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Fostering product development using combination of QFD and ANP: A case study

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Abstract: In this ever changing business scenario, success of the company lies in understanding the customer preferences, tastes and anticipating the changes required in existing or new products being offered. It was desired to develop a model which allows decision makers to decompose a complex problem in a hierarchical structure to show the relationship of the goals, objectives, criteria and alternatives. The paper contributes a method for evaluation and analysis of customer as well as technical data using a synergistic combination of techniques like analytical network process (ANP) with quality function deployment (QFD) to evaluate most satisfying design for customers. A case study for the development of cars has been presented here to illustrate and validate the proposed approach. This study has been performed for the assessment of strategies to synthesize qualitative and quantitative factors in decision making keeping reasonable checks on consistency. It finds the priority rating of criteria, weighs them down to lower levels, checks for inconsistencies between relationships and correlation matrices, weighs interdependencies in engineering characteristics, evaluates the modified house of quality and establishes the overall contribution of engineering characteristics to satisfy customer needs.

Keywords: *Quality function deployment (QFD); Analytical network process (ANP); New product development (NPD); Engineering characteristics (EC); Customer needs (CN)*

1. Introduction

New product development is the true manifestation of a company's business strategy. New products are proven to be the driving force behind change and renewal at corporate level (Daugherty, 1992). The new business environment today consists of high growth and innovative industries where organisations have to develop capabilities that allow them to be very flexible and agile, and at the same time, be able to incorporate new product and process technologies that enable them to develop and exploit better practices. The innovations enable companies to gear up to attack almost all business verticals and sub-verticals with cool, intelligent solutions that could soon change the way business are being conducted. Eisehnhardt and Tabrizi (1996) postulate that regular product introduction into the marketplace is the most effective way of a turning change into an endemic and continuous process. In a recent Deloitte touche tohmatsu study, over 89% of manufacturing companies globally viewed new products as the leading driver of future growth. It is however the most complex, financially taxing and multi-functional process within the organization requiring the co-ordination of individuals from sales to marketing to quality assurance.

Converging technologies are causing industry boundaries to shift and blur changing the very nature of products and services (Prahlad and Ramaswami, 2003). This can be seen in 'i-phone' launched by Apple in 2007 which syncs with PC like an iPod, organizing content for calling, texting, e-mailing, surfing, listening and watching even faster. Rapidly altering products demand has resulted in companies resorting to different tools and methodologies like multi-criteria analysis, quality function deployment (QFD), analytical hierarchy process (AHP), analytical network process (ANP), Pugh selection method, scoring and weightage methods, Suh's axiomatic method, goal programming; etc, for addressing the customer needs. Each of these methodologies has a unique way to address a problem with each leading the designer to the best choice, but choice of the method should be dictated by the objectives and constraints.

In order to remove the complications in product development aimed at reducing time-to-market and decreasing development cost, product development teams have modified QFD to deliver the right benefits at the right costs (Dahan and Houser, 2002). Traditional QFD involves translation of desires of customers into product design or engineering characteristics and subsequently into

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parts characteristics, process plans and production requirements. Each translation uses a matrix called House of Quality (HOQ) for identifying customers needs (CNs) and establishing priorities of engineering characteristics (ECs) to satisfy the customers needs (Griffin and Houser, 1993; Clausing and Pugh, 1991; Mazur, 2003). Some of the changes to traditional QFD are just-in-time QFD (Tessler *et al.*, 1993), Turbo QFD (Smith and Reinertsen, 1998), Fuzzy trends in QFD. Some of the recent applications are Extended QFD to multi-channel service concept design (Simons and Bouwman, 2006), Customer requirements segmentation (CRS) (Shahin and Chan, 2006), consistency ratio and number of alternatives with rank reversal (Raharjo and Endah, 2006), Improving product design (González *et al.*, 2003; Soota *et al.*, 2008b), strategic planning using QFD (Killen *et al.*, 2005), multi-criteria decision making in MQFD (Pramod *et al.*, 2007), integrated green QFD (Cagno and Trucco, 2007), Robust QFD (Kim *et al.*, 2007).

The multiple criteria decision analysis is an umbrella term to describe a collection of formal approaches that seek to take explicit account of multiple criteria in helping individuals or groups explore decisions that matter (Belton and Stewart, 2002). Previous works have already applied some multi-criteria analysis methods that include Diakoulaki's method (Diakoulaki *et al.*, 1992), goal programming (Karsak, 2002), the Analytic Hierarchy Process (AHP), Analytical Network Process (ANP) (Saaty, 2001), New product development (Ayag and Ozdemr, 2007). In prioritising the needs and preferences in the complex decision environment, which involves complex decision-making AHP and ANP are useful tools. ANP provides a solution to decision problems, which cannot be structured hierarchically when the interaction of higher-level elements with lower level elements and their dependencies should be taken into account. Not only does the importance of the criteria determine the importance of the alternatives as in a hierarchy, the importance of the alternatives themselves determine the importance of the criteria (Satty, 1996). Some of the recent applications include: integration with QFD for robot selection (Bhattacharya *et al.*, 2005), managing risk in supply chain (Faisal *et al.*, 2006), alternative of the supply chain in a company (Agarwal *et al.*, 2006), Cross-docking location allocation model using genetic algorithm (Ahmad *et al.*, 2006), expert analysis (Elfvengren *et al.*, 2007), maintenance application (Mishra *et al.*, 2007), evaluation of alternative feuls (Erdogmu and Koç, 2006), decision making (Sharma and Rawani, 2008), product development (Soota *et al.*, 2007; Soota *et al.*, 2008a, Soota *et al.*, 2008b), curriculum development (Soota *et al.*, 2009).

