# COMPARATIVE STUDY ON WEIGHTING CUSTOMER REQUIREMENTS USING FUZZY ANALYSIS HIERARCHY PROCESS WITH EXTENT ANALYSIS AND ANALYTIC HIERARCHY PROCESS

**M.T. Mastura[1], S.M. Sapuan[2], M.R. Mansor[3] and A.A. Nuraini[4]**

[1,2,4] Department of Mechanical and Manufacturing Engineering, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia

[1]Faculty of Engineering Technology,
Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia.

[3]Faculty of Mechanical Engineering,
Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia.

[2]Laboratory of Biocomposite Technology, Institute of Tropical Forestry and Forest Products (INTROP) Universiti Putra Malaysia
43400 UPM Serdang, Selangor, Malaysia.

Corresponding Author's Email: [2]sapuan@upm.edu.my

**Article History**: Received 18 August 2017; Revised 19 October 2017; Accepted 5 December 2017

**ABSTRACT:** Weighting customer requirement is not an easy task to undertake since it involves subjective human perception and judgement. In this study, both Analytic Hierarchy Process (AHP) and Fuzzy AHP with extent analysis (FAHP) methods were applied to determine and to compare the differences on the weight of customer requirements. Customer requirements for automotive anti-roll bar (ARB) were taken as a case study from related literature. The results from both methods showed slight differences in weighting customer requirements with an average of differences is 0.73%. Thus, the FAHP method could be applied in decision-making to find the weight of attributes whilst the AHP could also be applied in decision-making to deal with vague and imprecise information.

**KEYWORDS**: *Analytic Hierarchy Process; Fuzzy Analytic Hierarchy Process with Extent Analysis; Customer Requirements; Automotive Anti-Roll Bar*

## 1.0 INTRODUCTION

The voice of customers (VOC) is an important element that needs to be considered in the initial stage of the product development process since they are the real stakeholders of the product. The VOC is important because the customers would voice out what needs to be revised with regards to the features of the current products and also their expectations of new product features which need to be incorporated into the demand list [1]. This would serve as a guide for the design engineers on what they could suggest during brainstorming activities on product development. However, there are some issues which crop up related to human perception and preference. Nahm [2] in his study reported that customer perception is usually imprecise and uncertain in nature. Human perception is usually influenced by its surroundings and emotions [3]. This could lead to vague information. Therefore evaluating the perception and preference of this kind could be a relatively complicated task to perform. Besides this, in order to satisfy VOC, the technical team suggested attributes from the technical perspective to be connected to a product design [4]. In 1980 Saaty [5] developed the analytic hierarchy process (AHP) to rank the alternatives with respect to several criteria. The idea of Saaty [6] in prioritization multi attributes has been widely applied in various fields in academic research as well as industrial practice. In the product development process, AHP has been utilized as a tool to solve various design problems. For example, Hambali et al. [7-8] and Mansor et al. [9] had used AHP in the determination of a most suitable design concept in product design development. Sapuan et al. [10], Jahan et al. [11], Desai et al. [12], and Mansor et al. [13] had used AHP in material selection process. Gangurde and Akarte [14] and Li et al. [15] had used AHP to determine the importance of the alternatives based on customer satisfaction.

AHP has been chosen as a method to prioritize customer requirements because of its simplicity in the algorithms. Dalalah [16] reported in his study that results from AHP is acceptable with accurate decisions. Furthermore, it is easy for the decision maker to deal with imprecise human judgements as AHP does not require in-depth technological knowledge from the decision maker regarding the specifics of the study. Ho [17] in his study reported that it is possible to combine AHP with other techniques because of its simplicity and flexibility. Nevertheless, there are some issues on conventional AHP that has become a debate among researchers. The most common issue that has been discussed among researchers is the capability of conventional

