A Fuzzy Based Maintenance Quality Function Deployment Application for an Automoblie Service Station

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Abstract:

In this paper the capability of a customer focused quality engineering approach called "Maintenance Quality Function Deployment (MQFD)" has been reviewed. The paper describes the applicability of this framework in an Automotive Service Industry (ASI). The customer needs or critical factors have to be evaluated precisely for the successful implementation of MQFD. The paper aims to determine the degree of importance of critical quality and maintenance characteristics pertaining to an automobile service station. In this paper, a fuzzy modification of AHP is proposed which can improve the accuracy of determination of the weightages of critical factors. It has been found that fuzzy approach in MQFD gives superior results when evaluating the weightages.

Keywords: *Automotive Service Industry, Critical Factors, Fuzzy- Analytic Hierarchy Process,Maintenance Quality Function Deployment.*

1. Introduction

Customer is the focal point of business (Chakrabarty and K. C. Tan 2007). The very existence of business depends on customer satisfaction. Customer expects high quality services, even keen to pay premium for better service (R. Sousa and C. Voss, 2002). Good service quality leads to long-term customer relationships. In today's global and highly competitive market, it is essential for the survival of any firm involved in the service industry to be adaptive, responsive to changes, proactive and has the capability to deliver high quality products according to diverse customer requirements. Therefore, it is very important for any firms which involved in service industry to improve their service quality by reducing the gap between internal quality and external customer satisfaction (Lin 2007).

The last two decades witnessed the tremendous growth of service industry. Due to this growth, the quality of service becomes an important factor for the survival of the service provider. During this period the growth rate of automobile sector was very high. Along with this growth the automobile service sector too has shown an upward trend and it is undergoing some revolutionary changes. The focus is shifted to the customer's expectation about the quality of service being provided. However, not much research has been carried out on the service quality aspects in automobile service industry (Bendt, A., 2009). So there is a need of extensive study on the applicability of customer focused quality management tool like Quality Function Deployment (QFD) in the automobile service industry.

Understanding customers' needs and incorporating them in the product is a necessity to meet the customer's increasing dynamic demand for higher degree of quality and customer satisfaction. Quality Function Deployment (QFD) is a technique adopted in Total Quality Management(TQM) to translate customer's voice into technical language (Kathawala and Motwani, 1994). Researchers had realized the need to link Total Productive Maintenance (TPM) with QFD to include customers' voice in maintenance quality improvement plan. Pramod *et.*al. (2006) proposed a model called Maintenance Quality

Function Deployment (MQFD) to have a synergic gain in maintenance quality by linking TPM with QFD. This model has been validated in different practical scenarios (Pramod *et al.*, 2006, 2007b, 2008). MQFD is modified by including AHP for calculating the weightages of the critical factors (Pramod *et al.*, 2007b). Evaluation of the relative importance and weightages of customer needs are the critical steps during the MQFD process. Most of the decision making in the real world takes place in situations where the vagueness are associated with data. Due to the imprecision existing in judgement of the decison makers, the crisp pair-wise comparison in the conventional AHP may be insufficient to assess the degree of importance of customer requirements (Kwong. and Bai, 2002).

Considering the above facts, an extension of AHP-MQFD is proposed in this paper. Fuzzy-AHP (FAHP) is a powerful and flexible multi-criteria decision making (MCDM) tool for dealing with complex problems where both qualitative and quantitative aspects are to be evaluated and when the experts judgements are vague (Yang and Zhang, 2010). A fuzzy modification of AHP is exploited in this model to evaluate the weightages of the critical factors and sub factors. This paper is arranged as follows. MQFD is illustrated in section 2, Fuzzy –AHP is explained in section 3. Section 4 explains the proposed method followed by a sample case study in section 5. Results and conclusions are in the subsequent sections.

2. Maintenance Quality Function Deployment

The major features of MQFD are described in this section. The MQFD framework is shown in Figure 1. The customers' voice is gathered which are then used by the QFD team to develop the House of Qualtiy(HoQ) (Chein and Su, 2003). HoQ is a tool to translate customers voice into technical requirements, These requirements are submitted to the management for making strategic decisions.

The technical requirements concerning the improvement of maintenance quality are processed through the eight pillars of TPM to develop TPM methodologies. These methodologies are then applied in the production system. Their implementations is to be focussed on increasing the values of the maintenance quality parameters such as Overall Equipment Efficiency (OEE), Mean Time Between Failures (MRBF), Mean Time To Repair (MTTR), Performance Quality (PQ),Availability and Mean own Time (MDT).