The model proposed in this paper is an aid to product development managers, customers in arriving at a prudent decision for concept evaluation when the complexities of decision variables and multi-criteria decision environment make their decision task quite complicated. In this article a detailed multi-criteria analysis is carried out by synergistic use of the ANP and QFD. It includes a comprehensive framework using multi-criteria decision modelling (MCDM) for extending the network process to allow both dependence and feedback both within and between clusters. Although many decision problems are best studied through the ANP, one may wish to compare the results obtained with it to those obtained using AHP or any other decision approach with respect to the time it took to obtain the results, the efforts involved in making the judgments, relevance and accuracy of the results.

2. Integrative model for selection of engineering characteristics

This model works upon to develop synergistic use of analytical network process and quality function deployment for selection of proper set of engineering characteristics to produce a winning product. It uses analytical hierarchy process as well as analytical network process for finding the priority rating of higher and lower level criteria. It checks for inconsistency between relationships and correlation matrices and evaluates interdependencies in engineering characteristics (ECs) in absolute importance, It normalizes and evaluates the modified HOQ for establishing the overall contribution of ECs to satisfy customer needs (CNs).

The process begins with a systematic collection of customer needs, gathered by formal and informal means of customer contact in gemba, through focus groups, by conducting market surveys, through questionnaires. The process of identifying the engineering characteristics is akin to the process of translation of the verbatim of the customer into the patois of the engineers and other members of the design team. Pairwise comparison of CNs using eigenvector method is done as a part of multi-attribute decision to determine the importance weights of CNs. Many good problems can be modelled using a diagram called a network, which may not be linear as in a hierarchy with clusters instead of levels including feedback (Satty, 2001). The Consistency Ratio (CR) is calculated to check for inconsistency of judgements, such that the values exceeding 0.1 are indicative of the need to revise the judgements of comparison matrices.

Relationship rating between CNs and ECs is developed using strong, medium, weak, or no relationship method of eliciting contribution of ECs to the satisfaction of CNs. Detailed information for scoring methods can be obtained from Armacost *et al.* (1994). Pairwise comparison of ECs is done to find the interdependencies and interrelationships and integrating the conventional HOQ with the interrelationship matrix to obtain modified HOQ using product of the two. The modified HOQ should be normalized to generate more meaningful representation of ECs, thus distributing the contribution of CNs into the technical importance rating of ECs related to it in proportion to the relationship rating (Lyman, 1990). The following normalization procedure can be used to establish the correlations amongst the ECs.

$$C_{ij}^{\ N} = \frac{\sum_{j=1}^{n} C_{ij}}{\sum_{i=1}^{m}\sum_{j=1}^{n} C_{ij}} \qquad (1)$$

where $C_{ij}^{\ N}$ = normalized value.

The modified HOQ is evaluated to find the weighted priority of engineering characteristics. The proportion of EC's weight satisfying the CN's can be evaluated.

3. Application to development of car

A relevant case study of most aggressive automotive market segment of cars in India which have witnessed a unprecedented growth is presented to support and validate the study. After preliminary analysis of the models available in the market three car models i.e. Maruti Zen, Hyndai Santro and Tata Indica were selected due to close comparison of price. However, for the sake of academic interests only they have been represented as A, B and C, not in order.

Based on the primary and secondary information available after consultation with various dealers, customers, and auto magazines, criteria are chosen. Among these some are subjective while others can be evaluated quantitatively. Even when a criterion is quantitative it may be subjective, for example, if there is a slight difference in the price, other criterion will dominate the mind of the customer. The attributes which come out after deliberations and consultations include power, mileage, life, operation, style, comfort, acceleration, brakes, maintenance, resale value, availability of parts among others. After the customer attributes are identified, the requirements can be grouped based on factor analysis and affinity that they have with each other (Shin and Kim, 1997). Thus it will be perfectly appropriate to club some of the attributes into primary and secondary attributes as shown in table 6. The primary criteria include performance, design, ergonomics, durability and serviceability.

Determination of engineering characteristics was done through discussions with two engineers knowledgeable in car design after patient analysis, brainstorming and iterative deliberations. The engineering characteristics for the car obviously extend to at least items covering all aspects of the customer requirements. As per customer requirements, the engineering characteristics emerging out of patient deliberations are clubbed together systematically under the broad heading listed below:

- Engine characteristics (efficiency and mileage, power and torque),
- Fuel delivery system,
- Electrical and ignition,
- Power transmission and control
- Exteriors,
- Service and maintenance,
- Warranty.

The structure of the problem consists of three levels of hierarchy: customer needs (CN's), sub-attributes and engineering characteristics.

3.1. Structuring of the problem

Analytical Network Process is used for creating the network of clusters. ANP models have two parts: the first is a control hierarchy or network of objectives and criteria that control the interactions in the system under study; the second are the many sub-networks of influences among the elements and clusters of the problem, one for each control criterion. The key concept of the ANP is that the influence does not necessarily have to flow only downwards as is the case with the hierarchy in the AHP. Influence can flow between any factors in the network causing non-linear results of priorities of alternative choices. ANP differs from AHP in the synthesis phase with the introduction of super matrix which consists of clusters instead of levels. Not only does the importance of the criteria determine the importance of the alternatives as in a hierarchy, the importance's of the alternatives themselves determine the importance of the criteria (Saaty, 2001). The framework of clusters considering the five attributes can be represented as shown in Figure 1.