AHP in dealing with vague and imprecise information. Therefore, Laarhoven [18] proposed a method to deal with this problem using fuzzy judgement by a comparison of the triangular fuzzy number [19]. In another study by Leung [20], he stated the fuzzy approach used to evaluate human judgement enables a more accurate description for decision makers to make a correct decision compared with the conventional AHP approach. The conventional AHP is found incapable of processing imprecise or vague information [21]. Subsequently, Chang [22] had proposed a new approach from fuzzy judgement with extension analysis. Fuzzy AHP (FAHP) with extent analysis was proposed to obtain a crisp priority vector from a triangular fuzzy comparison matrix. This method is used by converting a linguistic assessment into a triangular fuzzy number. The "extent analysis" here is referred to as a consideration of the extent of an object to be satisfied for a goal [23]. While FAHP with extent analysis is being utilized by most decision makers from various fields, Wang [24] in his study had corrected normalization methods which provided more relevant results. In his study, he found that the existing normalization method at that time was incorrect and lead to unrealistic intervals and fuzzy weights. Later, Wang [25] re-examined FAHP with extent analysis using three numerical examples. He also suggested that misapplication in deriving priorities using fuzzy comparison matrix could occur because the extent method might assign irrational zero weight to some useful decision criteria and sub-criteria which would lead to wrong decisions. This has led to a study by Zhü [26] who pointed out more misunderstandings on FAHP with extent analysis. Before that, Saaty in his papers [27-29] had criticized fuzzy judgement used in AHP as invalid and concluded that fuzzifying inconsistent judgements could lead to a less favourable outcome. Comparative studies between FAHP and AHP have been conducted by a few researchers [30-31] and they showed that both methods have their own capabilities, yet applicable in any background of study. Nevertheless, the studies concurred that AHP was more superior and easy to use. Therefore, in this study, both methods: FAHP with extent analysis and AHP have been applied to compare customer judgement towards product design requirements based on the voice of customers.

## 2.0 METHODOLOGY

In this study, the automotive anti-roll bar (ARB) was chosen as the case study. Anti-roll bar is used to reduce the amount of body roll of vehicles during cornering. In order to make a suitable design of ARB, important design parameters have been taken out from literature studies in view of the various backgrounds of customers such as end users and environment.

As in Figure 1, AHP and FAHP with extent analysis are applied in parallel. Initially, the hierarchy of attributes was constructed and each of the elements was compared with another on a pairwise basis. As in Table 1, a nine-point scale was applied as it is commonly used to show judgment or preference between options and AHP employs crisp number. For FAHP with extent analysis, the triangular fuzzy number (TFN) technique was employed to represent a pairwise comparison.

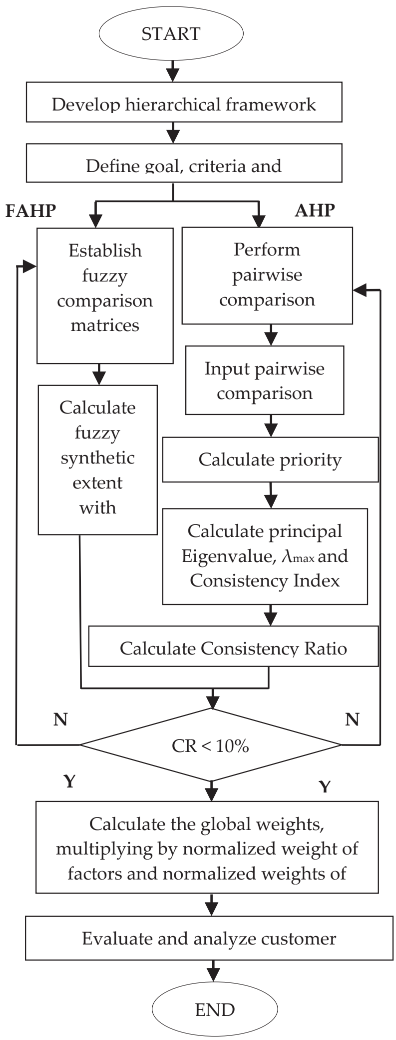


Figure 1: Methodology of utilization of FAHP and AHP in parallel.

## 2.1 Fuzzy AHP with extent analysis

A triangular fuzzy number can be denoted as M=ãij= (lij,mij,uij) where l ≤m≤u, l and u stands for lower and upper values of the support M, respectively and m is the mid-value of M. According to Table 1, TFN were used to represent the assessment from equal to extremely preferred for scale M1, M3, M5, M7 and M9 while M2, M4, M6, M8 were used to represent the moderate values.

