International Journal for Quality Research 10(3) 547–558
ISSN 1800-6450

Tarun Soota [1]

Article info:
Received 06.01.2016
Accepted 20.07.2016

UDC – 54.061
DOI – 10.18421/IJQR10.03-07

INTEGRATED METHODOLOGY FOR PRODUCT PLANNING USING MULTI CRITERIA ANALYSIS

Abstract: *Integrated approach to multi-criteria decision problems is proposed using quality function deployment and analytical network process. The objective of the work is to rationalize and improve the method of analyzing and interpreting customer needs and technical requirements. The methodology is used to determine, prioritize engineering requirements based on customer needs for development of best product. Framework allows decision maker to decompose a complex problem in a hierarchical structure to show relationship between objective and criteria. Multi-criteria decision modeling is used for extending the hierarchy process to both dependence and feedback. A case study on bikes is presented for the proposed model.*

Keywords: *Multi criteria analysis, product planning, AHP, ANP, QFD*

1. Introduction

While developing new products or improving existing products companies can choose any one or more of the design methods such as robust design, modular design, computer aided design (CAD), value analysis, quality function deployment (QFD) (Wang and Chen, 2012), conjoint analysis (Chaudhuri and Bhattacharyya, 2009), multi-criteria decision making (MCDM) (Soota, 2014). Most companies use a variety of methods to determine the customer requirements and their rating including Conjoint analysis (Chaudhuri and Bhattacharyya, 2009), analytic hierarchy process (AHP), (Rehman and Ahamri, 2013) fuzzy AHP, analytic network process (ANP) (Karsak *et al.*, 2003), fuzzy ANP, fuzzy weighted average, grey model, PROMETHEE (Ilangkumaran *et al.*, 2013), TOPSIS (Shahroudi and Rouydel, 2012), DEMATEL (Buyukozkan and Cifci, 2012), Vikor, group decision-making approach, etc.

Multi criteria methods are commonly in literature for conflicting requirements. Multi-criteria analysis methods have been applied in various ways including AHP, ANP (Ayag and Ozddemir, 2011), TOPSIS (Rao and Patel, 2010), Elimination and choice translating reality (ELECTRE) (Chatterjee *et al.*, 2011; Rehman and Ahamri, 2013), PROMETHEE (Ilangkumaran *et al.*, 2013), TOPSIS (Shahroudi and Rouydel, 2012), Goal programming (Karsak *et al.*, 2003), Digraph and matrix methods (Rao, 2006), Decision support system (DSS), etc. The multi criteria methods may be used to evaluate the selection and performance of new products under development. Selection of the best criteria for the product requires comprehensive evaluation conflicting

[1] Corresponding author: Tarun Soota
email: tarunsoota@rediffmail.com

requirements.

MCDM may be used for improving customer satisfaction, improving production of reliable and quality products, optimizing design specifications, decreasing costs, increasing efficiency, reducing development time and improving revenues (Zaim *et al.*, 2014). QFD may be used for design of complex systems, investment portfolios and management of services. (Chan and Wu, 2004) After identifying the customer demands about product or service, it is required to determine which technical specifications need to be developed further. A prevalent way to determine what customers want and how to channel their wants into a product design is through the QFD. The House of Quality (HOQ) is a tool used by QFD to define the relationships between customer desires and the product features (Smith, 2011). QFD has been used extensively for helping decision-makers (DMs) in product planning and improvement. The process of traditional quality deployment involving conversion of the customer requirements into technical requirements. Further stages involve part design, process planning and production planning. House of quality (HOQ) is involved in each stage as it tries to form a interrelationship matrix betweens the whats and the hows.

Integrating some of the recent applications with QFD include robot selection (Bhattacharya *et al.*, 2005), robust QFD (Kim *et al.*, 2007), weighted ANP approach for concept development (Zaim *et al.*, 2014), collaborative product design and optimal selection of module mix (Wang and Chen, 2012), conjoint analysis for concept development (Chaudhuri and Bhattacharyya, 2009), product development methodology (Soota, 2014; Zaim *et al.*, 2014), extensions of QFD (Mehrjerdi, 2010), etc.

ANP involves a broader approach as it overcomes the deficiencies of the AHP and its linear structure.ANP uses the feedbacks and interactions by considering the super-matrix approach. ANP has been used as the tool to supplement QFD. For instance, Karsak et al. (2003) combined goal programming approach with ANP for product planning in QFD.