To develop the priority of the alternatives; w.r.t. each criteria, pairwise comparisons is done for each of the three alternatives. One such pairwise comparison is shown in table 1, where the impact of performance on the three alternatives is evaluated. The Consistency Ratio (CR) is then calculated to check the inconsistency of judgments. The final priority matrix is obtained after making all the pairwise comparisons of attributes against alternatives as shown in Table 2.

3.2. Relative importance of attributes

Pairwise comparisons of criterion w.r.t. alternatives i.e. evaluating the effect of alternatives on criteria is done for each of the three alternatives. One such pairwise comparison is shown in Table 3 where the impact of the alternative 1 on the various criteria is evaluated.

Each ratio scale in comparison is approximately introduced as a column in the super matrix to represent the impact of element in a cluster on an element in another cluster or in element of cluster itself. Table 4 shows the super matrix presenting the results of the relative importance measures using pairwise comparisons for each of the alternatives. The values in the unweighted super matrix are adjusted so that it can achieve column stochastic or weighted. Then raising the weighted super matrix to limiting powers until the weights have converged and remain stable. The process would not converge unless the resulting matrix of priorities is column stochastic.

The limiting super matrix obtained after convergence is shown in Table 5, which gives stabilized values of the priorities of the attributes.

Relative weights of secondary criteria obtained from the above computations are shown in Figure 2.

After obtaining the relative priorities of the higher level attributes, the relative priorities of the lower level attributes are found out. The lower level criteria are weighted with respect to the higher level priorities, using pairwise comparisons matrices for secondary criteria. One such pairwise comparison based on performance is shown in Table 6. Finally relative priorities of primary, secondary attributes and the overall priority are evaluated. Table 7 summarizes the results obtained using the relative priorities of primary and secondary attributes.

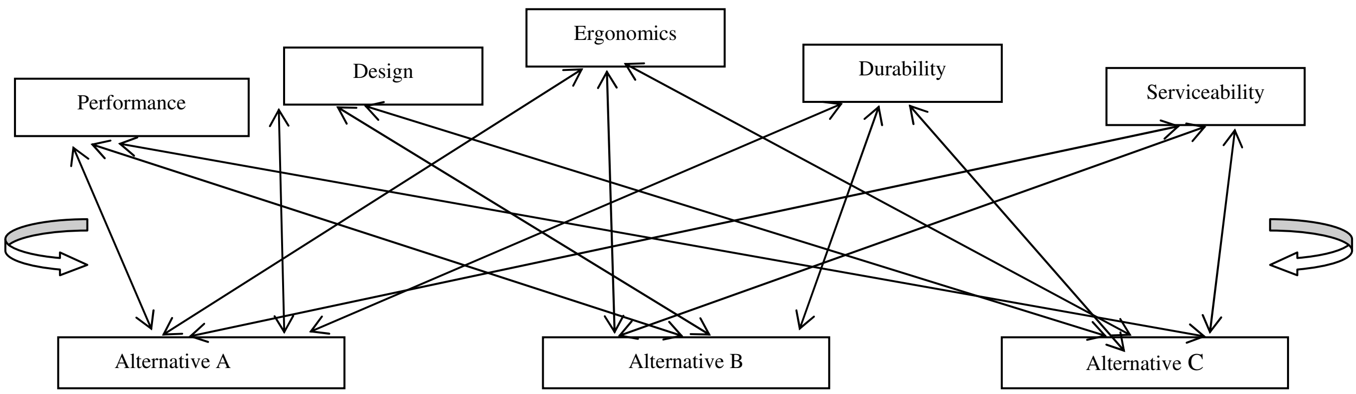

Figure 1: Structure of hierarchy.

Table 1: Evaluation of alternatives on the basis of performance.

Performance	Alternative A	Alternative B	Alternative C	e-vector
Alternative A	1	0.8	1.5	0.342
Alternative B		1	2	0.436
Alternative C			1	0.223

CR=0 which is less than 0.1 hence acceptable

Table 2: Final priority matrix.

Overall Priorities	Performance	Design	Ergonomics	Durability	Serviceability
Alternative A	0.342	0.353	0.308	0.333	0.375
Alternative B	0.436	0.353	0.380	0.333	0.313
Alternative C	0.223	0.294	0.312	0.333	0.313

Table 3: Matrix of pairwise comparison of criterion w.r.t. alternatives.

Alternative 1	a	b	c	d	e	e-vector
a: Performance	1	1	2	1.5	2	0.272
b: Design		1	2	1.5	2	0.272
c: Ergonomics			1	0.8	1.5	0.151
d: Durability				1	1.5	0.181
e: Serviceability					1	0.123

CR = 0.0 which is less than 0.1 hence acceptable

Table 4: Supermatrix before convergence.

	a	b	c	d	e	Alt A	Alt B	Alt C
a: Performance	0.000	0.000	0.000	0.000	0.000	0.272	0.279	0.268
b: Design	0.000	0.000	0.000	0.000	0.000	0.272	0.284	0.285
c: Ergonomics	0.000	0.000	0.000	0.000	0.000	0.151	0.158	0.164
d: Durability	0.000	0.000	0.000	0.000	0.000	0.181	0.169	0.173
e: Serviceability	0.000	0.000	0.000	0.000	0.000	0.123	0.110	0.109
Alt A	0.342	0.353	0.308	0.333	0.375	0.000	0.000	0.000
Alt B	0.436	0.353	0.380	0.333	0.313	0.000	0.000	0.000
Alt C	0.223	0.294	0.312	0.333	0.313	0.000	0.000	0.000