Table 1: Conversion scale of weighting set [33]

| Intensity of preference | | Verbal Definition |
|---|---|---|
| Crisp Number | Triangular Fuzzy Number | |
| 1 | 1,1,1 (M1) | Equally preferred |
| 3 | 2,3,4 (M3) | Moderately preferred |
| 5 | 4,5,6 (M5) | Strongly preferred |
| 7 | 6,7,8 (M7) | Very strongly preferred |
| 9 | 8,9,9 (M9) | Extremely strongly preferred |
| 2,4,6,8 | 1,2,3(M2),3,4,5(M4), 5,6,7(M6), 7,8,9 (M8) | Moderation |

Next, a triangular fuzzy comparison matrix is formed and is expressed by

$$\tilde{A} = (\tilde{a}_{ij})_{n\times n} = \begin{bmatrix} (1,1,1) & (l_{12}, m_{12}, u_{12}) & \ldots(l_{1n}, m_{1n}, u_{1n}) \\ \vdots & (1,1,1) & \ldots \quad \vdots \\ (l_{n1}, m_{n1}, u_{n1}) & (l_{n2}, m_{n2}, u_{n2}) & \ldots \quad (1,1,1) \end{bmatrix} \quad (1)$$

where $\tilde{a}_{ij}=(l_{ij},m_{ij},u_{ij})$ and $\tilde{a}_{ij}^{-1}=(1/u_{ij},1/m_{ij},1/l_{ij})$ for $i,j=1,\ldots,n$ and $i\neq j$.

An extent analysis method was used to calculate the priority vector of the above triangular fuzzy comparison matrix from formulas suggested by Chang [22] and modified by several researchers [24-25, 34] as follows:

Step 1: Each row of the fuzzy comparison matrix $\tilde{A}$ is summed up by fuzzy arithmetic operations as in Equation (2).

$$RS_i=\sum_{j=1}^{n} \tilde{a}_{ij} = \left(\sum_{j=1}^{n} l_{ij}, \sum_{j=1}^{n} m_{ij}, \sum_{j=1}^{n} u_{ij}\right), i = 1, \ldots, n \quad (2)$$

Step 2: According to Wang [25] normalization formula suggested by Chang [22] led to a wrong decision and some information from the comparison matrices would be wasted. Therefore, he suggested the following normalization formula for a set of triangular fuzzy weights is given by

$$\widetilde{S_i} = \frac{RS_i}{\sum_{j=1}^{n} RS_j} = \left(\frac{\sum_{j=1}^{n} l_{ij}}{\sum_{j=1}^{n} l_{ij} + \sum_{k=1,k\neq i}^{n}\sum_{j=1}^{n} u_{kj}}, \frac{\sum_{j=1}^{n} m_{ij}}{\sum_{k=1}^{n}\sum_{j=1}^{n} m_{kj}}, \frac{\sum_{j=1}^{n} u_{ij}}{\sum_{j=1}^{n} u_{ij} + \sum_{k=1,k\neq i}^{n}\sum_{j=1}^{n} l_{kj}}\right), i=1,\ldots,n \quad (3)$$

Step 3: Wang [25] and Zhu [26] in their studies mentioned that Chang's suggestion in the definition of priority vector does not reflect the true priorities and cannot be used to find relative priority values. Therefore, Roy et al. [34] in his study considered the method suggested by Liou and Wang [35] for finding the priorities of synthetic extent. Roy used the total integral value method to deal with the zero-weight problem found in Chang's method. The equation to find total integral value is shown as

$$J_T^{\alpha}(SE_j) = \frac{1}{2}\alpha\left(b_j + c_j\right) + \frac{1}{2}(1-\alpha)\left(a_j + b_j\right) = \frac{1}{2}\left[\alpha c_j + b_j + (1-\alpha)a_j\right] \quad (4)$$

where $\alpha$ represents the degree of optimism of the decision maker and its value can range from 0 to 1. When $\alpha$=0, it represents the pessimistic decision maker's point of view and $\alpha$=1 represents the optimistic decision maker's point of view. Thus, in this study $\alpha$=0.5 was used to represent moderation.

Step 4: Next, the normalized priority vector $W=(w_1,w_2,\ldots,w_n)^T$, non-fuzzy number, is calculated by formula (5) as follows:

$$w_j = \frac{J_T^{\alpha}(SE_j)}{\sum_{j=1}^{n} J_T^{\alpha}(SE_j)} \quad (5)$$

## 2.2 Analytic Hierarchy Process

In AHP, the common hierarchy is used whilst a nine-point scale with conversion value from TFN to crisp value is used to construct pairwise comparison matrixes. The method to obtain priority vectors is by calculating the eigenvector of comparison matrix. The eigenvalue of the comparison matrix would be used to calculate the consistency index (CI) and the consistency ratio (CR) of the judgments in pairwise comparison.