An integrated QFD–AHP approach can be successfully used in identifying and prioritizing customer requirements, dealing with conflicting situations, and rank ordering product features (Soota *et al.*, 2014). Some of the recent applications of ANP include product planning with goal programming (Karsak *et al.*, 2003), machine tool selection (Ayag and Ozddemir, 2011), flexible manufacturing system (FMS) selection (Chatterjee and Chakraborty, 2014; Maniya and Bhatt, 2011), product development (Soota *et al.*, 2011; Zaim *et al.*, 2014), optimum material evaluation for manufacturing of automobile bumper (Ilangkumaran *et al.*, 2013), multi-criteria inventory classification (Kabir and Hasin, 2013), operations management review (Subramanian and Ramanathan, 2012), supplier selection (Chatterjee and Chakraborty, 2014; Yazdani, 2014), sustainable energy planning (Pohekar and Ramachandran, 2004), material handling equipment selection (Onut *et al.*, 2009), evaluation of alternative industrial robots (Rehman and Ahamri, 2013), material selection (Rao and Patel, 2010), etc.

In real life situations, human judgements may not be expressed by exact crisp data, in such cases subjectivity or vagueness has to be taken into consideration. This philosophy may be extended to QFD environment to capture the inter-relationships between customer requirements and technical requirements in form of linguistic data. The linguistic data is processed by algorithms embedded in the systems internal environment (Mehrjerdi, 2010). The aim of fuzzy ANP is to capture the vagueness and uncertainties in the evaluation of alternative countermeasures particularly at the initial phase of remediation planning.

2. MCDM Methodology and Techniques

ANP is a generic form of AHP. It is more comprehensive, as apart from hierarchical relationships, it also uses feedbacks, interdependencies for evaluation. All the interactions and feedbacks within clusters are called interdependencies where as interactions and feedbacks between clusters are called outer dependencies (Soota *et al.*, 2011). The ANP is a more accurate method than many other complicated models which use criteria feedback and interrelationship. The method provides a tool to evaluate all the relationships systematically by adding all interactions, interdependences, and feedbacks in Decision Making (DM) system. Relationships between goals, factors, sub factors and alternatives have been represented along with feedbacks as applicable for comparison of AHP and ANP in figure 1.