Table 5: Limiting supermatrix after convergence.

	a	b	c	d	e	Alt A	Alt B	Alt C
a: Performance	0.273	0.273	0.273	0.274	0.273	0.000	0.000	0.000
b: Design	0.281	0.281	0.281	0.281	0.281	0.000	0.000	0.000
c: Ergonomics	0.157	0.157	0.157	0.157	0.157	0.000	0.000	0.000
d: Durability	0.175	0.175	0.175	0.175	0.175	0.000	0.000	0.000
e: Serviceability	0.113	0.113	0.113	0.113	0.113	0.000	0.000	0.000
Alt A	0.000	0.000	0.000	0.000	0.000	0.341	0.341	0.341
Alt B	0.000	0.000	0.000	0.000	0.000	0.372	0.372	0.372
Alt C	0.000	0.000	0.000	0.000	0.000	0.286	0.286	0.286

Table 6: Pairwise comparison based on performance.

Performance	a	b	c	d	Normalised Priority	Normalised wts (0.27)
a:Smooth run	1	1.5	1.5	3	0.376	0.10
b:Power		1	1	2	0.250	0.07
c: Mileage			1	2	0.250	0.07
d:Balance				1	0.125	0.03

CR=0.0 which is less than 0.1, hence acceptable

Table 7: Relative weights of primary and secondary attributes.

Primary	Secondary	%age
Performance (27%)	Smooth running	10
	Power	7
	Mileage	7
	Balance	3
Design (28%)	Aesthetic appeal	10
	State of art technology	10
	Safety	5
	Environment norms	3
Ergonomics (16 %)	Comfort driver	6.5
	Comfort passenger	6.5
	Features	3
Durability (18 %)	Sturdy	4.5
	Life	4.5
	Infrequent maintenance	4.5
	Less replacement of parts	4.5
Serviceability (11%)	Easy maintenance	3
	Component availability	2
	Reliable mechanism	3.5
	Warranty	2.5

Table 8: Correlations between CNs and ECs.

Customer Needs	ECs / CNs	Importance	Engineering Attributes: Engine characteristics	Fuel delivery /Tank Capacity	Electrical & Ignition	Power Transmission	Exteriors	Service and maintenance	Warranty periods
Performance	Smooth running	10	⊕	⊕	⊕	O			
	Power	7	⊕	⊕	⊕	O			
	Mileage	7	⊕	⊕	⊕	O			
	Balance	3				⊕	⊕		
Design	Aesthetics	10					⊕		
	Technology	10	⊕	⊕	⊕	⊕			
	Safety	5	Δ	Δ	O	O			
	Environment norms	3	⊕	⊕	O				
Ergonomics	Comfort driver	6.5	O			⊕	O		
	Comfort Passenger	6.5	O			O	O		
	Features	3	O						
Durability	Sturdy	4.5	⊕	Δ	Δ	O	Δ		
	Life	4.5	O	Δ	O				
	Infer Mainten	4.5	⊕	O	O	Δ		Δ	
	Less Replecemt parts	4.5	O	Δ	Δ	Δ			
Serviceability	Maintenance easy	3	Δ	Δ	Δ	Δ			
	Comp Availability	2						O	O
	Reliable mechanism	3.5	Δ	Δ	Δ	Δ			O
	Warranty	2.5						Δ	⊕

Table 9: Matrix for correlations in between ECs.

	a	b	c	d	e	f	g
a :Engine characteristics	1	0.692	0.692	0.231	0.077	0.231	0.077
b :Fuel delivery system	0.692	1	0.692	0	0.077	0.231	0
c :Electrical and Ignition	0.692	0.692	1	0.077	0	0.231	0
d :Power Transmission	0.231	0	0.077	1	0	0.231	0
e :Exteriors	0.077	0.077	0	0	1	0	0
f :Service and maintenance	0.231	0.231	0.231	0.231	0	1	0.692
g :Warranty periods	0.077	0	0	0	0	0.692	1