The CI and CR for a comparison matrix can be computed from Equations (6) and (7) as follows:

$$CI = \frac{\lambda_{\max} - n}{n-1} \tag{6}$$

$$CR = \left(\frac{CI}{RI(n)}\right) 100\% \tag{7}$$

where, $\lambda_{max}$ is the largest eigenvalue of the comparison matrix, n is the dimension of the matrix and RI(n) is a random index which depends on n. In this study, n is 15 , so RI(n) is 1.59 [36]. If the calculated consistency ratio is less than 10%, the pairwise judgement could be thought of as being acceptable.

## 3.0 RESULTS AND DISCUSSION

### 3.1 Hierarchy of Decision Problem

After identification of customer requirements from a literature review [37-45], a hierarchy framework of customer requirements was developed for weighting customer requirements as in Figure 2. The goal of this decision-making is to weight customer requirements which are in level 1 (L1). The second level (L2) represents three important criteria which include quality, cost and environmental concerns. The third level (L3) of the hierarchy represents 15 alternatives based on the criteria at the second level which need to be prioritized.

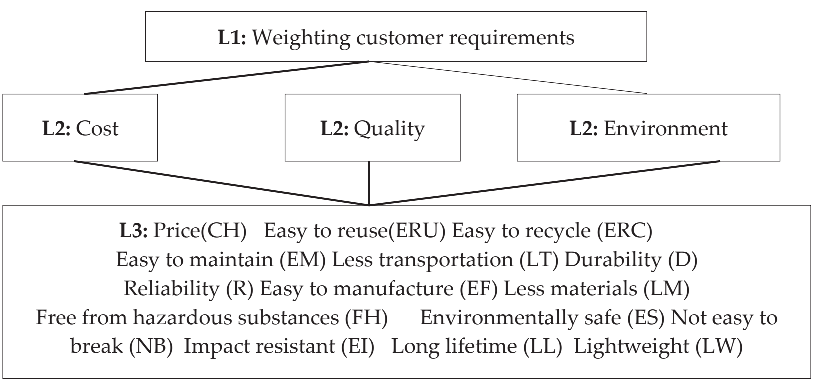


Figure 2: The hierarchy framework in weighting customer requirements

### 3.2 Fuzzy analytic hierarchy process (FAHP) with extent analysis

According to the hierarchy of weighting customer requirements, there are 15 alternatives with respect to the three criteria which are cost, quality and environment. Therefore, there are three comparison matrices for the 15 alternatives but only one of the comparison matrices with respect to quality is shown as in Table 2. From these comparison matrices, weights of the alternatives are calculated using Equations (2)-(5). Finally, the global weights are calculated and presented in Table 5. Considering all the criteria, "durability" is the most important feature and "less materials" is the least important feature for ARB.

Table 2: The fuzzy pairwise comparison matrix with respect to quality using FAHP

| | CH | | | ERU | | | ERC | | | LT | | | EF | | | D | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CH | 1 | 1 | 1 | 1/7 | 1/6 | 1/5 | 1/6 | 1/5 | 1/4 | 1/3 | 1/2 | 1 | 1 | 2 | 3 | 1/9 | 1/9 | 1/8 |
| ERU | 5 | 6 | 7 | 1 | 1 | 1 | 1 | 2 | 3 | 2 | 3 | 4 | 1 | 2 | 3 | 1/6 | 1/5 | 1/4 |
| ERC | 4 | 5 | 6 | 1/3 | 1/2 | 1 | 1 | 1 | 1 | 1 | 2 | 3 | 2 | 3 | 4 | 1/6 | 1/5 | 1/4 |
| LT | 1 | 2 | 3 | 1/4 | 1/3 | 1/2 | 1/3 | 1/2 | 1 | 1 | 1 | 1 | 1 | 2 | 3 | 1/8 | 1/7 | 1/6 |
| EF | 1/3 | 1/2 | 1 | 1/3 | 1/2 | 1 | 1/4 | 1/3 | 1/2 | 1/3 | 1/2 | 1 | 1 | 1 | 1 | 1/7 | 1/6 | 1/5 |
| D | 8 | 9 | 9 | 4 | 5 | 6 | 4 | 5 | 6 | 6 | 7 | 8 | 5 | 6 | 7 | 1 | 1 | 1 |
| LW | 6 | 7 | 8 | 2 | 3 | 4 | 2 | 3 | 4 | 4 | 5 | 6 | 4 | 5 | 6 | 1/5 | 1/4 | 1/3 |
| EM | 6 | 7 | 8 | 2 | 3 | 4 | 2 | 3 | 4 | 4 | 5 | 6 | 3 | 4 | 5 | 1/5 | 1/4 | 1/3 |
| R | 6 | 7 | 8 | 2 | 3 | 4 | 4 | 5 | 6 | 6 | 7 | 8 | 3 | 4 | 5 | 1/4 | 1/3 | 1/2 |
| LL | 6 | 7 | 8 | 2 | 3 | 4 | 2 | 3 | 4 | 4 | 5 | 6 | 4 | 5 | 6 | 1/4 | 1/3 | 1/2 |
| EI | 6 | 7 | 8 | 2 | 3 | 4 | 2 | 3 | 4 | 4 | 5 | 6 | 2 | 3 | 4 | 1/4 | 1/3 | 1/2 |
| NB | 6 | 7 | 8 | 1 | 2 | 3 | 1 | 2 | 3 | 3 | 4 | 5 | 2 | 3 | 4 | 1/6 | 1/5 | 1/4 |
| FH | 1/3 | 1/2 | 1 | 1/4 | 1/3 | 1/2 | 1/4 | 1/3 | 1/2 | 1/3 | 1/2 | 1 | 1/4 | 1/3 | 1/2 | 1/8 | 1/7 | 1/6 |
| LM | 1/4 | 1/3 | 1/2 | 1/7 | 1/6 | 1/5 | 1/6 | 1/5 | 1/4 | 1/5 | 1/4 | 1/3 | 1/3 | 1/2 | 1 | 1/9 | 1/9 | 1/8 |
| ES | 1/3 | 1/2 | 1 | 1/5 | 1/4 | 1/3 | 1/4 | 1/3 | 1/2 | 1/3 | 1/2 | 1 | 1/3 | 1/2 | 1 | 1/9 | 1/9 | 1/8 |

