Evaluation of Conceptual Product Design Solutions using House of Quality-TOPSIS Integrated Methodology

K.G.Durga Prasad [1], K.Venkata Subbaiah [2], Ch.Hima Gireesh[3], U.Koushik[4]

[1]*Professor*, [2] *Professor*, [3]*Assistant Professor*, [4] *Student*

[1, 3,4] *Department of Mechanical Engineering, G.V.P. School of Engineering, G.V.P. College for Degree & P.G.Courses(A), Visakhapatnam, Andhra Pradesh, India.*

[2]*Department of Mechanical Engineering, A.U. College of Engineering (A), Andhra University, Visakhapatnam, Andhra Pradesh, India.*

Abstract – *The product design concept selection is an integral part of product development process. It is a team based decision making effort to evaluate the product design concepts generated. In the present competitive market environment, the design team has to identify the design solution which should reflect the customer needs to ensure customer satisfaction. In this paper an attempt has been made to develop a methodology by integrating House of quality (HOQ) and the technique for order preference by similarity to ideal solution (TOPSIS) with a view to identifying the best design solution to meet the customer needs. The Analytic hierarchy process (AHP) is employed to prioritize the customer needs while constructing the HOQ. The proposed integrated methodology has been demonstrated through a numerical illustration in this paper.*

Keywords – ***Product design concept selection, House of quality, AHP, TOPSIS.***

I. Introduction

The manufacturing companies have been looking towards customer - focused product development with a view to maintaining competitive advantage in the market. The identification of customer needs and transforming them into a product is the prime focus in product development. There are different stages in product development process. But product conceptualization is the key stage which comprises two major activities, namely concept generation and concept selection (Yan et al., 2006). The concept selection is crucial as it determines the direction for the subsequent product design stages. The activity of judging and selecting from a range of competing design solutions is referred to as concept evaluation. After the concept generation, the evaluation is essentially required for the selection of best design option. The selection of optimum design solution is extremely important for making design decisions in product development process. The product design concept evaluation is characterized by multi-criteria decision-making under uncertainty. Tradeoffs must be evaluated among various conflicting criteria with respect to a set of competing alternatives (Jiao and Tseng, 1998). On the basis of subjective and incomplete design information collected at the early design stage, it is difficult to select the best design concepts from a number of alternatives. To tackle this problem Wang (2001) developed fuzzy outranking preference model based on the possibility theory. Ayag (2005) described an approach by integrating Analytic hierarchy process (AHP) and simulation techniques effectively to evaluate conceptual design alternatives in a new product development environment. In order to address product concept generation and evaluation, Huang et al., (2006) established an integrated computational intelligence approach by using genetic algorithm and fuzzy neural network. On the basis of grey relation analysis (GRA) and rough set theory, Zhai et al., (2009) proposed a methodology to improve the effectiveness and objectivity of the design concept evaluation process. Geng et al., (2010) established a new integrated design concept evaluation approach based on vague sets. Akay et al., (2011) emphasized the need for fuzzy decision models for selecting the best conceptual design among a set of alternatives. They presented a new concept selection methodology called interval-type-2 fuzzy information axiom (IT2-FIA). To improve the quality and effectiveness of concept evaluation in the early phases of new product development, Song et al., (2013) presented a novel integrated decision-making approach by using rough AHP and rough TOPSIS for manipulating subjective assessments in new product development environments. Kamal and Salhieh (2013) suggested methodology integrates the Weighted Concept Selection Matrix with the Analytical Hierarchal Process (AHP) under a Fuzzy environment. Salhieh and Al-Harris (2014) developed integrated methodology using Data Envelopment Analysis (DEA) and conjoint analysis (CA) for evaluating and selection of new concepts. Kang and Tang (2014) proposed a novel approach to analyze conceptual design activities. They adopted similarity theory and ant colony optimization for product solution generation and evaluation. Chang and Chen (2015) established a product concept evaluation and selection approach based on data mining and domain ontology to assist designers in processing crowd-sourced design concepts. To reduce the imprecise content of customer evaluation process during product design concept evaluation, Tiwari et al., (2016) proposed a methodology using rough sets and VIKOR technique.

