ISBN 978-93-5156-328-0
International Conference of Advance Research and Innovation (ICARI-2014)

Multiple Criteria Decision Making Techniques in Manufacturing Industries-A Review Study with the Application of Fuzzy

A K Madan *, Ranganath M S
Department of Mechanical Engineerng, Delhi Technological University, Delhi, India

Article Info

Article history:
Received 29December 2013
Received in revised form
10 January 2014
Accepted 20 January 2014
Available online 1 February 2014

Keywords

Fuzzy Logic
AHP
TOPSIS
Fuzzy MCDM

Abstract

Manufacturing industries are facing stiff market competition, work pressures and a very competitive environment. This has forced them to be alert and take the desired decisions in order to achieve their goals. In this paper, a review study has been made on MCDM techniques in Manufacturing Industries. We found that the managers and engineers of the industries face a number of problems and situations in which decision making is very difficult and the margin of safety is very less. Any wrong decision would lead to losses. These situations are mainly of multiple criteria decision making, in which decision has to be taken by analyzing various criteria's and them select the best alternatives among various alternatives present to him. These situations become more tough and complex when the data available for the analysis is not precise. The data is in imprecise form and vague. This requires use of Fuzzy Logic techniques to deal with these types of data. In order to overcome both the problems, the paper proposes Fuzzy MCDM techniques which can deal with these situations.

1. Introduction

Globalization has made a significant effect in the current market scenario. It has resulted in immense competition in the market among the manufacturing industries. Companies are forced to be very careful in decision making due to limited resources, stiff competition, etc. factors that affect the working of the organization in an efficient and effective manner. Any waste of resources such as money, time, workforce, etc., due to inappropriate decisions, directly increases the costs of companies, which, in turn, affects the customers. The manufacturing industries are presently being affected by the structural changes caused due to the internal and external factors of an enterprise. The market conditions are becoming more dynamic, more global, and more customers driven. The manufacturing performance is no longer driven by the product price; instead other competitive factors such as flexibility, quality, delivery, and customer service have become equally important. The demand of the customer for tailored product has resulted in a shorter product life, reduced batch quantities and increased product varieties. Manufacturing firms need to give prominence to issues such as reduction of manufacturing lead time and flexibility to adapt to changes in the market. The improvement in productivity and reduction of costs of goods and services has become the key for maintaining the market share.

Corresponding Author,
E-mail address: ashokmadan79@gmail.com

Real world engineering is full of chaotic disturbances, randomness and complex non-linear dynamics. Conventional methods such as trial and error are often used to solve complex optimization problems. This approach relies on the use of the analyst's qualitative knowledge to explore the design space. Expensive advanced computational analyses (such as finite element) are also used to understand the behavior of complex engineering problems. These are often invoked repeatedly during the search process making the optimization and concept exploration time consuming. This traditional search method often results in sub-optimal solutions due to inherent limitations in incomplete knowledge representation and the fact that elaborate exploration of the design space is inhibited. Competitive market conditions have forced the manufacturing industries to make carefuldecisions. Any waste of resources such as money, time, workforce, etc., due to inappropriate decisions, directly increases the costs of companies, which, in turn, is reflected to the customer.

There is a tendency to accept local optimal solutions considered to be sufficiently good for the chosen objective due to the following reasons: subjective judgment, similarity to historical result or simply constraint on time to deliver workable solutions. Multiple global optimal solutions are desirable for these classes of problems to give alternative solutions in the presence of increasing dynamic and ill-defined problem space.

In the current competitive business scenario, one of the key requirements on global as well as local firms is to provide their markets with products and services at lower costs, at a higher quality, with a shorter product development cycle, and with a shorter delivery time. In order to achieve these objectives, several important and critical decisions have to be taken at a tactical as well as a strategic level. Economic justification methods, such as return on investment, or analytic justification methods, such as linear programming, are frequently employed before making decisions involving significant investment decisions. It is important to note that irrespective of the kind of evaluation – economic or analytic – the information available for making the decision is generally vague and uncertain. It is very difficult to obtain exact data on attributes like investment cost, expenses, project lifetime, depreciation, etc. for making these decisions. Hence, these evaluation methods tend to be less effective in delivering required information in such an imprecise, or fuzzy, decision environment.