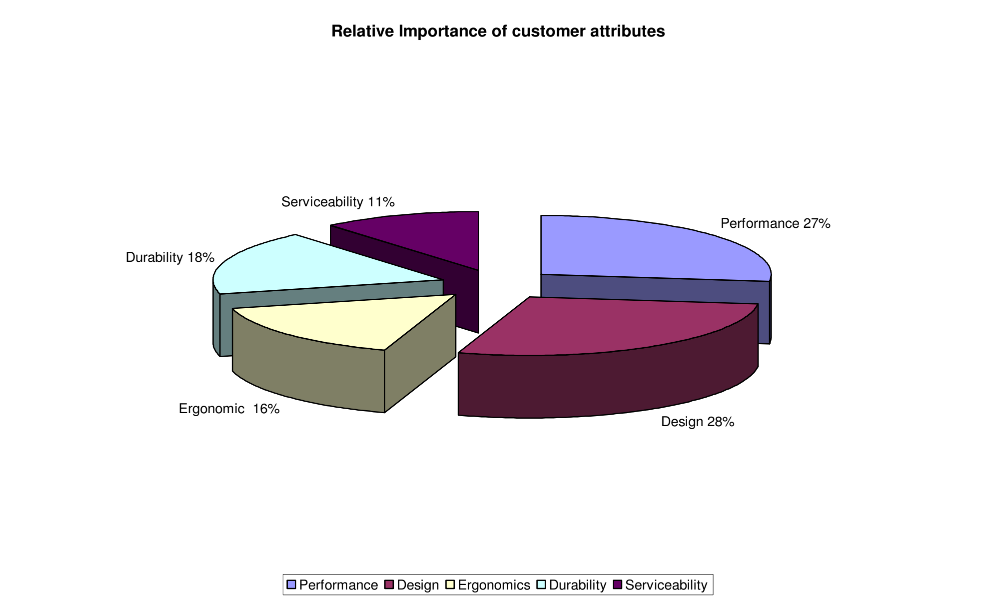

Figure 2: Relative Importance of secondary customer attributes.

3.3. House of quality

The nine areas of ECs identified were scored based on the direct impact of CNs in the HOQ between CN's and EC's. In Table 8, this is shown employing traditional (9, 3, 1, 0) scoring method depicted by (⊕, Δ, O, ' ') Nine indicates high impact, three indicates medium impact, one indicates small impact and zero indicates no impact.

3.4. Establishing interdependence among engineering characteristics

In Table 9 the strength of reinforcement be two ECs is evaluated. The interaction between a pair of ECs is a fractional value between ± 1. Using the relation rating scale of (9, 3, 1, 0) a parallel set of interaction score are defined. High interaction between two ECs is assigned a score of [9/(9+3+1)] = 0.692.

Medium interaction between two ECs is assigned a score of [3/13] = 0.231. Low interaction is scored as [1/13] = 0.077.

No interaction results in zero score. Consistent with the concept of correlation, the matrix assumes that the interaction of ECs is mutually equivalent.

For example the 'fuel delivery system' has a strong positive impact on 'engine characteristics' is seen by a score of 0.692 at the interaction of these columns.

3.5. Integrated relationship matrix

Let us denote Table 8 as matrix **A** of m rows representing CNs and n columns representing ECs. The elements of this matrix may be described as aik (i = 1, 2,…, m and k = 1, 2,…,n). Similarly, the interaction data in Table 9 denoted as n x n matrix B with elements bkj (k, j = 1,2,…, n). The combined impact of ECs on CNs may be defined by the 'm x n' matrix **C,** the result of the matrix product ($A\times B = C$) as shown in Table 10. The elements of matrix demonstrate the complete impact of ECs on CNs including direct and interaction impact. The elements of C (cij) describe the complete impact of ECs on CNs.

$$C_{ij} = \sum_{k=1}^{n} a_{ik} b_{kj} \quad (2)$$

In case of 'engine characteristics' impact on 'Mileage'

$$C_{31} = 9*1 + 9*0.692 + 9*0.692 + 3*0.231 = 22.15 \quad (3)$$

The total of the row elements are defined by the sum of the row impact values. The case of row total for 'smooth running' is illustrated below.

$$\sum_{j=1}^{n} C_{ij} = 22.15 + 21.456 + \ldots + 6.93 + 0.693 = 80.073 \quad (4)$$

This is used to evaluate the weighted priority, for example for ‘smooth running’ relative importance percentage is 11.9 % as given below:

$$C_{ij}^{N} = \frac{\sum_{j=1}^{n} C_{ij}}{\sum_{i=1}^{m}\sum_{j=1}^{n} C_{ij}} = 80.073 / 672.23 = 0.119 \quad (5)$$

The modified HOQ is normalized to get Table 11.The column totals are obtained from the product of importance rating and normalized values, which are then converted to percentages

$$\sum_{i=1}^{m} w_i C_{ij} = 0.277*10 + 0.277*7 + \ldots + 3.5*0.187 + 2.5*0.050 = 0.227 \quad (6)$$

Where w_i shows the weights of the criteria and C_{ij} shows the normalised values of the matrix shown in Table 12.

The normalized weights of engineering characteristics represented in Figure 3.

4. Information and results obtained

4.1. Assessment of proportional EC importance

The total priority values obtained in Table 9 provide a basis for analyzing whether the impact on ECs is consistent with the stated importance of CNs. For instance the criteria ‘power’ of CNs has an importance of 7%, yet it receives 11.9 % of the ECs influence. This indicates a disproportionate allocation of the engineering characteristics and there is a need to redefine the importance to the various customer needs. The comparison of priorities of criteria using AHP, ANP and after ECs impact are shown in Figure 4.

4.2. Assessment of Customers needs importance

The elements of the resultant matrix i.e. Table 11 provide direct insight into the importance of the ECs for a specific CNs. For example the normalized impact of ‘engine characteristics’ on the ‘smooth running’

$$C_{ij}^{N} = \frac{C_{ij}}{\sum_{j=1}^{n} C_{ij}} = 22.15 / 80.07 = 0.277 \quad (7)$$

Table 10: Matrix for modified HOQ.