Tiwari et al., (2017) presented a novel method of mapping customer requirements to design concepts through the application of soft set theory.

In order to satisfy the rapidly changing customer demands and to manage the shorter product life cycle in terms of high quality output, the manufacturing firms are under increasing pressure to establish customer-focused product development. In this context, it is necessary for appropriate evaluation and selection of optimum design solution to meet the expectations of the customers. To address the evaluation of product design concepts under customer-focused product development an integrated methodology using House of quality (HOQ), AHP and TOPSIS has been proposed in this paper. Prior to present the proposed methodology, the overview of HOQ, AHP and TOPSIS techniques are discussed briefly in the following paragraphs.

A. HOQ

The first phase of Quality Function Deployment (QFD), a customer-focused product development technique is known as House of Quality (HOQ). It helps to understand the voice of customer and translate it into the voice of the engineer (Hauser, 1993). The basic structure of HOQ appears like a normal house shown in Fig.1.

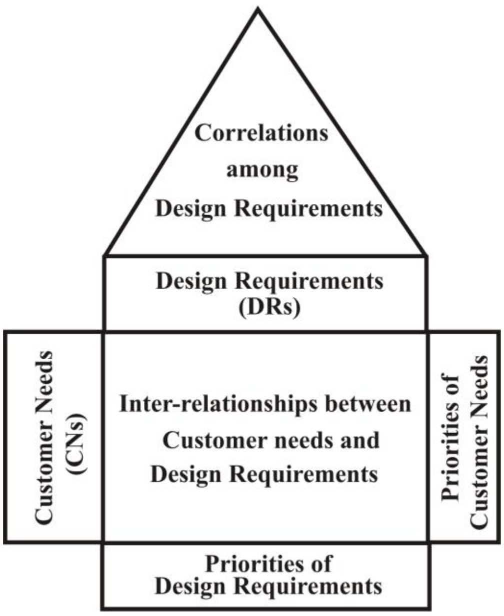

Fig. 1: House of Quality

The exterior walls of the house are the descriptions of customer needs and expectations. The Voice of customer is located on the left side and the priority structure of customer needs is placed on the right side. The priority structure reflects the importance of customer needs. The design requirements are occupied at the ceiling of the house. The important part of the house is the interior or living room which holds the inter-relationships among customer needs and design requirements. The exact translation between customer needs and design requirements takes place in this inter-relationship matrix. The roof of the house is provided with correlations among design requirements. The prioritized design requirements are the outcome of HOQ and hence the priority structure of design requirements forms the foundation for the house. The priorities of the design requirements show the excellence of construction of HOQ. The customer perceptions are reflected in the priorities of the design requirements.

B. AHP

The Analytic Hierarchy Process (AHP) is a decision support tool which can be used to solve complex decision problems. It uses a multi-level hierarchical structure of objectives, criteria, sub criteria, and alternatives. The pertinent data are derived by using a set of pair-wise comparisons (Khan et al., 2014). The pair-wise comparisons are quantified by using a scale proposed by Saaty used for one-to-one mapping between the set of discrete linguistic choices available to the decision maker and a discrete set of numbers which represent the importance or weight of the previous linguistic choices. In the Saaty scale 9 indicates the upper limit and 1 as the lower limit and a unit difference between successive scale values. The values of the pair-wise comparisons in the AHP are determined using Saaty scale. According to Saaty scale, the available values for the pair-wise comparisons are members of the set: {9, 8, 7, 6, 5, 4, 3, 2, 1, 1/2, 1/3, 1/4, 1/5, 1/6, 1/7, 1/8, 1/9} (Triantaphyllou and Mann, 1995). These comparisons are used to obtain the weights of importance of the decision criteria, and the relative performance measures of the alternatives in terms of each individual decision criterion. If the comparisons are not perfectly consistent, then it provides a mechanism for improving consistency. AHP aims at quantifying relative priorities for a given set of alternatives on a ratio scale, based on the judgment of the decision-maker, and stresses the importance of the intuitive judgments of a decision-maker as well as the consistency of the comparison of alternatives in the decision-making process (Kamal, 2001). Saaty (1980) proposed consistency index (CI) and consistency ratio (CR) for checking the consistency of the pair-wise judgments. The CI and CR are defined as follows.

