text{Criteria} & 0 & W2 & 0 \\
    \text{Sub-criteria} & W4 & W3 & 0 \\
    \text{Alternatives} & 0 & W6 & W5 \\
\end{bmatrix}
\]

Three stages should be followed in order to estimate final priority of decision alternatives; transferring all estimated priority vectors into corresponding cells and forming unweighted supermatrix, normalizing each column of unweighted supermatrix in order to obtain column stochastic matrix, and rising this matrix to power of large arbitrary number to obtain limit supermatrix where final priority of decision alternatives with respect to goal are obtained.

### 3.4 Illustrative Example

In this study, implementation of QFD up to part deployment stage for a laptop manufacturer company whose market focuses on university students was regarded as a case study. The three steps of the methodology were applied to the case study as follows. To hear the voice of customers interview, telephone survey was conducted with 20 students who were selected randomly. During the interview session, they were asked to express their expectations. A preliminary list of 15 customer demands was created. Next, with the aid of questionnaire the initial list was verified and validated. The aim of this step is to ensure that customer did not emotionally respond, and their real voice is heard. Hence, 4 unimportant demands were identified and the final list of 11 customer needs was given to the company. Then, focus groups of 5 technical experts were formed and participants were asked to determine part characteristics as well as technical measures for each and every customer demand. Once the decision elements entirely identified, the participants were asked to find relationships and correlations between them.

It is obviously possible to obtain 5 different networks since experts might have different opinion about the relationships and correlations. In this case study, the same situation happened. In order to reach a consensus, experts were asked to give at least one logical reason for each connection they made. The connections regarded acceptable if at least 3 participants agreed upon the given reason. Then, with the aid of The Super decision software network of interactions were depicted\(^3\). Table 2 and Figure 1 show the decision components and network model of this case study respectively.

For the purpose of knowledge acquisition, since two different target groups were involved in the decision making process, two sets of questions were designed, one for students in which they were asked...
to prioritise their expectations; and the second one designed to acquire the knowledge of focus group’s participants. The responses were made on the scale of 1–9, following the framework of pairwiser approach (Table 1). Once the pairwisers finished, the results were translated from crisp into fuzzy linguistic variables. Then, in order to aggregate different responses, geometric mean of answers was calculated; prior to use Equation (1), fuzzy judgments were transformed into crisp values and then by solving Equation (1) vectors of priority were estimated. Finally, consistency of judgments was tested to measure accuracy of estimated priorities.

The knowledge acquisition process when four decision elements, viz., ‘slow battery drains’, ‘better process’, ‘display brightness optimization’ and ‘better hardware and software compatibility’ are compared with respect to ‘long operating time’ as shown in Tables 3–6. Table 3 shows the responses of 5 participants when they were asked to score the influential elements. As it is shown in Table 4, by applying pairwiser rules, given scores were converted to pairwise comparisons. Table 5 shows how to transform crisp pairwise comparisons into fuzzy linguistic variables, followed by aggregation of five fuzzy judgments and defuzzification. And finally, Table 6 represents estimated priority vectors of four decision elements whose inconsistency ration is reasonably acceptable (less than 0.1).

It is noteworthy to mention, it is possible to use the super decision software for the purpose of deriving local priority vectors. Decision makers need to enter aggregated defuzzified outputs into the Matrix tab of software since the outputs are usually decimal numbers. This software is not only helpful for this purpose, it can also raise a huge supermatrix to power in order to estimate final priority of decision alternatives with higher reliability and accuracy. Therefore, all the estimated priority vectors were transferred in the corresponding supermatrix cells, and the software formed column stochastic and finally computed limit supermatrix. Figure 4 shows the limit supermatrix of this case study when the superdecision was employed. The overall priority of decision alternatives with respect to goal in three different formants: raw, normalized and idealized are shown in Table 7.
### Table 4. Conversion from pairwise to pairwise comparison

<table>
<thead>
<tr>
<th>wrt LOT</th>
<th>DBO</th>
<th>HSC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>E1</td>
<td>E2</td>
</tr>
<tr>
<td>SBD</td>
<td>0.1667</td>
<td>0.333</td>
</tr>
<tr>
<td>BP</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>DBO</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>HSC</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

### Table 5. Linguistic pairwise comparisons

<table>
<thead>
<tr>
<th>wrt LOT</th>
<th>E1</th>
<th>E2</th>
<th>E3</th>
<th>E4</th>
<th>E5</th>
<th>SBD</th>
<th>BP</th>
</tr>
</thead>
<tbody>
<tr>
<td>SBD</td>
<td>(1/7,1/6,1/5)</td>
<td>(1/4,1/3,1/2)</td>
<td>(1/5,1/4,1/3)</td>
<td>(1/6,1/5,1/4)</td>
<td>(1/6,1/5,1/4)</td>
<td>(1/4,1/3,1/2)</td>
<td>(1/4,1/3,1/2)</td>
</tr>
<tr>
<td>BP</td>
<td>(4,5,6)</td>
<td>(1,2,3)</td>
<td>(1,2,3)</td>
<td>(1,2,3)</td>
<td>(2,3,4)</td>
<td>(1/6,1/5,1/4)</td>
<td>(1/6,1/5,1/4)</td>
</tr>
<tr>
<td>DBO</td>
<td>(1,1,1)</td>
<td>(1,1,1)</td>
<td>(1,1,1)</td>
<td>(1,1,1)</td>
<td>(1,1,1)</td>
<td>(1,1,1)</td>
<td>(1,1,1)</td>
</tr>
</tbody>
</table>