The outputs are used to compare with the set targets and to develop HoQ for the next cycle.The result of the implementation of MQFD will be the improvement in maintenance quality, enhancement in profit etc. The implementation of MQFD model is a continuous improvement process. A unique feature of the MQFD model is that it does not necessitate extensive changes in the existing continuous improvement processes like TQM and TQM which may be practised in the company. Thus, MQFD model enables the link between QFD and TPM. For further illustrations about MQFD, readers are advised to refer the following articles . (Pramod *et al.*, 2006, 2007b, 2008)

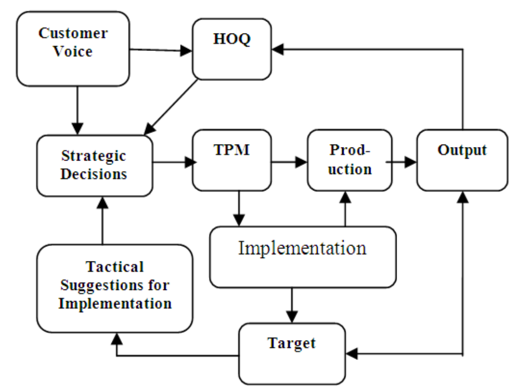

Figure 1 MQFD model

3. Fuzzy – Analytic Hierarchy Process

The Analytic Hierarchy Process (AHP) is a systematic technique for organizing and analyzing complex decisions. It was developed by Thomas L Saaty in the 1970s and has been studied and modified by the researchers. There are three steps of AHP methodology (Saaty, 2008), structuring the hierarchy, performing the comparative pair-wise judgement and synthesising results. AHP is one of the dominant MCDM methods (Payman *et al*., 2012). Fuzzy set theory can be used in situations where uncertainty and ambiguity are associated with the mapping of decision maker's judgement to crisp numbers (Mechefske and Wang, 2001). This necessitated the development of Fuzzy-AHP model (Payman *et al*., 2012). FAHP has been applied successfully in different areas.

4. Proposed Model

In the conventional AHP eigen vectors are used to calculate the final weights. However, Lootsma (1988) suggested that normalized column and row weights are equivalent to normalized eigen vectors. Verma (2006) proposed that average of two normalized weights can be considered as final weightages. Rajesh,. *et al.*(2010) applied this method for a maintenance strategy selection problem.

In this paper this method is applied to calculate the final weight. In AHP, a group of experts would fill the pairwise comparison matrix. Another method is that experts would give the importance for each criteria in a scale, (usually 1-9) and then the average values are converted into equivalent Saaty's score using equation (7).

The conversion of values into scores of Saaty's scale is a vital step in AHP (Karapetrovia and Rosenbloom 1999). Figure 2 illustrates the stepes involved in the proposed model.

Table 1 Saaty's Scales (1 – 9) expressed as Triangular Fuzzy Number(TFN).

Table 1 Triangular fuzzy number		
Scale	**Defination**	**Membership values**
1	Equally Important	(1, 1, 2)
3	Moderate more Important	(2, 3, 4)
5	Strongly more Important	(4, 5, 6)
7	Very strongly more important	(6, 7, 8)
9	Exceedingly more important	(8, 9, 9)

$$Y = 1 + \left[\left(x - x_{\min} \right) * \frac{8}{\left(x_{\max} - x_{\min} \right)} \right] \quad (1)$$

where Y = equivalent score in Saaty's 1-9 scale

x = average values computed against each criticalfactor/sub factor.

$x_{\min}$ = minimum average value in each group critical factor/subfactor.

$x_{\max}$ = maximum average factor in each group criticalfactor/subfactor.

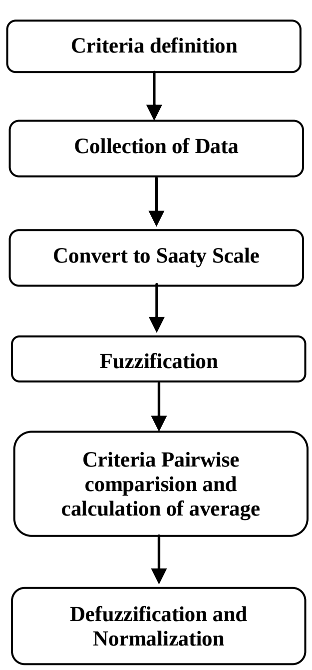

Figure 2 Steps in the proposed model

These scores are used to construct the pairwise comparison matrix (Pramod et al 2007b) in conventional AHP. However, in this model these Saaty's scores are converted to fuzzy numbers. The steps involved in this model are shown in the Figure 2.

After the fuzzification of data, a fuzzy pairwise comparision matrix is constructed as given by the equation (2). $\tilde{x}_{ij}$ dentoes the fuzzy values assigned to the relative importance of criteria C_i to C_j. These values are obtained by calculating the ratio of fuzzy number associated with C_i to the fuzzy number associated with C_j.