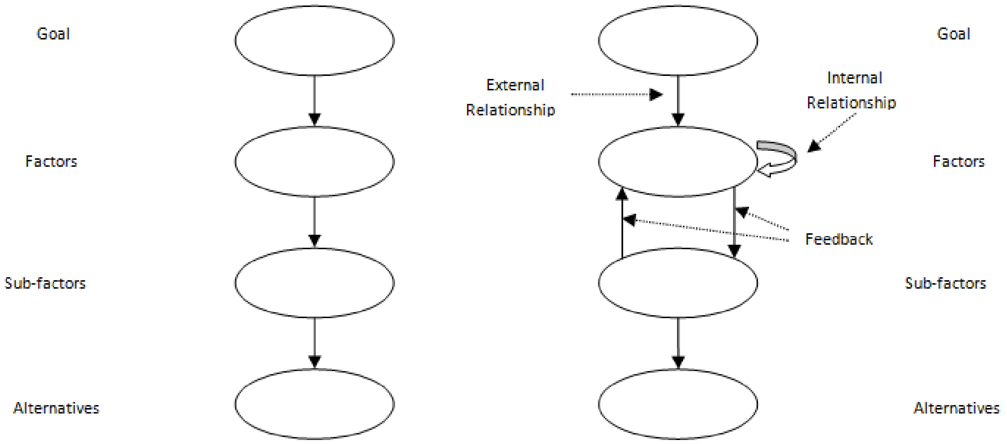

Figure 1. Comparison of AHP and ANP

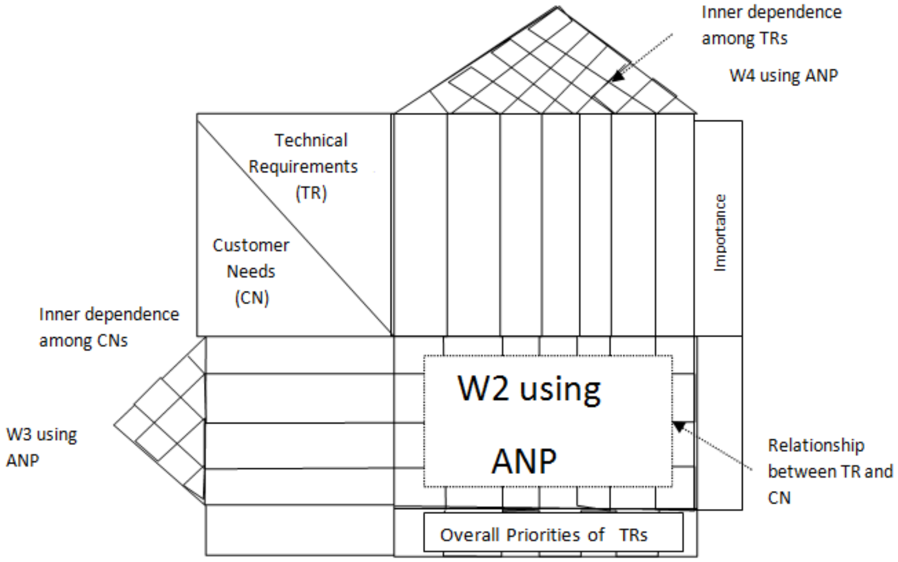

Figure 2. Representation of ANP in QFD (Karsak *et al.* 2003)

The calculation need to be performed to evaluate interdependencies within clusters and outer dependencies between clusters A complicated analysis is necessary to figure out the weights of all components in following circumstances. The model defines all components and relationships which are then determined as two way interactions. ANP approach is capable of capturing and representing the interrelationship between and within QFD components. To enhance the design process, this study takes in to account the ANP in the process of QFD in developing a product.

3. Proposed Methodology

Representation of ANP in QFD using House of Quality has been shown in figure 2, showing the respective priorities of various dependence and without dependence criteria of customer needs and technical requirements and their respective places.

$$W = \begin{array}{c} \\ Goal(G) \\ CNs \\ TRs \end{array} \begin{array}{c} \begin{matrix} G & CNs & TRs \end{matrix} \\ \begin{bmatrix} 0 & 0 & 0 \\ w1 & W3 & 0 \\ 0 & W2 & W4 \end{bmatrix} \end{array}$$

Where w_1 is a vector of the CNs that represent the impact of the goal that satisfies a customer. W_2 is a matrix that denotes the impact of the CNs on each TRs. W_3 and W_4 are the matrices that represent the inner dependencies of CNs and inner dependencies of TRs respectively.

2.1. Integrated decision framework

This model works upon to develop comprehensive framework using ANP and quality function deployment. House of Quality (HOQ) which is a planning matrix is used to prioritizing the customer needs against a set of product attributes using QFD and ANP. Initial step involves identification of the customer needs (CNs) and technical requirements (TRs). CNs corresponds to the alternatives which have inner dependence within themselves.

The decision methodology involves the following procedure: Identification of the customer needs (CNs) and the technical requirements (TRs), determination of the priorities of CNs by assuming that there is no dependence among the CNs (w_1), determination of the priorities of TRs with respect to each CN by assuming that there is no dependence among the TRs (W_2), determination of the inner dependency matrix of the CNs with respect to each CNs (W_3), determination of the inner dependency matrix of the TRs with respect to each TR (W_4), determination of the interdependent priorities of the CNs ($Wc = W_3 \times w_1$), determination of the interdependent priorities of the TRs ($W_A=W_4 \times W_2$), evaluate overall priorities of TR’s ($W_{ANP} = W_A * W_C$)

It is used for selection of set of TRs to produce a promising product. It finds the priorities of criteria. It weighs interdependencies in TRs to evaluate the modified HOQ. A case study was carried out on bikes for illustration of the above approach.

4. Case study

A case study was carried out to apply the methodology for product bike. Initial step involves identification of the customer needs (CNs) and the technical requirements (TRs). In order to elicit the customer needs, primary information and secondary information is utilized for selection of the criteria which includes brainstorming, surveys, catalogues,etc. Customer needs is finalized as per user preferences includes: mileage, comfort, handling and control, safety, aesthetics, reliability, speed. Then pairwise comparison of the criteria are carried out to find the relative priorities using AHP. To dertermine w1 i.e. the priorities of CNs by assuming that there is no dependence among the CNs. This pairwise comparison has been shown below in Table 1.