### 3.3 Analytic Hierarchy Process (AHP)

As in the FAHP method, there are 15 alternatives with respect to the three criteria which are cost, quality and environment. With the same 15 alternatives, there are three comparison matrices. From these comparison matrices, the criteria and weights of the alternatives are calculated by obtaining the eigen vector and eigen value. The consistency ratio for comparison matrix with respect to goal is less than 10% which is 4.73%. This would indicate that judgment on the criteria with respect to goal is considered consistent. Finally, the global weights were calculated and presented in Table 5. Considering all the criteria, as in the FAHP method, "durability" is the most important feature and "less materials" is the least important feature for ARB which appeared as a result of the AHP method.

In the final evaluation, all priority rate of each customer requirement obtained using both methods are as shown in Table 3. The difference in percentage was calculated and the values were found to be less than 3%. The average value of differences is only 0.73%. The differences in the values may have occurred due to the effect of rounding-off when converting crisp numbers into triangular fuzzy numbers for intensity of preference. If actual values (without round-offs) were applied during calculation, then the lower value of differences between both methods would be achieved.

Table 3: Comparison of global weight results from FAHP and AHP methods

| Alternatives | Global weight (Wg) | | |
|---|---|---|---|
| | FAHP | AHP | Value of differences (%) |
| Price | 0.0391 | 0.0417 | 0.26 |
| Easy to reuse | 0.0946 | 0.0886 | 0.61 |
| Easy to recycle | 0.0810 | 0.0713 | 0.96 |
| Less transportation | 0.0653 | 0.0577 | 0.76 |
| Easy to manufacture | 0.0304 | 0.0278 | 0.27 |
| Durability | 0.1284 | 0.1534 | 2.50 |
| Lightweight | 0.0732 | 0.0835 | 1.03 |
| Easy to maintain | 0.0729 | 0.0779 | 0.51 |
| Reliability | 0.0845 | 0.0868 | 0.23 |
| Long lifetime | 0.0764 | 0.0731 | 0.33 |
| Impact resistant | 0.0629 | 0.0568 | 0.61 |
| Not easy to break | 0.0609 | 0.0514 | 0.95 |
| Free from hazardous substances | 0.0614 | 0.0708 | 0.94 |
| Less materials | 0.0249 | 0.0220 | 0.29 |
| Environmentally safe | 0.0442 | 0.0373 | 0.69 |

The ranking amongst the alternatives in FAHP and AHP is different. Thus, it can be noted that the use of FAHP to determine the weights of customer requirements is acceptable. On the other hand, in view of AHP, it shows that AHP could be considered in weighting customer requirements and would not provide much difference in results from the fuzzy environment even though the issue on vague and imprecise judgement has been raised by fuzzy practitioners.