$$\text{CI} = \frac{\lambda_{\max} - n}{n-1} \quad \text{and} \quad \text{CR} = \frac{\text{CI}}{\text{RI}}$$

Where $\lambda_{\max}$ = maximum principal eigen value of the comparison matrix

and n = number of elements

The value of $\lambda_{\max}$ is obtained by first multiplying the pair-wise comparison matrix with the priority matrix. Then divide the first element of the resulting matrix by the first element of the priority matrix, the second element of the resulting matrix by the second element in the priority matrix, and so on. A single column matrix is obtained and the average of the elements of the matrix gives the value of $\lambda_{\max}$. The RI in the above equation represents the average consistency index for numerous random entries of same-order reciprocal matrices (Saaty, 1980). It is important to note that the AHP results are consistent only when the value of CR is less than 0.10 (Chang et al., 2007).

C. TOPSIS

The TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) is a multi-attribute decision making technique proposed by Hwang and Yoon. The main idea of TOPSIS came from the concept of the compromise solution to choose the best alternative nearest to the positive ideal solution (optimal solution) and farthest from the negative ideal solution (inferior solution). Then, choose the best one of sorting, which will be the best alternative (Tzeng and Huang, 2011). The TOPSIS has two main advantages: its mathematical simplicity and very large flexibility in the definition of the choice set. When solving real-life problems, or representing real world phenomena, linguistic variable usually appears to be an important output of the process (Hsu et al., 2009). To apply TOPSIS technique, attribute values must be numeric, monotonically increasing or decreasing, and have commensurable units. After forming an initial decision matrix, the TOPSIS procedure starts by normalizing the decision matrix. This is followed by building the weighted normalized decision matrix. Then the positive and negative ideal solutions have to be determined. The separation measures for each alternative are calculated in the next step. The procedure ends by computing the relative closeness coefficient. The set of alternatives can be ranked according to the descending order of the closeness coefficient (Behzadian et al., 2012). However, the highest ranked alternative by TOPSIS is the best in terms of the ranking index. Therefore, in the present work an integrated methodology is proposed by using TOPSIS along with HOQ with a view to evaluate product design solutions under customer-focused product development, which is discussed below.

II. PROPOSED METHODOLOGY

In order to take appropriate decision on selection of product design solution, a methodology is proposed by integrating HOQ, AHP and TOPSIS. In this methodology the priority structure of customer needs is obtained by using AHP. The translation of customer's conception into designer's conception takes place in HOQ. The outcome of HOQ provides the weightages for the design requirements and is used in determining the closeness coefficient for each design solution. On the basis of TOPSIS closeness coefficient values, it is easier for a decision maker to identify the best design solution which ensures customer satisfaction. The step by step methodology is discussed below.

***Step* 1: Identification of customer needs**

One of the critical aspects in constructing HOQ is the identification of customer needs. Customer needs are usually generated by carrying out a customer survey for a product. After the identification of targeted customers and demographics, questionnaire survey has to be conducted to obtain the responses of the customers regarding their views and desires and these are to be incorporated in the product. Market survey reports also useful means of capturing the voice of customer.

***Step* 2: Prioritization of customer needs**

The relative importance values of the customer needs are required to construct HOQ. The use of AHP is a more adequate approach for the prioritization of customer needs (Armacost et al., 1994). Therefore, AHP procedure (Durga Prasad et al., 2011) can be employed to obtain priority structure of customer needs.