Customer Needs	ECs / CNs	Importance	Engineering Attributes: Engine character-istics	Fuel de-livery /Tank Capacity	Electrical & Igni-tion	Power Trans-mission	Exteriors	Service and mainte-nance	Warranty periods	Row sums	Relative wts
Perfor-for-mance	Smooth running	10	22.15	21.456	21.687	5.772	1.386	6.93	0.693	80.073	0.119
	Power	7	22.15	21.456	21.687	5.772	1.386	6.93	0.693	80.073	0.119
	Mileage	7	22.15	21.456	21.687	5.772	1.386	6.93	0.693	80.073	0.119
	Balance	3	2.772	0.693	0.693	9	9	2.079	0	24.237	0.036
Design	Aesthetics	10	0.693	0.693	0	0	9	0	0	10.386	0.015
	Technology	10	23.54	21.456	22.149	11.772	1.386	8.316	0.693	89.307	0.133
	Safety	5	4.461	3.768	4.615	3.462	0.154	1.848	0.077	18.385	0.027
	Environment norms	3	17.30	17.304	15.456	2.31	1.386	4.851	0.693	59.304	0.088
Ergo-nomics	Comfort driver	6.5	5.31	2.307	2.769	9.693	3.231	2.772	0.231	26.313	0.039
	Comfort Passenger	6.5	3.924	2.307	2.307	3.693	3.231	1.386	0.231	17.079	0.025
	Features	3	3	2.076	2.076	0.693	0.231	0.693	0.231	9	0.013
Durabil-ity	Sturdy	4.5	11.15	7.997	8.151	5.156	1.77	3.234	0.693	38.155	0.057
	Life	4.5	5.768	5.152	5.768	0.924	0.308	1.617	0.231	19.768	0.029
	Infer Mainten	4.5	13.61	11.535	11.612	3.541	0.924	4.696	1.385	47.307	0.070
	Less Replecemt parts	4.5	4.615	3.768	3.845	1.77	0.308	1.386	0.231	15.923	0.024
Service vice-ability	Maintenance easy	3	2.615	2.384	2.461	1.308	0.154	0.924	0.077	9.923	0.015
	Comp Availability	2	0.924	0.693	0.693	0.693	0	5.076	5.076	13.155	0.020
	Reliable mechanism	3.5	2.846	2.384	2.461	1.308	0.154	3	3.077	15.23	0.023
	Warranty	2.5	0.924	0.231	0.231	0.231	0	7.228	9.692	18.537	0.028
			169.9	149.1	150.3	72.87	35.395	69.896	24.697	672.23	

Table 11: Normalized Matrix for the modified HQQ.

Customer Needs	ECs / CNs	Importance	Engineering Attributes: Engine character-istics	Fuel de-livery /Tank Capacity	Electrical & Igni-tion	Power Trans-mission	Exteriors	Service and main-tenance	Warranty periods
Perfor-mance	Smooth running	10	0.277	0.268	0.271	0.072	0.017	0.087	0.009
	Power	7	0.277	0.268	0.271	0.072	0.017	0.087	0.009
	Mileage	7	0.277	0.268	0.271	0.072	0.017	0.087	0.009
	Balance	3	0.114	0.029	0.029	0.371	0.371	0.086	0.000
Design	Aesthetics	10	0.067	0.067	0.000	0.000	0.867	0.000	0.000
	Technology	10	0.264	0.240	0.248	0.132	0.016	0.093	0.008
	Safety	5	0.243	0.205	0.251	0.188	0.008	0.101	0.004
	Environment norms	3	0.292	0.292	0.261	0.039	0.023	0.082	0.012
Ergo-nomics	Comfort driver	6.5	0.202	0.088	0.105	0.368	0.123	0.105	0.009
	Comfort Passenger	6.5	0.230	0.135	0.135	0.216	0.189	0.081	0.014
	Features	3	0.333	0.231	0.231	0.077	0.026	0.077	0.026
Durabil-ity	Sturdy	4.5	0.292	0.210	0.214	0.135	0.046	0.085	0.018
	Life	4.5	0.292	0.261	0.292	0.047	0.016	0.082	0.012
	Infer Mainten	4.5	0.288	0.244	0.245	0.075	0.020	0.099	0.029
	Less Replecemt parts	4.5	0.290	0.237	0.241	0.111	0.019	0.087	0.015
Service-ability	Maintenance easy	3	0.264	0.240	0.248	0.132	0.016	0.093	0.008
	Comp Availability	2	0.070	0.053	0.053	0.053	0.000	0.386	0.386
	Reliable mechanism	3.5	0.187	0.157	0.162	0.086	0.010	0.197	0.202
	Warranty	2.5	0.050	0.012	0.012	0.012	0.000	0.390	0.523
	Wts		0.227	0.184	0.186	0.119	0.095	0.121	0.068

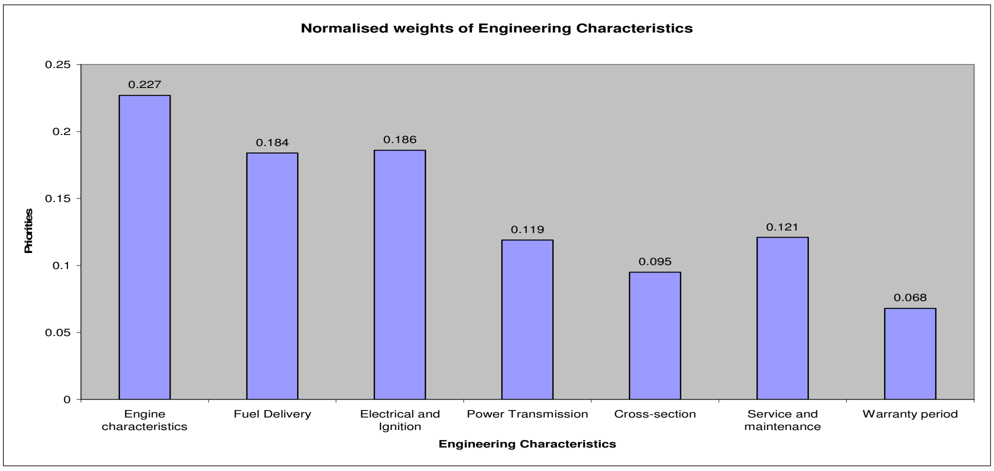

Figure 3: Normalized weights of engineering characteristics.