As mentioned earlier, FAHP is considered invalid by a few researchers. However, this study has shown that FAHP is less likely to give a ranking on each attribute but it is more on giving a rating on how much should be considered as compared to another attribute. In which case, most FAHP applications have been integrated into QFD in order to rank the technical attributes with respect to customer requirements [33]. FAHP with extent analysis with the utilization of TFN in customer judgement would be more accurate since it has the lower and upper values implied in the range of preference intensity. Unlike AHP with its utilization of crisp numbers, the intensity of preference is more rigid and has no range as compared to the TFN in FAHP. Hence, FAHP is more suitable to be used in fuzzy environments and in a way where uncertainty exists in the evaluation of certain judgments. On the other hand, AHP is more likely to be used when there are certain judgments to be made. Furthermore, this case study has also demonstrated that FAHP is not as complicated as it is reported to be and can be easily understood by practitioners of AHP as the concept is quite similar.

## 4.0 CONCLUSION

In conclusion, both FAHP and AHP methods have their own characteristics that are reflected in the results obtained in prioritization. Based on the case study, this implies that both methods are acceptable in giving a weight for each attribute in decision-making by only having less than 3% difference in final results. However, ranking the attributes in order to decide which attributes are the best or the worst is not appropriate since the ranking numbers of each attribute in this study are different in both methods. Moreover, identification of the type of judgment, either subjective or objective judgment is the initial process to be conducted before evaluation. This is to determine which method is more appropriate to apply for the evaluation - either conventional AHP or FAHP. Further studies need to be conducted on the sensitivity analysis for both methods in order to obtain validation for both methods on the weighting of customer requirements. Thus, both methods are acceptable in giving weight such as problems which concern determining the weightage of customer requirements.

## ACKNOWLEDGMENTS

The authors would like to thank the Universiti Putra Malaysia for the financial support provided through the Putra Grant IPB (GP-

IPB/2014/9441500) as well as to the Universiti Teknikal Malaysia Melaka and the Ministry of Education of Malaysia for providing the scholarship award to the principal author to carry out this research project.

## REFERENCES

[1] C.Y. Chen, L.C. Chen and L. Lin, "Methods for processing and prioritizing customer demands in variant product design," *IIE Transactions*, vol. 36, no. 3, pp. 203–219, 2004.

[2] Y. E. Nahm, H. Ishikawa and M. Inoue, "New rating methods to prioritize customer requirements in QFD with incomplete customer preferences," *International Journal of Advanced Manufacturing Technology*, vol. 65, no. 9-12, pp. 1587–1604, 2013.

[3] L. C. Chen and P. Y. Chu, "Developing the index for product design communication and evaluation from emotional perspectives," *Expert Systems with Applications*, vol. 39, no. 2, pp. 2011–2020, 2012.

[4] Z. Iqbal, N. Peter Grigg, K. Govindaraju and N. M. Campbell-Allen, "Enhancing prioritisation of technical attributes in quality function deployment," *Inernational Journal of Productivity and Performance Managemen*t, vol. 64, no. 3, pp. 398–415, 2014.

[5] T. L. Saaty, *The Analytic Hierarchy Process*. New York: McGraw-Hill, 1980.

[6] O. S. Vaidya and S. Kumar, "Analytic hierarchy process: An overview of applications," *European Journal of Operational Research*, vol. 169, no. 1, pp. 1–29, 2006.

[7] A. Hambali, S. M. Sapuan, N. Ismail and Y. Nukman, "Application of Analytical Hierarchy Process (AHP) and Sensitivity Analysis for Selecting the Best Design Concepts during Conceptual Design Stage," *Multidiscipline Modeling in Materials and Structures*, vol. 5, no. 3, pp. 289–294, 2009.

[8] A. Hambali, S. M. Sapuan, A. S. Rahim, N. Ismail and Y. Nukman, "Concurrent Decisions on Design Concept and Material Using Analytical Hierarchy Process at the Conceptual Design Stage," *Concurrent Engineering*, vol. 19, no. 2, pp. 111–121, 2011.

[9] M. R. Mansor, S. M. Sapuan, E. S. Zainudin, A. A. Nuraini and A. Hambali, "Conceptual design of kenaf fiber polymer composite automotive parking brake lever using integrated TRIZ–Morphological Chart–Analytic Hierarchy Process method," *Materials & Design*, vol. 54, pp. 473–482, 2014.