***Step* 3: Establishment of product design requirements**

After capturing the voice of customer, the appropriate product design requirements are established by the design experts in view of achieving customer satisfaction. The outcome of the brainstorming sessions held with the design experts provide the list of design requirements for a product to ensure customer satisfaction.

***Step* 4: Establishment of inter-relationship matrix of HOQ**

The inter-functional team prepares the inter-relationship matrix by using 1-3-9 rating scale which shows the strength of relationship between customer needs and design requirements.

***Step* 5: Obtain weightages for the design requirements**

The absolute and relative importance of design requirements is computed using the priority ratings of customer needs and the inter-relationship values of HOQ matrix. The relative importance values of the design requirements are the weightages for the design requirements. For each design requirement, the absolute importance rating is computed by using

$$a_{ij} = \sum_{j=1}^{n} S_i R_{ij}$$

Where a_{ij} = Absolute importance of the j^{th} design requirement $(j = 1, 2, 3, \ldots n)$ with respect to i^{th} customer need.

S_i = Priority rating of the i^{th} customer need.

R_{ij} = Inter-relationship value for the i^{th} customer need and j^{th} design requirement.

The relative importance values (weightages) of design requirements are calculated by using the formula

$$w_j = \frac{a_{ij}}{\sum_{j}^{n} a_{ij}}$$

***Step* 6: Generation of conceptual design solutions**

The product design concept is an approximate description of the product. It is the concise description of how the product will satisfy the customer needs. During the concept generation stage of product development, the design team has to develop different alternative concepts (design solutions) with their expertise in the field of designing the particular product. Usually the design solutions are having different values for the design requirements of the product. Customer focus should be considered while generating design solutions. The competitors design strategy is also to be considered with a view to achieve market position. After developing the design solutions, the next task is to identify the optimal design solution.

***Step 7*: Formulation of MCDM decision matrix**

The MCDM decision matrix has to be formed as shown below

	C_1	C_2	C_3	.	.	C_m
A_1	x_{11}	x_{12}	x_{13}	.	.	x_{1m}
A_2	x_{21}	x_{22}	x_{23}	.	.	x_{2m}
A_3	x_{31}	x_{32}	x_{33}	.	.	x_{3m}
.	.	.	.	.	.	.
.	.	.	.	.	.	.
A_n	x_{n1}	x_{n2}	x_{n3}	.	.	x_{nm}

Where A_i = the i^{th} alternative (i =1, 2,………., n)

C_j = the j^{th} criterion (j =1, 2,........., m)

x_{ij} = individual performance rating.

***Step 8*: Representation of normalized decision matrix**

The normalized decision matrix can be developed by determining normalized ratings using the following formula.

$$r_{ij}(x) = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{n} x_{ij}^2}}$$

, i =1,2,……,n; j =1,2,…,m; and x_{ij} is the performance of alternative A_j with respect to the j^{th} criterion.

***Step 8*: Construction of weighted normalized decision matrix**

Weighted normalized matrix is developed by determining the weighted normalized ratings using the following expression.

$$v_{ij}(x) = w_j\left[r_{ij}(x)\right]$$

Where w_j = weightage of j^{th} design requirement.

***Step 9*: Deriving positive-ideal solution and negative-ideal solution**

The positive ideal solution V^+ and the negative ideal solution V^- are determined as follows:

$$V^+ = \max\left\{v_1^+(x), v_2^+(x), ,.., v_j^+(x)\right\}, j = 1, 2, ...m$$

$$V^- = \min\left\{v_1^-(x), v_2^-(x), ,.., v_j^-(x)\right\}, j = 1, 2, ...m$$

***Step 10*: Calculation of separation measures for each alternative**

The separation measures from the positive and the negative ideal solution between the alternatives are calculated. The separation (distances) of each alternative from positive ideal solution can be calculated by the equation given below.

$$D_i^+ = \sqrt{\sum_{j=1}^{m}\left\{\left[v_{ij}(x) - v_j^+(x)\right]\right\}^2}$$