To tackle the problem mentioned above, fuzzy set theory can play a significant role. The approximate reasoning of fuzzy set theory can properly represent linguistic terms [1]. To deal quantitatively with imprecision and uncertainty, all of the assessment data can be specified as triangular fuzzy numbers [2, 3]. Subsequently, a fuzzy multi-criteria decision-making (MCDM) method can be applied to integrate various linguistic assessments and weights in order to determine the best selection. In contrast to traditional approaches, which tend to adopt only one specific evaluation technique, an integrative approach is proposed, combining strategic, economic, and analytic justification approaches.

2. Decision Making

A decision is a choice made from two or more alternatives. Decision-making is the process of sufficiently reducing uncertainty and doubt about alternatives to allow a reason able choice to be made among them. Researchers have studied different decision-making problems by using different decision-making methods such as the analytic hierarchy process (AHP), fuzzy multiple-attribute decision making model, linear and 0 – 1 integer programming models, genetic algorithms (GA), etc.

The analysis of the way the people makes decisions (prescriptive theories) or the way people ought to make decisions (normative theories) is perhaps as old as the recorded history of mankind. The development of the development of the perfect decision making method for rational real life decision making still remains an elusive goal. The contradiction between the extensiveness of the study on this subject and the elusiveness of the final goal of the real life applicability of the findings constitutes in a way the ultimate decision making paradox.

Decision making is one of the main abilities of human being that differs them from other creatures. Now, decision making and analysis is an important part of management sciences, and it is perhaps as old as history of mankind. In many real-world problems, the decision maker likes to pursue more than one target or consider more than one factor or measure. Such a desire transforms the decision making problem to a multi-objective decision making (MODM) problem or a multi-attribute decision making (MADM) problem. These groups of problems all come together in one category, named multi-criteria decision making (MCDM) problems.

Multi-Criteria Decision Making (MCDM) is one of the most well-known branches of decision making. MCDM is divided into multi-objective decision making (MODM) and multi-attribute decision making (MADM). However, very often the terms MADM and MCDM are used to mean the same class of models (i.e. MCDM).

MODM studies decision problems in which the decision space is continuous. An example is mathematical programming problems with multiple objective functions. MCDM/MADM concentrates on the problems with discrete decision spaces. In these problems, the set of decision alternatives have been predetermined.

Alternatives are the different choices of action available to the decision maker. The set of alternatives are assumed to be finite ranging from several to hundreds. They are supposed to screened, prioritized and eventually ranked according to the weights obtained.

Multiple attributes are the main constituent of the MCDM problems. The attributed can also be referred as goals or decision criteria. Attributes represent the different dimensions from which the alternatives can be viewed.

A Decision making problem can be defined as the process of finding the best alternative from all of the feasible alternatives available for the decision maker (DM). This means that the DM encounters a number of MCDM problems. In these kinds of problems the multiplicity of criteria for judging the alternatives is found to be pervasive.

3. Need of Fuzzy MCDM in Manufacturing Industries

Manufacturing organizations are very challenging as they involve in number of multiple activities. In order to achieve best results all the multiple activities must be properly planned, designed, coordinated and executed through a collective effort. The managers of the company may be an expert in their respective areas, all the persons has to work collectively in order to achieve the desired goals. Hence only an efficient and productive organization can survive in today's competitive environment. We all know that a manufacturing industry faces a number of day to day challenges. In order to sustain decision making is an important aspect of the industry.