[10] S. M. Sapuan, J. Y. Kho, E. S. Zainudin, Z. Leman, B. A. Ahmed Ali, and A. Hambali, "Materials selection for natural fiber reinforced polymer composites using analytical hierarchy process," *Indian Journal of Engineering and Materials Sciences*, vol. 18, pp. 255–267, 2011.

[11] A. Jahan, F. Mustapha, S. M. Sapuan, M. Y. Ismail and M. Bahraminasab, "A framework for weighting of criteria in ranking stage of material selection process," *International Journal of Advanced Manufacturing Technology*, vol. 58, no. 1-4, pp. 411–420, 2012.

[12] S. Desai, B. Bidanda and M. R. Lovell, "Material and process selection in product design using decision-making technique (AHP)," *European Journal of Industrial Engineering*, vol. 6, no. 3. p. 322, 2012.

[13] M. R. Mansor, A. Hambali, M. D. Azaman, S. M. Sapuan, E. S. Zainudin and A. A. Nuraini, "Material Selection of Thermoplastic Matrix for Hybrid Natural Fiber/Glass Fiber Polymer Composites Using Analytic Hierarchy Process Method," in Proceedings of the International Symposium on the Analytic Hierarchy Process, Kuala Lumpur, 2013, pp.1-8.

[14] S. R. Gangurde and M. M. Akarte, "Customer preference oriented product design using AHP-modified TOPSIS approach," *Benchmarking: An International Journal*, vol. 20, no. 4, pp. 549–564, 2013.

[15] X. Li, W. Zhao, Y. Zheng, R. Wang and C. Wang, "Innovative Product Design Based on Comprehensive Customer Requirements of Different Cognitive Levels," *The Scientific World Journal*, vol. 2014, pp. 1-11, 2014.

[16] D. Dalalah, F. Al-oqla and M. Hayajneh, "Application of the Analytic Hierarchy Process ( AHP ) in Multi- Criteria Analysis of the Selection of Cranes," *Jordan Journal of Mechanical and Industrial Engineering*, vol. 4, no. 5, pp. 567–578, 2010.

[17] W. Ho, "Integrated analytic hierarchy process and its applications - A literature review," *European Journal of Operational Research*, vol. 186, no. 1, pp. 211–228, 2008.

[18] P. J. M. van Laarhoven and W. Pedrycz, "A fuzzy extension of Saaty's priority theory," *Fuzzy Sets and Systems*, vol. 11, no. 1-3, pp. 199–227, 1983.

[19] K.J. Zhu, Y. Jing and D.Y. Chang, "A discussion on Extent Analysis Method and applications of fuzzy AHP," *European Journal of Operational Research*, vol. 116, pp. 450–456, 1999.

[20] L. C. Leung and D. Cao, "On consistency and ranking of alternatives in fuzzy AHP," *European Journal of Operational Research*, vol. 124, no. 1, pp. 102–113, 2000.

[21] T.C. Wang and Y.H. Chen, "Applying fuzzy linguistic preference relations to the improvement of consistency of fuzzy AHP," *Information Sciences*, vol. 178, no. 19, pp. 3755–3765, 2008.

[22] D.Y. Chang, "Applications of the extent analysis method on fuzzy AHP," *European Journal of Operational Research*, vol. 95, no. 3, pp. 649–655, 1996.

[23] C. K. Kwong and H. Bai, "Determining the Importance Weights for the Customer Requirements in QFD Using a Fuzzy AHP with an Extent Analysis Approach," *IIE Transactions*, vol. 35, pp. 619–626, 2003.

[24] Y.M. Wang and T. M. S. Elhag, "On the normalization of interval and fuzzy weights," *Fuzzy Sets and Systems,* vol. 157, no. 18, pp. 2456–2471, 2006.

[25] Y.M. Wang, Y. Luo and Z. Hua, "On the extent analysis method for fuzzy AHP and its applications," *European Journal of Operational Research*, vol. 186, no. 2, pp. 735–747, 2008.

[26] K. Zhü, "Fuzzy analytic hierarchy process: Fallacy of the popular methods," E*uropean Journal of Operational Research*, vol. 236, no. 1, pp. 209–217,2014.

[27] T. L. Saaty, "There is no mathematical validity for using fuzzy number crunching in the analytic hierarchy process," *Journal of Systems Science and Systems Engineering*, vol. 15, no. 4, pp. 457–464, 2006.

[28] T. L. Saaty and L. T. Tran, "On the invalidity of fuzzifying numerical judgments in the Analytic Hierarchy Process," *Mathematical and Computer Modelli*ng, vol. 46, no. 7–8, pp. 962–975, 2007.