Similarly the separation (distances) of each alternative from negative ideal solution can be calculated by using the following equation.

$$D_i^- = \sqrt{\sum_{j=1}^{m}\left\{\left[v_{ij}(x) - v_j^-(x)\right]\right\}^2}$$

***Step 11*: Computation of closeness coefficient**

The closeness coefficients for all the alternatives are calculated by using the following expression.

$$C_i^+ = \frac{D_i^-}{D_i^+ + D_i^-} \quad (\text{where } i = 1, 2, 3....., n)$$

The value of closeness coefficient $\left(C_i^+\right)$ lies in between 0 and 1.

***Step 12*: Rank the alternatives**

The alternatives have to be ranked on the basis of closeness coefficient values.

***Step 13*: Select the best alternative**

The preferred alternative (design solution) is the one which has the highest value of closeness coefficient (closest to 1).

III. NUMERICAL ILLUSTRATION

In India, most of the people adopted to use ceiling fans which create a wind chill effect that makes people comfortable during hot weather. Ceiling fans induce air movement distribution within a room and alleviate physiological discomfort because of sweat evaporation. A case of designing a domestic ceiling fan is considered to demonstrate the proposed methodology. Personnel interviews were conducted with the customers to capture the voice of customer. After several comprehensive discussions, seven major customer needs are identified and are shown in Table1. The priority structure of the customer needs is obtained by using AHP. The pair-wise comparison matrix and the normalized pair-wise comparison matrix have been developed using AHP procedure (Venkata Subbaiah et al., 2011). The Table 2 shows the normalized pair-wise comparison matrix. In the present work, the value of consistency ratio is computed and is 0.0194. As the value of consistency ratio is less than 0.10, the AHP results were consistent.

Table1. List of customer needs

Sl.No	Customer needs
1	More human comfort (MC)
2	High speed (HS)
3	Less noise (LN)
4	Less power consumption (LPC)
5	Smaller size (SS)
6	Less cost (LC)
7	Service reliability (SR)

Table 2. Normalized pair-wise comparison matrix

	MC	HS	LN	LPC	SS	LC	SR
MC	0.411	0.463	0.417	0.416	0.337	0.314	0.265
HS	0.206	0.231	0.278	0.250	0.280	0.235	0.235
LN	0.136	0.116	0.139	0.166	0.168	0.196	0.177
LPC	0.082	0.076	0.069	0.083	0.112	0.118	0.147
SS	0.069	0.046	0.046	0.042	0.056	0.078	0.088
LC	0.051	0.039	0.028	0.027	0.028	0.051	0.059
SR	0.046	0.029	0.023	0.017	0.019	0.019	0.029

The priority ratings of the customer needs are obtained by dividing each row sum of Table 2 with the number of customer needs. The priority structure of customer needs is presented in Table 3.

Sl.No	Customer needs	Priority rating
1	MC	0.374
2	HS	0.245
3	LN	0.156
4	LPC	0.098
5	SS	0.061
6	LC	0.040
7	SR	0.026

Table 3.Priority structure of customer needs

After several discussions made with the design experts, six design requirements have been explored to satisfy the customer needs which are shown in Table 4.

Table 4.List of design requirements

Sl.No	Design requirements
1	Air delivery (AD)
2	Number of blades (NB)
3	Span length (SL)
4	Motor speed (MS)
5	Power rating (PR)
6	Warranty (WR)

In order to establish inter-relationship matrix between customer needs and design requirements rigorous brainstorming sessions are conducted with the experts in the field of design. The strength of the relationships between customer needs and design requirements is represented by adopting 1(weak)-3(moderate) -9 (strong) scale. The inter-relationship matrix is shown in the Table 5.