Managers confront with a number of problems which involves decision making in multiple criteria situations i.e the manager has to decide among a set of alternatives present in front of him. They may occur with fuzzy nature i.e the data available to the manager is not precise and exact. Hence these types of problems require special attention because decision making is very important. A bad decision can result into heavy loses to the industry and this in turn will affect the customers also. In order to deal with these types of situations Fuzzy MCDM techniques have been proposed which take into account both the fuzzy nature of the problem and the multiple criteria confronted by the managers. Use of these techniques help in reaching to a best optimal solution which takes into account all the alternatives present in front of him.

Some of the areas which require Fuzzy MCDM techniques in the manufacturing industry are:

Selection of best Supply Chain

- Vendor Selection
- 3PL selection
- Machine Tool selection
- Plant/Site Selection for a new plant, etc.

Fuzzy MCDM methods help the decision makers to take best decisions. They are like an aid in the decision making in fuzzy and multiple criteria environment. An appropriate decision taken results into best results in the field and hence will add to the profits of the organization.

Fuzzy MCDM technique has been discussed in details later.

The main steps of multiple criteria decision making are as follows:

a) Establishing system evaluation criteria that relate system capabilities to goals.
b) Developing alternative systems for attaining the goals (generating alternatives).
c) Evaluating alternatives in terms of criteria (the values of the criterion functions)
d) Applying a normative multi-criteria analysis method.
e) Accepting one alternative as ‘‘optimal’’ (preferred).
f) If the final solution is not accepted, gather new information and go into the next iteration of multi-criteria optimization.

Steps (a) and (e) are performed at the upper level, where decision makers have the central role, and the other steps are mostly engineering tasks. For step (d), a decision maker should express his/her preferences in terms of the relative importance of criteria, and one approach is to introduce criteria weights. These weights in MCDM do not have a clear economic significance, but their use provides the opportunity to model the actual aspect s o f decision making (the preference structure). Various MCDM techniques have been discussed below.

4. Classification of MCDM Methods

Multiple criteria decision-making (MCDM) [35] is one of the most well-known branches of decision-making. It refers to making decisions in the presence of multiple, usually conflicting, objectives. The basic idea behind MCDM is the construction of a decision tree using a selection of criteria relevant to a particular decision and the weighting scoring of the criteria and the alternatives for each different criterion.

Various MCDM methods are:

1. Weighted Sum Model (WSM)
2. Weighted Product Model (WPM)
3. Analytic Hierarchy Process (AHP)
4. Revised AHP Method
5. ELECTRE Method
6. TOPSIS Method

5. Analytic Hierarchy Process AHP

The analytic hierarchy process (AHP) was developed by Thomas L. Saaty (36). The AHP is designed to solve complex problems involving multiple criteria. An advantage of the AHP is that it is designed to handle situations in which the subjective judgments of individuals constitute an important part of the decision process.

Basically the AHP is a method which involves various processes. They are as follows:

1. Breaking down a complex, unstructured situation into its component parts.
2. Arranging the parts, or variables into a hierarchic order.
3. Assigning numerical values to subjective judgments on the relative importance of each variable and
4. Synthesizing the judgments to determine which variables have the highest priority and should be acted upon to influence the outcome of the situation.

5.1 Advantages of AHP

AHP provides a single easily understood, flexible model for a wide range of unstructured problems.

- It enables people to refine their definition of a problem and to improve their judgment and understanding through repetition.
- It does not insist on consensus but synthesizes a representative outcome from diverse judgments.
- It takes into consideration the relative priorities of factors in a system and enables people to select the best alternative based on their goal.
- It leads to an overall estimate of the desirability of each alternative.
- It integrates deductive and system approaches in solving complex problems.
- It can deal with the interdependence of the elements in a system and does not insist on linear thinking.
- It reflects the natural tendency of the mind to sort elements of a system into different levels and to group like elements in each level.
- It provides a scale for measuring intangibles and a method for establishing priorities.
- It tracks the logical consistency of judgments used in determining priorities.