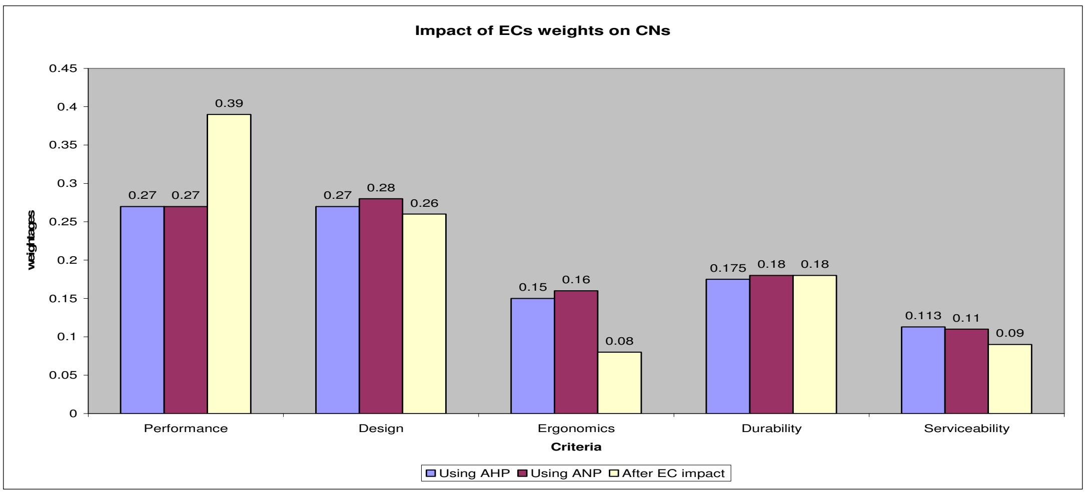

Figure 4: Impact of engineering characteristics on customer needs.

4.3. Importance of the ECs to the CNs and overall project

The importance of 'engine characteristics' to the CNs can be determined as shown in Equation 6. For example 'engine characteristics' has 27.7% influence for achieving the objective of 'smooth running' and 22.7 % for the overall objective.

5. Conclusion

The model proposed is an aid to product development managers, customers in arriving at a prudent decision when the complexities of decision variables and multi-criteria decision environment make the decision task quite complicated. This approach enables us to analyze whether the impact of engineering characteristics is consistent with the importance of customer needs. With the model it is possible to identify the disproportionate allocation of the engineering characteristics and need for restructuring engineering characteristics. So it suggests how the priorities of the engineering characteristics can be modified to conform to the stated objectives.

Structuring of the decision problem is done for assessment of impact of decisions after identification of customer attributes and preferences. Model enables assessment of strategies to synthesize qualitative and quantitative factors in decision making keeping checks on consistency. The additive synthesis of priorities and general feedback network is used to accommodate variety of interactions, dependencies and feedback between various elements. The model weighs interdependencies in engineering characteristics and evaluates the modified house of quality. Also an insight is obtained about the importance of engineering characteristics for specific customer needs and to the overall objective. The model is validated using results of the case study.

References

Agarwal, A.; Shankar, R.; Tiwari, M. K., (2006), Modeling the metrics of lean, agile and leagile supply chain: An ANP-based approach. *European Journal of Operational Research*, 173(1), 211-225.

Makui, A.; Haerian, L.; Eftekhar, M., (2006), Designing a multi-objective nonlinear cross-docking location allocation model using genetic algorithm. *Journal of Industrial Engineering International*, 2(3), 27-42.

Ayag, Z.; Ozdemr, R. G., (2007), An analytical network process based approach to concept evaluation in new product development environment. *Journal of Engineering Design*, 18(3), 209-226.

Armacost, R. L.; Componation. P J., Mullens, M. A.; Swart, W. W., (1994), An AHP framework for prioritizing customer rating in QFD: An industrialized housing application. *IIE Transactions*, 26(4), 72-79.

Belton, V.; Stewart, T. J., (2002), *Multiple criteria decision analysis: An integrated approach.* Boston: Kluwer Academic Publishers.

Bhattacharya, A.; Sarkar, B.; Mukherjee, S. K., (2005), Integrating AHP with QFD for robot selection under requirement perspective. *International Journal of Production Research*; 43(17), 3671-3685.

Clausing, D.; Pugh, S., (1991), *Enhanced quality function deployment*. Proceedings of Design Productivity Conference. Honolulu, HI.

Cagno, E.; Trucco, P., (2007), Integrated green and quality function deployment. *International Journal of Product Lifecycle Management*, 2(1), 64-83.

Chan, L. W.; Wu, M. L., (2002), Quality function deployment: A comprehensive review of its concepts and methods. *Quality Engineering*, 15(1), 23-35.

Daugherty, D., (1992), Interpretive barriers to successful product innovation in large firms. *Organization Science*, 3(2), 179-202.