Table 5. Inter-relationship matrix of HOQ

		Design requirements					
		AD	NB	SL	MS	PR	WR
Customer needs	MC	9	1	3	9	3	1
	HS	1	3	1	9	9	1
	LN	1	9	1	9	3	1
	LPC	3	1	3	9	9	1
	SS	3	3	9	1	1	1
	LC	3	9	9	3	1	1
	SR	1	1	1	9	1	9

The absolute and relative importance values of design requirements are computed as discussed in step 6 of the proposed methodology. The Table 6 shows the absolute and relative importance values of all the design requirements.

Sl. No	Design requirements	Absolute importance	Relative importance (weightages)
1	Air delivery	4.387	0.178
2	No. of blades	3.171	0.129
3	Span length	2.743	0.112
4	Motor speed	8.269	0.336
5	Power rating	4.803	0.195
6	Warranty	1.207	0.049

Table 6. Absolute and relative importance values of design requirements

The conceptual design solutions summarized in Table 7 have been generated through focus group discussions for manufacturing domestic ceiling fans to meet the expectations of the customers.

DS	AD (cmm)	NB (No.)	SL (inch)	MS (rpm)	PR (W)	WR (years)
DS1	220	3	50	350	38	1
DS2	230	3	48	385	35	1
DS3	270	4	56	350	38	1
DS4	235	3	47	340	74	1
DS5	205	4	49	310	70	1
DS6	210	5	52	290	50	1
DS7	187	4	42	255	75	1

Table 7. Design solutions (DS) for domestic ceiling fans

On the basis of data of seven design solutions, normalized decision matrix is developed as discussed in step 8 of the proposed methodology. The normalized decision matrix is obtained as given below.

$$\begin{bmatrix} 0.371 & 0.3 & 0.383 & 0.403 & 0.252 & 0.377 \\ 0.388 & 0.3 & 0.367 & 0.443 & 0.232 & 0.377 \\ 0.456 & 0.4 & 0.429 & 0.403 & 0.252 & 0.377 \\ 0.396 & 0.3 & 0.360 & 0.391 & 0.492 & 0.377 \\ 0.346 & 0.4 & 0.375 & 0.356 & 0.465 & 0.377 \\ 0.354 & 0.5 & 0.398 & 0.333 & 0.332 & 0.377 \\ 0.315 & 0.4 & 0.321 & 0.293 & 0.498 & 0.377 \end{bmatrix}$$

The weighted normalized decision matrix is developed by multiplying the normalized decision matrix with the weightages of the design requirements. The weighted normalized decision matrix is given below.

$$\begin{bmatrix} 0.066 & 0.038 & 0.042 & 0.135 & 0.049 & 0.018 \\ 0.069 & 0.038 & 0.041 & 0.148 & 0.045 & 0.018 \\ 0.081 & 0.051 & 0.048 & 0.135 & 0.049 & 0.018 \\ 0.070 & 0.038 & 0.040 & 0.131 & 0.095 & 0.018 \\ 0.061 & 0.051 & 0.042 & 0.119 & 0.090 & 0.018 \\ 0.063 & 0.064 & 0.044 & 0.111 & 0.064 & 0.018 \\ 0.056 & 0.051 & 0.035 & 0.098 & 0.097 & 0.018 \end{bmatrix}$$

The positive ideal solution (PIS) and negative ideal solutions (NIS) are determined by considering the data under two approaches such as larger is better and smaller is better. The PIS $\left(V^{+}\right)$ and NIS $\left(V^{-}\right)$ are expressed as follows.

$$V^{+} = \{0.081, 0.038, 0.044, 0.148, 0.045, 0.018\}$$

$$V^{-} = \{0.056, 0.064, 0.040, 0.098, 0.097, 0.018\}$$

The distance of each alternative (design solution) from positive ideal solution as well as from negative ideal solution can be calculated as discussed in the step 10 of the methodology discussed in the previous section. For instance, the distance of DS1 from the PIS and NIS are computed as follows.