5.2 Disadvantages of AHP

- Linear hierarchy structure
- Static decision evaluation
- Independence assumption among criteria
- Simple matrix algorithm to find maximum eigen-value
- No feedback mechanism

6. Fuzzy AHP

Analytic hierarchy process (AHP) has been widely used as a useful multiple criteria decision making (MCDM) tool or a weight estimation technique in many areas such as selection, evaluation, planning and development, decision making, forecasting, and many more. The traditional AHP requires exact judgments. However, due to the complexity and uncertainty involved in real world decision problems, a decision maker (DM) may sometimes feel more confident to provide fuzzy judgments than exact comparisons.

7. Fuzzy TOPSIS

TOPSIS is called technique for order preference by similarity to ideal solution. It is very effective in multi-criteria decision making (MCDM). It was developed by Yoon and Hwang in 1980 [58] as an alternative to other MCDM methods. The basic concept of this method is that the alternative should have the shortest distance from the ideal solution and farthest distance from the negative-ideal solution in some geometrical case. Positive ideal solution is a solution that maximizes the benefit criteria and minimizes cost criteria, whereas the negative ideal solution maximizes the cost criteria and minimizes the benefit criteria

The TOPSIS method assumes that each criterion has a tendency of monotonically increasing and decreasing utility. Therefore, it is to define the ideal and negative-ideal solutions. The Euclidean distance approach was proposed to evaluate the relative closeness of the alternatives to the ideal solution. Thus, the preference order of the alternatives can be derived by a series of comparisons of these relative distances.

In the classical TOPSIS method, the weights of the criteria and the ratings of alternatives are known precisely and crisp values are used in the evaluation process. However, under many conditions crisp data are inadequate to model real-life decision problems. Therefore, the fuzzy TOPSIS method is proposed where the weights of criteria and ratings of alter natives are evaluated by linguistic variables represented by fuzzy numbers to deal with the deficiency in the traditional TOPSIS. There are necessary steps in utilizing TOPSIS involving numerical measures of the relative importance of various criteria and the performance of each alternative with respect to these criteria. However, exact numerical data are inadequate to model real life situations since human judgments are often vague under many conditions. This method has been successfully used in land use planning project, venture evaluation of project, the evaluation of hospital performance, optimal material selection, Etc., it makes the evaluation decision more scientific, accurate and operable.

8. Literature Review

De Grann (1980) first adopted triangular fuzzy numbers in the traditional AHP. Then in 1983, Van Laarhoven and Pedrycz [37] extended and modified the fuzzy AHP approach of De Grann (1980) by using extended theory and approximation theory. Buckley in 1985 addressed the concept of consistency into fuzzy AHP model.

A number of methods have been developed to handle fuzzy comparison matrices. Some of them are given below:

- Logarithmic least squares method (LLSM) [38], to obtain triangular fuzzy weights from a triangular fuzzy comparison matrix.
- Geometric mean method to calculate fuzzy weights [39].
- Extent analysis method by Chang [40], which derives crisp weights for fuzzy comparison matrices.
- Fuzzy preference programming method (PPM), by Mikhailov [41].
- Lambda-Max method, which is the direct fuzzification of the well-known kmax method by Csutora and Buckley [42].

Among the above approaches, the extent analysis method has been employed in quite a number of applications due to its computational simplicity. However, such a method is found unable to derive the true weights from a fuzzy or crisp comparison matrix. The weights determined by the extent analysis method do not represent the relative importance of decision criteria or alternatives at all. Therefore, it should not be used as a method for estimating priorities from a fuzzy pair wise comparison matrix

Many fuzzy AHP methods have been proposed by various authors. These methods are systematic and useful approaches to the alternative selection and gives justification to the problem by using the concepts of fuzzy set theory and hierarchical structure analysis. Decision makers have experienced that it is more confident and easy to give interval judgments than fixed value judgments. This is due to the fuzzy nature of the comparison process.