[29] T. L. Saaty and L. T. Tran, "Fuzzy Judgments and Fuzzy Sets," *International Journal of Strategic Decision Sciences*, vol. 1, no. 1, pp. 23–40, 2010.

[30] A. Ishizaka, "Comparison of Fuzzy logic, AHP, FAHP and Hybrid Fuzzy AHP for New Supplier Selection and Its Performance Analysis," *International Journal of Integrated Supply Management*, vol. 9, no. 1991, pp. 1–22, 2014

[31] G. Kabir and M. H. Akhtar Hasin, "Comparative Analysis of Ahp and Fuzzy AHP Models For Multi-criteria Inventory Classification," *International Journal of Fuzzy Logic Syste*ms, vol. 1, no. 1, pp. 1–16, 2011.

[32] H. Bayrakceken, S. Tasgetiren and K. Aslantas, "Fracture of an automobile anti-roll bar," *Engineering Failure Analysis*, vol. 13, no. 5, pp. 732–738, 2006.

[33] I. Bereketli and M. Erol Genevois, "An integrated QFDE approach for identifying improvement strategies in sustainable product development," *Journal of Cleaner Production*, vol. 54, pp. 188–198, 2013.

[34] M. K. Roy, A. Ray and B. B. Pradhan, "Non-traditional machining process selection using integrated fuzzy AHP and QFD techniques : a customer perspective," *Production & Manufacturing Research*, vol. 2, no. 1, pp. 530–549, 2014.

[35] T.S. Liou and M. J. J. Wang, "Ranking fuzzy numbers with integral value," *Fuzzy Sets and Systems*, vol. 50, no. 3, pp. 247–255, 1992.

[36] H. Raharjo and D. Endah, "Evaluating Relationship of Consistency Ratio and Number of Alternatives on Rank Reversal in the AHP," *Quality Engineering*, vol. 18, pp. 39–46, 2006.

[37] P. Bharane, K. Tanpure, A. Patil and G. Kerkal, "Design, Analysis and Optimization of Anti-Roll Bar," *International Journal of Engineering Research and Applications*, vol. 4, no. 9, pp. 137–140, 2014.

[38] M. Doody, "Design and Development of a Composite Automotive Anti-Roll Bar," M.S. thesis, Department of Mechanical, Automotive & Materials Engineering, University of Windsor, Ontario, Canada, 2013.

[39] P. Laxminarayan Sidram Kanna, P. S.V. Tare, and P. A.M. Kalje, "Feasibility of hallow stability bar," *IOSR Journal of Mechanical and Civil Engineering*, vol. 2014, pp. 76–80, 2014.

[40] Y. Prawoto, J. R. P. Djuansjah, K. B. Tawi, and M. M. Fanone, "Tailoring microstructures: A technical note on an eco-friendly approach to weight reduction through heat treatment," *Materials & Design*, vol. 50, pp. 635–645, 2013.

[41] K. Sharma, P. M. Bora, and P. K. Sharma, "Hollow Cross-Section vs. Solid Cross-Section & Increasing the Diameter of Solid Cross-Section by using finite element Analysis of Anti-Roll Bar," *International Journal of Advanced Research in Science and Engineering*, vol. 1, no. 1, pp. 1–11, 2012.

[42] A.-M. Wittek, H.-C. Richter, and B. Lazarz, "Stabilizer Bars : Part 2 . Calculations-Example," *Transport Problems*, vol. 6, no. 1, pp. 137–145, 2011.

[43] A.-M. Wittek, H.-C. Richter, and B. Lazarz, "Stabilizer Bars : Part 1 . Calculations and Construction," *Transport Problems*, vol. 5, no. 4, pp. 135–143, 2010.

[44] P. Shinde and M. M. M. Patnaik, "Parametric Optimization to Reduce Stress Concentration at Corner Bends of Solid and Hollow Stabilizer Bar," *International Journal of Research in Aeronautical and Mechanical Engineering*, vol. 1, no. 4, pp. 1–15, 2013.

[45] A. Z. Mohamed Noor, M.H.F. Md Fauadi, F.A. Jafar, M.H. Nordin, S.H. Yahaya, S. Ramlan, M.A. Shri Abdul Aziz, "Fuzzy Analytic Hierarchy Process (FAHP) Integration for Decision Making Puposes: A Review," *Journal of Advanced Manufacturing Technology*, vol. 11, no. 2, pp. 139–154, 2017.