$$D_1^{+} = \sqrt{\begin{matrix}(0.081-0.066)^2 + (0.038-0.038)^2 + (0.044-0.042)^2 + \\ (0.148-0.135)^2 + (0.045-0.049)^2 + (0.081-0.018)^2\end{matrix}}$$
$$= 0.002689$$

$$D_1^{-} = \sqrt{\begin{matrix}(0.066-0.056)^2 + (0.038-0.064)^2 + (0.042-0.04)^2 + \\ (0.135-0.098)^2 + (0.049-0.097)^2 + (0.081-0.018)^2\end{matrix}}$$
$$= 0.004453$$

In the same way the distances are measured for all the remaining design solutions and are summarized in the Table 8. The closeness coefficient for design solution DS 1 is computed as shown below.

$$C_1^{+} = \frac{0.004453}{0.002689 + 0.004453} = 0.5629$$

Similarly the closeness coefficients for the remaining design solutions are calculated and the closeness coefficients for all the design solutions are shown in Table 8. The priority ranks are assigned to the design solutions on the basis of closeness coefficient values and are also presented in Table 8.

Table 8. Separation measures, Closeness coefficients and Ranks of design solutions

Design solution	Separation measures		Closeness coefficient $\left(C_i^{+}\right)$	Rank
	D_i^{+}	D_i^{+}		
DS 1	0.002689	0.004453	0.5629	2
DS 2	0.001409	0.000605	0.3960	3
DS 3	0.001801	0.004531	0.6135	1
DS 4	0.006805	0.001965	0.3497	4
DS 5	0.008470	0.000688	0.2217	6
DS 6	0.011630	0.001323	0.2522	5
DS 7	0.013085	0.000194	0.0906	7

Ii is observed from the Table 8, the closeness coefficient of design solution DS-3 is higher than that of the remaining design solutions. According to TOPSIS the design solution DS-3 is the best design solution to attain complete satisfaction of the customers.

IV. CONCLUSIONS

Product design concept evaluation is one of the major activities for obtaining an optimal concept in conceptual design stage of product development. The evaluation of design options is a multi-attribute decision making problem. To solve the problem of evaluating design solutions, a methodology has been proposed in this paper. In the case of customer-focused product development, the customer desires have to be considered while taking decision on the selection of design solution. In order to address this issue, methodology is developed by integrating HOQ and TOPSIS for successful product development. The HOQ analysis provides the priority ratings of the design requirements through aligning customer perception and designer conception. These priority ratings are used in TOPSIS methodology to explore optimal design solution for achieving customer satisfaction. The proposed methodology can support the decision makers for identifying appropriate design solution of any product under customer centric product development.

REFERENCES

[1] Akay, D., Kulak, O. and Henson, B., 2011. Conceptual design evaluation using interval type-2 fuzzy information axiom. *Computers in Industry*, *62*(2), pp.138-146.

[2] Armacost, R.L., Componation, P.J., Mullens, M.A. and Swart, W.W., 1994. An AHP framework for prioritizing customer

requirements in QFD: an industrialized housing application. *IIE transactions*, *26*(4), pp.72-79.

[3] Ayağ, Z., 2005. A fuzzy AHP-based simulation approach to concept evaluation in a NPD environment. *IIE transactions*, *37*(9), pp.827-842.

[4] Behzadian, M., Otaghsara, S.K., Yazdani, M. and Ignatius, J., 2012. A state-of the-art survey of TOPSIS applications. *Expert Systems with Applications*, *39*(17), pp.13051-13069.

[5] Chang, D. and Chen, C.H., 2015. Product concept evaluation and selection using data mining and domain ontology in a crowdsourcing environment. *Advanced Engineering Informatics*, *29*(4), pp.759-774.

[6] Chang, C.W., Wu, C.R., Lin, C.T. and Lin, H.L. (2007), 'Evaluating digital video recorder systems using analytic hierarchy and analytic network processes', *Information Sciences*, Vol.177, No.16, pp.3383-3396.

[7] Geng, X., Chu, X. and Zhang, Z., 2010. A new integrated design concept evaluation approach based on vague sets. *Expert Systems with Applications*, *37*(9), pp.6629-6638.