The earliest work in fuzzy AHP was by Van Laarhoven and Pedrycz (1983) [37], which compared fuzzy ratios described by triangular membership functions.

Stam et al. (1996) [43] explore, how recently developed artificial intelligence techniques can be used to determine or approximate the preference ratings in AHP. They concluded that the feed-forward neural network formulation appears to be a powerful tool for analyzing discrete alternative multi-criteria decision problems with imprecise or fuzzy ratio-scale preference judgments. Chang (1996) [44] introduces a new approach for handling fuzzy AHP, with the use of triangular fuzzy numbers for pairwise comparison scale of fuzzy AHP, and the use of the extent analysis method for the synthetic extent values of the pairwise comparisons.

Cheng (1997) [45] proposes an algorithm for evaluating naval tactical missile systems by the fuzzy AHP based on grade value of membership function.

Weck et al. (1997) [46] gave a method to evaluate different production cycle alternatives adding the mathematics of fuzzy logic to the classical AHP. Any production cycle evaluated in this manner yields a fuzzy set. The outcome of the analysis can finally be defuzzified by forming the surface centre of gravity of any fuzzy set, and the alternative production cycles investigated can be ranked in order in terms of the main objective set.

Kahraman et al. (1998) [47] employed a fuzzy objective and subjective method obtaining the weights from AHP and make a fuzzy weighted evaluation. Deng (1999) [48] presents a fuzzy approach for tackling qualitative multi-criteria analysis problems in a simple and straight forward manner. Lee et al. (1999) [49] review the basic ideas behind the AHP. Based on these ideas, they introduce the concept of comparison interval and propose a methodology based on stochastic optimization to achieve global consistency and to accommodate the fuzzy nature of the comparison process. Cheng et al. (1999) [50] propose a new method for evaluating weapon systems by analytical hierarchy process based on linguistic variable weight. Zhu et al. (1999) [51] make a discussion on extent analysis method and applications of fuzzy AHP.

Chan et al. (2000a) [52] presented a technology selection algorithm to quantify both tangible and intangible benefits in fuzzy environment. They describe an application of the theory of fuzzy sets to hierarchical structural analysis and economic evaluations. By aggregating the hierarchy, the preferential weight of each alternative technology is found, which is called fuzzy appropriate index. The fuzzy appropriate indices of different technologies are then ranked and preferential ranking orders of technologies are found. From the economic evaluation perspective, a fuzzy cash flow analysis is employed. Chan et al. (2000b) [53] report an integrated approach for the automatic design of FMS, which uses simulation and multi-criteria decision-making techniques. The design process consists of the construction and testing of alternative designs using simulation methods. The selection of the most suitable design (based on AHP) is employed to analyze the output from the FMS simulation models. Leung and Cao (2000) [54] propose a fuzzy consistency definition with consideration of a tolerance deviation. Essentially, the fuzzy ratios of relative importance, allowing certain tolerance deviation, are formulated as constraints on the membership values of the local priorities. The fuzzy local and global weights are determined via the extension principle. The alternatives are ranked on the basis of the global weights by application of maximum–minimum set ranking method.

Kuo et al. (2002) [55] develop a decision support system for locating a new convenience store. The first component of the proposed system is the hierarchical structure development for fuzzy analytic process.

In the year 2003, CengizKahraman et al. (2003) [56], employed fuzzy AHP technique for comparison of catering service companies. He carried out the process on certain main and sub attributes which were proposed by experts that are required in a catering firm. He then proposed the best firm out of the three firms presented and also concluded that fuzzy AHP can be effectively applied in the given field.

A brief literature review about the fuzzy TOPSIS technique has been discussed below.

Jahanshaloo et al. [59] developed an algorithmic method to extend TOPSIS for decision making problems with interval data. Yang and Hung [60] utilized TOPSIS for solving a plant layout design problem. In particular, Wang and Lee [61] proposed two operator Up and Lo to find positive-ideal and negative-ideal solutions and used these operators to solve fuzzy multiple-criteria group decision making problem.