The following steps are used to calculate the average weightage of each criteria

Row Sum , $r\tilde{s}_i = \sum_{j=1}^{n} \tilde{x}_{ij}$

$\forall \quad i = 1,2,3............, n$ (2)

Column Sum, $c\tilde{s}_j = \sum_{i=1}^{n} \tilde{x}_{ij}$

$\forall \quad j = 1,2,3........, n$ (3)

Cumulative Row Sum, $cr\tilde{s} = \sum_{i=1}^{n} r\tilde{s}_i$ (4)

Normalized Row Vector $\tilde{n}_i = r\tilde{s}_i \div cr\tilde{s}$

(5)

Normalized Column Vector, $i\tilde{n}_i = \left(cs_i \right)^{-1}$

(6)

Average weightage of criteria i,

$$\tilde{w}_i = \left(\frac{\tilde{n}_i \oplus i\tilde{n}_i}{2} \right) \quad (7)$$

Defuzzification is the process of converting a fuzzy number to a crisp number and in the proposed method the center of gravity method is adopted (Timothy, 2010). The following equation is used to calculate the same.

$$w_i^d = \left(\frac{\left(w_u - w_l \right) + \left(w_m - w_l \right)}{3} \right) + w_l ,$$

$\forall \ i = 1,2,...., n$ (8)

Normalization, $\overline{w}_i = \frac{w_i^d}{\sum_{i=1}^{n} w_i^d}$, $\forall$

$i = 1,2,3...., n$ (9)

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5. Sample case Study

Pramod,V.R(2007b) had conducted a sample application study in a public sector automobile service station. The aim of the study was to examine the practicality of applying AHP in MQFD (Pramod *et al*,. 2007b). The data collected in that study are used in this paper. They discretisation hierarchy of MQFD is that study is illustrated in (Pramod *et al*,. 2007b). Table 2 shows the components of MQFD such as HoQ, Decision system, TPM, Maintenance Parmeters and Quality parameters and the corresponding critical factors considered for the case study which is related to Automotive Service Industry (ASI). The average score, Saaty's score and the corresponding TFNs assigned are also given in Table 2. The TFN is assigned in such a manner that the lower value is not less than 1 and upper value is not greater than 9. The Saaty's score is taken as the corresponding modal values. A sample calculation for the component HoQ is shown in Table 3 and Table 4. These calculations are carried out for the other components and critical facors. The results are tabulated in the Table 5.

Table 2 Fuzzy Pair-Wise Comparison Matrix of the Component HoQ

Component	Critical Factors	Avg. Value	Score in Saaty's Scale	TFN
HoQ	Customer (C1)	7.9	9.0	8.0 9.0 9.0
	Technology (C2)	7.3	5.6	4.6 5.6 6.6
	Competitors (C3)	6.5	1.0	1.0 1.0 2.0
Decision system	Personnel Factor (C4)	8.1	9.0	8.0 9.0 9.0
	Value of Decisions (C5)	6.3	1.0	1.0 1.0 2.0
	Reliability of Decisions (C6)	7.0	4.1	3.1 4.1 5.1
TPM	Autonomous Maintenance (C7)	7.7	9.0	8.0 9.0 9.0
	Individual Improvement (C8)	7.0	6.6	5.6 6.6 7.6
	Planned Maintenance (C9)	7.6	8.7	7.7 8.7 9.0
	Quality Maintenance (C10)	7.5	8.3	7.3 8.3 8.3
	Education And Training (C11)	7.5	8.3	7.3 8.3 9.0
	Development management (C12)	6.6	5.1	4.1 5.1 6.1
	Office TPM (C13)	5.4	1.0	1.0 1.0 2.0
	Safety Health And Environment (C14)	7.5	8.3	7.3 8.3 9.0
Maintenance Parmeters	Overall equipment effectiveness (C15)	7.3	6.7	5.7 6.7 7.7
	Mean time between failure (C16)	5.6	1.0	1.0 1.0 2.0
	Mean time to repair (C17)	6.0	2.3	1.3 2.3 3.3
	Performance efficiencies (C18)	8.0	9.0	8.0 9.0 9.0
	Mean down time (C19)	7.0	5.7	4.7 5.7 6.7
	Availability (C20)	7.1	6.0	5.0 6.0 7.0
Quality parameters	Improved Maintenance (C21)	8.0	9.0	8.0 9.0 9.0
	Increased Profit (C22)	5.3	1.0	1.0 1.0 2.0
	Upgraded core competence (C23)	5.5	4.7	3.7 4.7 5.7
	Enhanced good will (C24)	8.0	9.0	8.0 9.0 9.0