[8] Hauser, J.R., 1993. How Puritan-Bennett used the house of quality. *Sloan Management Review*, *34*(3), p.61.

[9] Hsu, T.K., Tsai, Y.F. and Wu, H.H., 2009. The preference analysis for tourist choice of destination: A case study of Taiwan. *Tourism management*, *30*(2), pp.288-297

[10] Huang, H.Z., Bo, R. and Chen, W., 2006. An integrated computational intelligence approach to product concept generation and evaluation. *Mechanism and Machine Theory*, *41*(5), pp.567-583.

[11] Jiao, J. and Tseng, M.M., 1998. Fuzzy ranking for concept evaluation in configuration design for mass customization. *Concurrent Engineering*, *6*(3), pp.189-206.

[12] Kamal.M., Al-Subhi Al-Harbi (2001), " Application of the AHP in project management", *International Journal of Project Management*, Vol.19, No.1 , pp 19-27.

[13] Kamal, A.A. and Salhieh Sa'Ed, M., 2013. A Fuzzy Based Approach for New Product Concept Evaluation and Selection. *Industrial Engineering Letters*, *3(12)*, pp.1-16.

[14] Kang, Y. and Tang, D., 2014. An approach to product solution generation and evaluation based on the similarity theory and ant colony optimisation. *International Journal of Computer Integrated Manufacturing*, *27*(12), pp.1090-1104.

[15] Khan.S, Aruna, B.D and Verma M (2014), "Adaptation of the AHP as multi-criteria decision making approach and testing the original AHP over two evaluative criteria", *International Journal of Scientific and Engineering Research*, Vol.5 No.6, pp963-968

[16] Saaty, T.L (1980), "The Analytic Hierarchy Process", McGraw-Hill Company, New York.

[17] Salhieh Sa'Ed, M.S. and Al-Harris, M.Y., 2014. New product concept selection: an integrated approach using data envelopment analysis (DEA) and conjoint analysis (CA). *International Journal of Engineering & Technology*, *3*(1), p.44.

[18] Song, W., Ming, X. and Wu, Z., 2013. An integrated rough number-based approach to design concept evaluation under subjective environments. *Journal of Engineering Design*, *24*(5), pp.320-341.

[19] Tiwari, V., Jain, P.K. and Tandon, P., 2016. Product design concept evaluation using rough sets and VIKOR method. *Advanced Engineering Informatics*, *30*(1), pp.16-25.

[20] Tiwari, V., Jain, P.K. and Tandon, P., 2017. A bijective soft set theoretic approach for concept selection in design process. *Journal of Engineering Design*, pp.1-18.

[21] Triantaphyllou. E and Mann.S.H., 1995. Using the Analytic hierarchy process for decision making in engineering applications: some challenges, *International Journal of Industrial Engineering: Applications and Practice*, *2*(1), pp.35-44.

[22] Tzeng G.H. and Huang, J.J., 2011. *Multiple attribute decision making: methods and applications*. Chapman and Hall/CRC.

[23] Venkata Subbaiah.K, Durga Prasad.K.G., Uma Bharathi and Soma Sekhara Rao.K., 2011.Integrating Factor analysis and Analytic Hierarchy process for library service quality. *International Journal for Quality Research*,.*5*(3), pp.205-212.

[24] Wang, J., 2001. Ranking engineering design concepts using a fuzzy outranking preference model. *Fuzzy sets and systems*, *119*(1), pp.161-170.

[25] Yan, W., Chen, C.H. and Shieh, M.D., 2006. Product concept generation and selection using sorting technique and fuzzy c-means algorithm. *Computers & Industrial Engineering*, *50*(3), pp.273-285.

[26] Zhai, L.Y., Khoo, L.P. and Zhong, Z.W., 2009. Design concept evaluation in product development using rough sets and grey relation analysis. *Expert Systems with Applications*, *36*(3), pp.7072-7079.