Chen and Tsao [62] extended the concept of TOPSIS to develop a method for solving MADM problems with interval-valued fuzzy data and compared the results using different distance measures, including Hamming distance, Euclidean distance and their normalized forms.

9. Conclusion & Future Scope

Globalization has made a global impact on the current market scenario. It has resulted in immense competition in the market among the manufacturing industries. In this competitive environment everyone is trying to compete in the market. In order to achieve the desired goals industries have to make a lot of major changes that would help in increasing their productivity, reducing lead times, improving quality, etc. This requires the managers and the engineers to take appropriate decisions very rapidly that would help in growth of the industry. Any waste of resources such as money, time, workforce, etc., due to inappropriate decisions, directly increases the costs of companies, which, in turn, affects the customers.

In many real-time problems in the industries, managers and engineers are faced with situations where multiple criteria has to be taken into account while selecting the best alternative or solution to that situation among various alternatives available to him. The situations can be the following have been listed earlier in the work.

In these cases careful decision has to be taken by doing various analyses in order to select the best alternative or solution that would not harm the industry and would lead to industrial growth. So these types of problems are known as Multi-Criteria Decision Making (MCDM) problems and hence require the use of MCDM techniques (AHP, WSM, ELECTRE, TOPSIS, etc.) to find their solutions.

Not all of the decision data can be precisely assessed. When information is easily measurable or accessible, the information should be coded in crisp (real) numbers. For those data that cannot be precisely obtained or is too costly to assess, fuzzy numbers are used to denote them. Fuzzy set theory makes it possible to incorporate un-quantifiable information, incomplete information, non-obtainable information, and partially ignorant facts into the decision model.

The above discussion depicts the need of both MCDM and Fuzzy methodology. In this work a systematic and an integrated approach has been proposed and discussed incorporating both the techniques and are called Fuzzy MCDM techniques. The advantages of this new approach over the existing ones are as follows:

- Conventional approaches, both deterministic and stochastic, tend to be less effective in conveying the imprecision or vagueness of the linguistic assessment.
- By using the concepts of fuzzy numbers and linguistic variables, the objective and subjective factors are evaluated in such a manner that the viewpoints of an entire decision-making body can be expressed with minimal constraints.
- The proposed approach allows multiple criteria decision making problems to take data in the form of linguistic terms, fuzzy numbers, and/or crisp numbers. This facilitates more realistic decision models compared to those generated using existing methods to be created.

- Triangular fuzzy numbers are mathematically easy to implement in comparison to trapezoidal fuzzy numbers and the mathematical computations are reduced. The easy-to-use and easy-to-understand characteristics of this new approach provide a valuable evaluation tool for management and system analysts.

Some research areas that require special attention in the future have been identified. In a decision process, conflict, uncertainty, fuzziness, imprecision, and randomness simultaneously exist.

- Due to its complex nature, research on searching and solving multiple criteria decision-making problems is suggested.
- Since the proposed methodology is generic enough for other decision-making processes, applications of the proposed methodology to other business or engineering problems are encouraged.
- Ranking approaches are very important to solve fuzzy or imprecise attributes and constraints. It is worth noting that even though most of the existing ranking methods are not perfect, they have shown the process of human efforts to find ways of solving problems. There are always some benefits produced by each method. Recognizing and continuing the effort in improving these methods is necessary.
- Flawless ranking methods may possibly be obtained by combining some of the good points of each of these methods into one algorithm. In this connection, searching for better ranking methods is urgently needed to solve fuzzy or imprecise constraints and other problems.