Table 1. Pairwise comparison of customer needs

Customer requirements W_1	Mileage	Comfort	Handling And Control	Safety	Aesthetic	Reliability	Speed	Priorities (W_1)
Mileage	1	3	3	4	3	3	2	0.29
Comfort	1/3	1	1/2	1/4	1/2	1/4	2	0.07
Handling and control	1/3	2	1	1/3	1	1/3	1	0.08
Safety	1/4	4	3	1	4	3	3	0.22
Aesthetics	1/3	2	1	1/4	1	1/3	1/2	0.07
Reliability	1/3	4	3	1/3	3	1	1/3	0.14
Speed	1/2	1/2	1	1/3	2	3	1	0.12

After finding the priorities of customer needs and TRs need to be found considering that they are likely to affect these needs. They are identified as Power, Suspension, Brakes, Tyres, Low weight, Auto-choke, LED Lamps and lights, Electric start, Alloy wheels, Battery.

Matrix W2 evaluation It determines the degree of importance with respect to each Customer Needs by assuming that there is no dependence among the Technical Requirements. The Technical Requirements are compared with respect to each customer requirements assuming no dependence yielding the eigenvectors regarding each customer need (Soota *et al.*, 2011).

Such a matrix w.r.t. C.N. Mileage is illustrated in Table 2. The process is repeated for each C.N. and final matrix W2 obtained after the process is shown in Table 3.

Table 2. Pairwise comparison of technical requirements w.r.t. Mileage

MIileage	Power	Auto Choke	Electric start	Suspension	Brakes	Alloy Wheels	L.E.D Lamp	Tyres	Battery	Weight	Priority Vector
Power	1	3	5	5	5	5	5	5	5	3	0.30
Auto Choke	1/3	1	5	5	5	5	5	5	5	1	0.22
Electric Start	1/5	1/5	1	1	1	1	1	1	1	1/3	0.05
Suspension	1/5	1/5	1	1	1	1	1	1	1	1/3	0.05
Brakes	1/5	1/5	1	1	1	1	1	1	1	1/3	0.05
Alloy wheels	1/5	1/5	1	1	1	1	1	1	1	1/3	0.05
L.E.D Lamp	1/5	1/5	1	1	1	1	1	1	1	1/3	0.05
Tyres	1/5	1/5	1	1	1	1	1	1	1	1/3	0.05
Battery	1/5	1/5	1	1	1	1	1	1	1	1/3	0.05
Weight	1/3	1	3	3	3	3	3	3	3	1	0.15

Table 3. Matrix W_2

W_2	Mileage	Comfort	Handling And Control	Safety	Aesthetic	Reliability	Speed
Power	0.30	0.04	0.09	0.06	0.06	0.29	0.35
Auto Choke	0.22	0.21	0.04	0.03	0.06	0.05	0.07
Electric Start	0.05	0.21	0.04	0.03	0.06	0.05	0.07
Suspension	0.05	0.21	0.24	0.16	0.06	0.14	0.07
Brakes	0.05	0.04	0.24	0.27	0.06	0.05	0.07
Alloy wheels	0.05	0.04	0.04	0.04	0.28	0.05	0.07
L.E.D Lamp	0.05	0.04	0.04	0.14	0.28	0.05	0.07
Tyres	0.05	0.04	0.18	0.16	0.06	0.14	0.13
Battery	0.05	0.07	0.04	0.06	0.06	0.13	0.07
Weight	0.15	0.08	0.04	0.04	0.06	0.06	0.07

Table 4. Pairwise comparison of CNs w.r.t. Mileage assuming inner dependence

Mileage	Mileage	Comfort	Handling And Control	Safety	Aesthetic	Reliability	Speed	Priority Vector
Mileage	1	4	5	5	5	5	2	0.40
Comfort	1/4	1	3	3	3	3	1/3	0.17
Handling and control	1/5	1/3	1	0	0	0	1/4	0.04
Safety	1/5	1/3	0	1	0	0	1/4	0.04
Aesthetic	1/5	1/3	0	0	1	0	1/4	0.04
Reliability	1/5	1/3	0	0	0	1	1/4	0.04
Speed	1/2	3	4	4	4	4	1	0.28