Table 3 Fuzzy Pair-Wise Comparison Matrix of the Component HoQ

Criteria	C1	C2	C3	$\tilde{FS}$
	1	1.21	4.0	6.21
C1	1	1.61	9.0	11.61
	1	1.96	9.0	11.96

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C2	.51 .62 .83	1 1 1	2.3 5.6 6.6	3.81 7.22 8.43
C3	.11 .11 .25	.15 .18 .43	1 1 1	1.26 1.29 1.68
$\widetilde{crs}$	1.62 1.73 2.08	2.36 2.79 3.39	7.3 15.6 16.6	11..28 20.12 22.07

The value of cumulative row sum $\widetilde{crs}$ = (11.28 20.12 22.07)

Table 4 Final Weightages of the Critical Factors of HoQ

Criteria	C1	C2	C3
$\widetilde{rs}_i$	6.21 11.61 11.96	3.81 7.22 8.43	1.26 1.29 1.68
$\widetilde{cs}_i$	1.62 1.73 2.08	2.36 2.79 3.39	7.3 15.6 16.6
$\widetilde{n}_i$	.28 .58 1.06	.17 .36 .75	.06 .06 .15
$\widetilde{in}_i$	.48 .58 .62	.29 .36 .43	.06 .06 .14
$\widetilde{w}_i$	.38 .58 .84	.23 .36 .59	.06 .06 .15
w_i^d	.60	.39	.09
$\bar{w}_i$	.56	.36	.08

Table 5 Local Weightages of Critical Factors of MQFD model

Critical Factors	Local sensitivity AHP - MQFD	Local sensitivity FAHP - MQFD	% Change	Rank. AHP - MQFD	Rank FAHP MQFD
C1	0.62	.56	9.7	1	2
C2	0.32	.36	12.5	5	5
C3	0.06	.08	33.3	20	20
C4	0.60	.61	1.7	2	1
C5	0.08	.09	12.5	19	19
C6	0.32	.30	6.3	6	6
C7	0.15	.16	6.7	12	12
C8	0.14	.12	14.3	17	17
C9	0.15	.15	0.0	13	13
C10	0.15	.15	0.0	14	14
C11	0.15	.15	0.0	15	15
C12	0.09	.10	11.1	18	18
C13	0.02	.02	0.0	24	24
C14	0.15	.15	0.0	16	18
C15	0.23	.22	4.3	8	8
C16	0.03	.04	33.3	23	23
C17	0.06	.08	33.3	21	21
C18	0.28	.28	0.0	7	7
C19	0.21	.19	9.5	9	11
C20	0.19	.20	5.3	11	10
C21	0.38	.37	2.6	3	3
C22	0.04	.06	50.0	22	22
C23	0.20	.21	5.0	10	9
C24	0.38	.37	2.6	4	4

6. Results

The results are tabulated in Table 5. For comparison purpose sthe corresponding values obtained using the conventional AHP method(Pramod *et al*,. 2007) are also shown.The result showed that the critical factor, the personal factor $(C4)$ has the highest ranking when fuzzy AHP method is used, whereas critical factor customer $(C1)$ had the highest ranking when the conventional AHP method is used. The percentage differencee in local weightages of the critical factors are shown in Figure 3. The average difference of weightages between the two methods is about 11% per factor. The results showed that there is some marked difference in the values of weightages and rank orders obtained by the two methods namely, AHP - MQFD and Fuzzy AHP - MQFD methods. Since it is already established by the researchers that fuzzy operations are more appropriate when dealing with vague data, this method will improve the accuracy of results in MQFD.

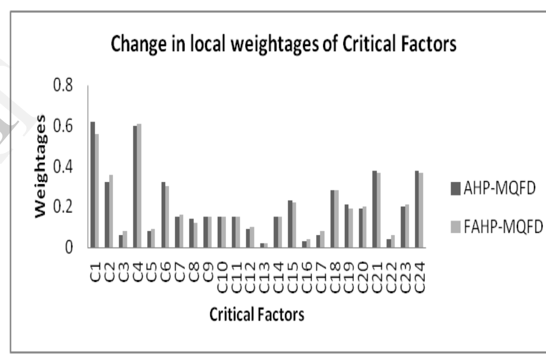

Figure 3 Difference in Local Weightages of Critical Factors

7. Conclusions

The proposed methodology improves the determination of weightages of critical factors in MQFD. Here a fuzzy – AHP method is proposed to calculate weightages of the same. The technique proposed here successfully addresses the drawbacks of conventional AHP based MQFD in dealing with imprecision of customer voice. Since the proper evaluation of weightages of critical factors is a crucial step in the implementation of MQFD, the proposed methodology may guide to the formulation of a more accurate MQFD based technique for multi criteria decision making.

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