References

[1] L. A. Zadeh, “The concepts of linguistic variable and its application to approximate reasoning”, InfSci 8(1):199–249, 1975

[2] G. S. Liang, M. J. Wang, “A fuzzy multi-criteria decision making method for facility site selection. Int J Prod Res 29(11):2313–2330, 1991

[3] T. R. Prabhu, K. Vizayakumar “Fuzzy hierarchical decision making method (FHDM): A methodology for technology choice”, Int J ComputApplTechnol 9(5):322–329, 1996

[4] Z. C. Lin, C. B. Yang, “Evaluation of machine selection by the AHP method. Journal of Materials Processing Technology”, 57, 253–258, 1994

[5] M. T. Tabucanon, D. N. Batanov, D. K. Verma, “Intelligent Decision Support System (DSS) for the selection process of alternative machines for Flexible Manufacturing Systems (FMS)”, Computers in Industry, 25, 131–143, 1994

[6] A. Atmani, R. S. Lashkari, “A model of machine tool selection and operation allocation in flexible manufacturing systems”, International Journal of Production Research, 36, 1339–1349,

[7] Devedzic Goran B., Pap Endre, “Multicriteria-multistages linguistic evaluation and ranking of machine tools”, Fuzzy Sets and Systems 102, 451-61

[8] T. Y. Wang, C. F. Shaw, Y. L. Chen, “Machine selection in flexible manufacturing cell: A fuzzy multiple attribute decision making approach”, International Journal of Production Research, 38, 2079–2097, 2000

[9] M. C. Arslan, B. Catay, E. Budak, “A decision support system for machine tool selection”, Journal of Manufacturing Technology Management, 15, 101–109, 2004

[10] M. Yurdakul, “AHP as a strategic decision-making tool to justify machine tool selection”, Journal of Materials Processing Technology, 146, 365–376, 2004

[11] C. Chung, Q. Peng. “The selection of tools and machines on web-based manufacturing environments”, International Journal of Machine Tools & Manufacture 44 317–326, 2004

[12] M. Yurdakul, “AHP as a strategic decision-making tool to justify machine tool selection”, Journal of Materials Processing Technology 146 365–376, 2006

[13] H. Chtourou, W. Masmoudi, A. Maalej, “An expert system for manufacturing systems machine selection”, Expert Systems with Applications 28 (2005) 461–467, 2005

[14] Z. Ayag, R. G. Ozdemir, “A fuzzy AHP approach to evaluating machine tool alternatives”, Journal of Intelligent Manufacturing, 17, 179–190, 2006

[15] Z. Ayag, “A hybrid approach to machine tool selection through AHP and simulation”, International Journal of Production Research, 45(9), 2029–2050, 2007

[16] E. Çimren, B. Çatay, E Budak, “Development of a machine tool selection system using AHP”, Int. J Adv Manuf. Technology 35:363 – 376 DOI 10.1007/s00170-006-0714-0, 2007

[17] O. Duran J. Aguilo, “Computer-aided machine-tool selection based on a Fuzzy-AHP approach”, Expert Systems with Applications 34 (2008) 1787–1794, 2008

[18] Z. Ayag, R. G. Ozdemir, “An intelligent approach to machine tool selection through fuzzy

analytic network process", J IntellManuf DOI 10.1007/s10845-009-0269-7, 2006

[19] M. Alberti, J. Ciurana, C. A. Rodríguez, "Özel T, "Design of a decision support system for machine tool selection based on machine characteristics and performance tests", J IntellManuf DOI 10.1007/s10845-009-0286-6, 2009

[20] M. Yurdakul, Y. Tansel, "Analysis of the benefit generated by using fuzzy numbers in a TOPSIS model developed for machine tool selection problems", Journal of materials processing technology 2 0 9 (2009) 310–317, 2009

[21] K. P. Jarboe, "Location decisions of high-technology firms: a case study", Technovation, 4, pp. 117–129, 1986

[22] G. A. Spohrer, T. R. Kmak, "Qualitative analysis used in evaluating alternative plant location scenarios" Industrial Engineering, pp. 52–56, 1984