Table 5. Matrix W_3

W_3	Mileage	Comfort	Handling And Control	Safety	Aesthetic	Reliability	Speed
Mileage	0.40	0.13	0.04	0.04	0.04	0.04	0.22
Comfort	0.17	0.33	0.10	0.08	0.04	0.14	0.05
Handling and control	0.04	0.13	0.35	0.24	0.04	0.19	0.10
Safety	0.04	0.08	0.25	0.24	0.21	0.13	0.10
Aesthetics	0.04	0.04	0.04	0.11	0.59	0.04	0.05
Reliability	0.04	0.25	0.14	0.24	0.04	0.37	0.10
Speed	0.28	0.04	0.08	0.05	0.04	0.08	0.38

Matrix W_3 evaluation : It is the matrix between the customer needs and the customer needs assuming the inner dependency among the customer needs. The inner dependence among the technical requirements is determined through analyzing the impact of each technical requirement on other technical requirements by using pairwise comparisons (soota et al 2011). One such pairwise comparison w.r.t. CN Mileage is shown below in table 4. The process is repeated for each C.N. The resulting eigenvectors obtained from pairwise comparisons are presented in table 5 i.e. final matrix W_3

Matrix W_4 evaluation It is the matrix between technical requirements and technical requirements assuming inner dependency among the technical requirements. The inner dependence among the technical requirements is determined through analyzing the impact of each technical requirement on other technical requirements by using pairwise comparisons. One such pairwise comparison w.r.t. T.R. power is shown below in table 6. The process is repeated for each C.N. The resulting eigenvectors obtained from pairwise comparisons are presented in table 7 i.e. final matrix W_4 .

Table 6. Pairwise comparison of TRs w.r.t. power assuming inner dependence

Power	Power	Auto Choke	Electric start	Suspension	Brakes	Alloy Wheels	E.D Lamp	Tyres	Battery	Weight	Priority Vector
Power	1	5	5	5	5	5	5	5	5	4	0.58
Auto Choke	1/5	1	0	0	0	0	0	0	0	1/2	0.03
Electric Start	1/5	0	1	0	0	0	0	0	0	1/2	0.03
Suspension	1/5	0	0	1	0	0	0	0	0	1/2	0.03
Brakes	1/5	0	0	0	1	0	0	0	0	1/2	0.03
Alloy wheels	1/5	0	0	0	0	1	0	0	0	1/2	0.03
L.E.D Lamp	1/5	0	0	0	0	0	1	0	0	1/2	0.03
Tyres	1/5	0	0	0	0	0	0	1	0	1/2	0.03
Battery	1/5	0	0	0	0	0	0	0	1	1/2	0.03
Weight	1/4	2	2	2	2	2	2	2	2	1	0.22

Table 7. Matrix W_4

W_4	Power	Auto Choke	Electric start	Suspension	Brakes	Alloy Wheels	L.E.D Lamp	Tyres	Battery	Weight
Power	0.58	0.02	0.02	0.03	0.03	0.03	0.02	0.03	0.02	0.10
Auto Choke	0.03	0.27	0.14	0.03	0.03	0.02	0.13	0.03	0.15	0.10
Electric Start	0.03	0.19	0.29	0.03	0.03	0.02	0.19	0.02	0.23	0.10
Suspension	0.03	0.02	0.03	0.58	0.03	0.03	0.02	0.03	0.03	0.10
Brakes	0.03	0.02	0.03	0.03	0.58	0.03	0.02	0.03	0.03	0.10

Alloy wheels	0.03	0.02	0.03	0.03	0.03	0.58	0.02	0.03	0.03	0.10
L.E.D Lamp	0.03	0.14	0.14	0.03	0.03	0.02	0.27	0.02	0.15	0.10
Tyres	0.03	0.02	0.02	0.03	0.03	0.03	0.02	0.58	0.02	0.10
Battery	0.03	0.27	0.29	0.03	0.03	0.02	0.27	0.02	0.32	0.10
Weight	0.22	0.02	0.02	0.22	0.22	0.22	0.02	0.22	0.02	0.10

Matrix Wc evaluation: Calculated by multiplying W3 and W1.i.e. WC = W3*W1

Wc^T = 0.171 0.155 0.142 0.141 0.076 0.160 0.148

Calculation of Matrix W_A: Calculated by multiplying W4 and W2, i.e. WA= W4*W2, as shown below in table 8.