**DBO**

\[ \sqrt[5]{\left(\frac{a_{ij}1^{*}a_{ij}2^{*}a_{ij}3^{*}a_{ij}4^{*}a_{ij}5}{5}\right)}^{1/5} \]

\[ a_{ij} = \frac{L_{ij} + (U_{ij} - L_{ij} + T_{ij} - L_{ij})}{3} \]

\[ a_{ij} = (L_{ij}, T_{ij}, U_{ij}) \]

**Aggregated**

\[ (0.259,0.550,0.759) \]

**Defuzzified**

\[ 0.172 \]

### Table 6. Linguistic pairwise comparisons

<table>
<thead>
<tr>
<th>wrt LOT</th>
<th>E1</th>
<th>E2</th>
<th>E3</th>
<th>E4</th>
<th>E5</th>
<th>SBD</th>
<th>BP</th>
</tr>
</thead>
<tbody>
<tr>
<td>SBD</td>
<td>(1/7,1/6,1/5)</td>
<td>(1/6,1/5,1/4)</td>
<td>(1/6,1/5,1/4)</td>
<td>(1/6,1/5,1/4)</td>
<td>(1/6,1/5,1/4)</td>
<td>(1/4,1/3,1/2)</td>
<td>(1/4,1/3,1/2)</td>
</tr>
<tr>
<td>BP</td>
<td>(1,1,1)</td>
<td>(1,1,1)</td>
<td>(1,1,1)</td>
<td>(1,1,1)</td>
<td>(1,1,1)</td>
<td>(1,1,1)</td>
<td>(1,1,1)</td>
</tr>
</tbody>
</table>

**DBO**

\[ \sqrt[5]{\left(\frac{a_{ij}1^{*}a_{ij}2^{*}a_{ij}3^{*}a_{ij}4^{*}a_{ij}5}{5}\right)}^{1/5} \]

\[ a_{ij} = \frac{L_{ij} + (U_{ij} - L_{ij} + T_{ij} - L_{ij})}{3} \]

\[ a_{ij} = (L_{ij}, T_{ij}, U_{ij}) \]

**Aggregated**

\[ (0.259,0.550,0.759) \]

**Defuzzified**

\[ 0.172 \]

### Table 7. Linguistic pairwise comparisons

<table>
<thead>
<tr>
<th>wrt LOT</th>
<th>E1</th>
<th>E2</th>
<th>E3</th>
<th>E4</th>
<th>E5</th>
<th>SBD</th>
<th>BP</th>
</tr>
</thead>
<tbody>
<tr>
<td>SBD</td>
<td>(1/3,1/2,1)</td>
<td>(1/3,1/2,1)</td>
<td>(1/4,1/3,1/2)</td>
<td>(1/6,1/5,1/4)</td>
<td>(1/4,1/3,1/2)</td>
<td>(1/6,1/5,1/4)</td>
<td>(1/4,1/3,1/2)</td>
</tr>
<tr>
<td>BP</td>
<td>(1,1,1)</td>
<td>(1,1,1)</td>
<td>(1,1,1)</td>
<td>(1,1,1)</td>
<td>(1,1,1)</td>
<td>(1,1,1)</td>
<td>(1,1,1)</td>
</tr>
</tbody>
</table>

**DBO**

\[ \sqrt[5]{\left(\frac{a_{ij}1^{*}a_{ij}2^{*}a_{ij}3^{*}a_{ij}4^{*}a_{ij}5}{5}\right)}^{1/5} \]

\[ a_{ij} = \frac{L_{ij} + (U_{ij} - L_{ij} + T_{ij} - L_{ij})}{3} \]

\[ a_{ij} = (L_{ij}, T_{ij}, U_{ij}) \]

**Aggregated**

\[ (0.259,0.550,0.759) \]

**Defuzzified**

\[ 0.172 \]
4. Conclusion and Recommendation

The methodology of this paper was developed for the first two stages of a four-phase model, namely, product planning and parts deployment. However, this methodology is able to cover all four phases, if extended. In this paper, a new ANP based extension was proposed for QFD in response to two major bottlenecks: the problem or difficulty of data collection, and the possibility of receiving inconsistent judgments when ANP is utilized to model a QFD with large number of components. These two issues led our research team to introduce a fuzzy cybernetic ANP as a new extension for QFD in which subjectivity of judgments is handled by applying fuzzy set theory. In this regard, for the proposed case study, instead of performing 130 pairwise comparisons, experts were asked to answer only 66
questions which significantly facilitate data collection process. Furthermore, while there are two ways to estimate final priority of decision alternatives, a careful selection should be made in order to select either supermatrix or simple matrix manipulation method. Although, simple matrix manipulation is more popular, supermatrix approach is more versatile and able to analysis more complex models. Nevertheless, it is less favourable when there are many inner-dependence between QFD elements. The reason behind is, in the second or third cycle of rising weighted supermatrix into power, priority of decision alternatives shifts to zero. Therefore, in such cases, it is recommended to use simple matrix manipulation method. In addition, this research used triangular fuzzy numbers whose membership function was adapted from previous research. Researchers are encouraged to apply other types of fuzzy numbers, such as trapezoidal or bell shape fuzzy numbers together with a proper membership function.

5. Acknowledgement

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