Dahan, E.; Hauser, J. R., (2002), The virtual customer. *Journal of Product Innovation Management*. 19(5), 332-354.

Deloitte Touche Tohmatsu, (2007), The challenge of complexity in global manufacturing. Growth Insights.

Diakoulaki, D.; Mavrotas, G.; Papayannakis, L., (1992), *Objective weights of criteria for interfirm comparisons.* 36e Journées du Groupe Européen Aide Multicritère à la Décision, Luxembourg.

Eisehnhardt, K. M.; Tabrizi, B. N., (1996), Accelerating adaptiveness process: product innovation in the global computer industry. *Administrative Science Quarterly*, 40, 84-110.

Elfvengren, K.; Korpela, J.; Tuominen, M.; Sierila, P., (2007), AHP based expert analysis of forest industry strategies. *International Jour-*

nal of Industrial and System Engineering, 2(4), 375-393.

Erdogmu, A. H.; Koç, E., (2006), Evaluation of alternative fuels for residential heating in Turkey using analytic network process (ANP) with group decision-making. *Renewable and Sustainable Energy Reviews*, 10(3), 269-279.

Faisal, M. N.; Banwet, D. K.; Shankar, R., (2006), Supply chain risk mitigation: Modeling the enablers. *Business Process Management Journal*, 12(4), 535-552.

González Marvin, E.; Quesada, G. B.; Terry, A., (2003), Improving product design using quality function deployment: The school furniture case in developing countries. *Quality Engineering*, 16(1), 45-56.

Griffin, A.; Hauser, J. R., (1993), The voice of the customer. *Marketing Science,* 12(1), 1-27.

Karsak, E. E.; Sozer, S.; Alptakin, S. E., (2002), Product planning in quality function deployment using a combined analytical network process and goal programming approach. *Computers and Industrial Engineering,* 44(1), 171-190.

Kim, K.; Kim, D.; Min, D., (2007), Robust QFD: Framework and a case study. *Quality and Reliability Engineering International,* 23(1), 31-44.

Killen Catherine, P.; Walker, M.; Hunt Robert, A., (2005), Strategic planning using QFD. *International Journal of Quality & Reliability Management*, 22(1), 17-29.

Lyman, D., (1990), *Deployment normalisation' transactions from a second symposium on QFD, A conference co sponsored by the automotive division of the American society for quality control*. The American supplier Institute, Dearborn, MI, and GOAL/ QPC, Metheuen, MA, 307-315.

Mazur, G., (2003), *Voice of the customer (define): QFD to define value.* Proceedings of the 57th American Quality Congress. Kansas City. May.

Mishra, R. P.; Anand, G.; Kodali, R., (2007), An AHP model for quantification of benefits of world class maintenance systems. *International Journal of Industrial and Systems Engineering*, 2(2), 166-194.

Prahlad, C. K.; Ramaswami, V., (2003), The new frontier of experienced innovation. *MIT Sloan Management Review*, 44(4), 12-18.

Pramod, V. R.; Sampath, k.; Devadasan, S. R.; Jagathy Raj, V. P.; Moorthy, G. D., (2007), Multicriteria decisions making in maintenance quality function deployment through the analytical hierarchy process. *International Journal of Industrial and system engineering*, 2(4), 454-478.

Raharjo, H.; Endah, D., (2006), Evaluating relationship of consistency ratio and number of alternatives on rank reversal in the AHP. *Quality Engineering*, 18(1), 39-46.

Saaty, T. L., (2001), *Decision making with independence and feedback: The analytic network process.* Pittsburgh: RWS Publications.

Shahin, A.; Chan, J. F. L., (2006), Customer requirements segmentation (CRS): A prerequisite technique for quality function deployment (QFD). *Total Quality Management & Business Excellence*, 17(5), 567-587.

Sharma, J. R.; Rawani, A. M., (2008), Quality function deployment: Integrating comprehensive matrix and SWOT analysis for effective decision making. *Journal of Industrial Engineering International*, 4(6), 19-31.

Shin, J.; Kim, K., (1997), Restructuring a house of quality using factor analysis. *Quality Engineering*, 9(4), 739-746.

Simons, L.; Bouwman, H., (2006), Extended QFD: Multi-channel service concept design. *Total Quality Management & Business Excellence*, 17(8), 1043-1062.

Soota, T.; Singh, H.; Mishra, R. C., (2007), *Heuristic approach to product development using multi-objective decision making.* The 8th International Research Conference on Quality, Innovation and Knowledge Management (QIK 2007), N Delhi, India.

Soota, T.; Singh, H.; Mishra, R. C., (2008 a), Developing strategies fostering product development using multicriteria analysis. *International Journal of Industrial and Systems Engineering,* 3(1), 87-103.

Soota, T.; Singh, H.; Mishra, R. C., (2008 b), Defining characteristics for product development using quality function deployment: A case study on Indian Bikes. *Quality Engineering*, 20(02), 195-208.

Soota, T.; Singh, H.; Mishra, R. C., (2009), Selection of curricular topics using framework for enhanced quality function deployment. *International Journal of Industrial Engineering*

Theory Applications and Practice, 16(2), 108-115.

Smith, P. G.; Donald, G. R., (1998), *Developing Products in Half the Time.* 2nd edition, New York, NY: John Wiley & Sons, Inc.

Tessler, A.; Norm, W.; Robert, L. K., (1993), *QFD at PG&E*. Transactions from the Fifth Symposium on Quality Function Deployment, June.