Table 8. Matrix W_A

0.2241	0.0666	0.0868	0.0703	0.0756	0.2012	0.2370
0.1024	0.1301	0.0514	0.0642	0.0946	0.0797	0.0761
0.0798	0.1252	0.0510	0.0645	0.0940	0.0808	0.0754
0.0866	0.1601	0.1693	0.1253	0.0756	0.1187	0.0830
0.0866	0.0666	0.1693	0.1858	0.0756	0.0692	0.0830
0.0866	0.0666	0.0593	0.0593	0.1966	0.0692	0.0830
0.0781	0.1059	0.0510	0.0782	0.1226	0.0792	0.0754
0.0866	0.0666	0.1363	0.1253	0.0756	0.1187	0.1160
0.0810	0.1172	0.0506	0.0662	0.0956	0.0827	0.0747
0.1020	0.0980	0.0990	00990	0.1040	0.1010	0.1040

Calculation of Matrix W_{ANP} : Calculated by multiplying W_A and W_C.

WANP=WA*WC

$WANP^T$ = 0.144 0.085 0.080 0.118 0.104 0.080 0.081 0.104 0.080 0.100

The respective weights of TRs as determined from W_{ANP} are shown in Table 9 below.

Table 9. Respective weights of TRs as determined from W_{ANP}

Power	0.144
Auto Choke	0.085
Electric Start	0.080
Suspension	0.118
Brakes	0.104
Alloy Wheels	0.080
LeD lamps	0.081
Tyres	0.104
Battery	0.080
Weight	0.100

The various columns in the House Of Quality are filled by the various matrices that were calculated with the help of A.N.P. This can be illustrated with a model of House of Quality as a network between CNs and TRs in HOQ as shown in the table 10.

Table 10. HOQ between CNs and TRs

HOQ	Technical Requirements	Priorities	Power	Auto choke	Electric start	Suspension	Brakes	Alloy wheels	LED tail Lamps	Tyres	Battery	Low weight
Customer Requirements	Mileage	0.29	0.3	0.22	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.15
	Comfort	0.07	0.04	0.21	0.21	0.21	0.04	0.04	0.04	0.04	0.07	0.08
	Handling & Control	0.08	0.09	0.04	0.04	0.24	0.24	0.04	0.04	0.18	0.04	0.04
	Safety	0.22	0.06	0.03	0.04	0.16	0.27	0.04	0.14	0.16	0.06	0.04
	Aesthetics	0.07	0.06	0.06	0.06	0.06	0.06	0.28	0.28	0.06	0.06	0.06
	Reliability	0.14	0.29	0.05	0.05	0.14	0.05	0.05	0.05	0.14	0.13	0.06
	Speed	0.12	0.35	0.07	0.07	0.07	0.07	0.07	0.07	0.13	0.07	0.07
	WANP		0.144	0.085	0.08	0.118	0.1047	0.08	0.081	0.104	0.08	0.1

5. Conclusions

The proposed method illustrates the use of decision tools to evaluate product attributes and requirements. It is used to identify the essential product features and determine the design targets qualitatively and objectively through a series of proven multi criteria decision methodologies. This approach incorporates the Voice of Customer (VOC) in order to interpret the customer requirements and translate it using the demands to desirable design features of product.

The ANP process not only evaluates the outer independence (among different elements) but also finds inner dependence (within a set of elements).

It enables incorporating several matrices into an integrated super matrix involving four-level hierarchy structure and dealing with inner dependences without independence assumptions. It involves refinement of requirement using matrices and charts based on group decided priorities. The customer requirement mileage is most preferred with a weight of 0.29. In order to provide good mileage to the customers power is the TR that influences it the most with a weight of 0.30. The second requirement is safety with 0.22 weight which can be fulfilled by awesome suspension system with 0.16 weight, advanced braking systems like A.B.S anti-lock braking systems with 0.27 weight as well as good road gripping tyres with 0.16 weight. The proposed method is comprehensive and suitable to solve multi-criteria issues to for better decisions in planning or evaluation problems.

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Tarun Soota
Bundelkhand Institute of Engineering & Technology, Department of mechanical engineering Jhansi 284128
India
tarunsoota@rediffmail.com