[23] J. A. Tompkis, J. A. White, Facilities Planning, John Wiley, 1984

[24] M. D. Dahlberg, J. H. May, "Linear programming for siting of energy facilities. Journal of Energy Engineering, pp. 5–14, 1980

[25] K. Yoon, C. L. Hwang, "Manufacturing plant location analysis by multiple attribute decision making: single-plant strategy", International Journal of Production Research, 23, pp. 345–359, 1985

[26] L. A. Zadeh, "The concept of a linguistic variable and its application to approximate reasoning, Part 1, 2 and 3", Information Science, 8, pp. 199–249, pp. 301–357 1975; 9, 43–80, 1976

[27] G. S. Liang, M. -J. J Wang, "A fuzzy multi-criteria decision making method for facility site selection", International Journal of Production Research, 29, pp. 2313–2330, 1991

[28] J. Yang, H. Lee, "An AHP decision model for facility location selection", Facilities 15(9/10)· pp. 241–254 © MCB University Press · ISSN 0263-2772

[29] T.-C. Chu, "Selecting Plant Location via a Fuzzy TOPSIS Approach", Int J Adv ManufTechnol 20:859–864, 2002

[30] K. F. Au, W. K. Wong, X. H. Zeng, "Decision model for country site selection of overseas clothing plants", Int J Adv ManufTechnol DOI 10.1007/s00170-004-2505-9, 2005

[31] D. Yong, "Plant location selection based on fuzzy TOPSIS", Int J Adv ManufTechnol 28: 839–844 DOI 10.1007/s00170-004-2436-5, 2006

[32] C. H. Chen, W. Y. Yu, "Using a strategic approach t o analysis the location selection for high-tech fir ms in Taiwan", Management Research News 31(4), pp. 228-244. 0140-9174 DOI 10.1108/01409170810851311, 2008

[33] Z. R. Farahani, M. SteadieSeifi, N. Asgari "Multiple criteria facility location problems: A survey. Applied Mathematical Modelling 34, 1689–1709, 2010

[34] L. Zadeh, "Fuzzy sets", Information Control 8, 338–353, 1965

[35] Book title: - "Multi-Criteria Decision Making Methods: a Comparative Study". By: Evangelos Triantaphyllou

[36] T. L. Satty, "The Analytical Hierarchy Process"

[37] P. J. M. Van Laarhoven, W. Pedrycz, "A fuzzy extension of Saaty's priority theory. Fuzzy Sets and Systems", 11,229–241, 1983

[38] M. Weck, F. Klocke, H. Schell, E. R. uenauver, "Evaluating alternative production cycles using the extended fuzzy AHP method", European Journal of Operational Research 100 (2), 351–366, 1997

[39] U. Cebeci, C. Kahraman, "Measuring customer satisfaction of catering service companies using fuzzy AHP: The case of Turkey", Proceedings of International Conference on Fuzzy Systems and Soft Computational Intelligence in Management and Industrial Engineering, Istanbul, 29–31May, pp. 315–325

[40] D.-Y. Chang, "Extent Analysis and Synthetic Decision", Optimization Techniques and Applications, 1, World Scientific, Singapore, p. 352, 1992

[41] P. Tsvetinov, L. Mikhailov, "Reasoning under Uncertainty during Pre-negotiations Using a Fuzzy AHP", Available at http://www.expertguide.qut.com/guide/expert-details.jsp, 2004

[42] J. J. Buckley, "Fuzzy Analytical hierarchical analysis", Fuzzy Sets and Systems 17, 233–247, 1985

[43] A. Stam, S. Minghe, M. Haines, "Artificial neural network representations for hierarchical preference structures", Computers and Operations Research 23 (12), 1191–1201, 1996

[44] D.-Y. Chang, "Applications of the extent analysis method on fuzzy AHP", European Journal of Operational Research 95, 649–655, 1996

[45] C.-H. Cheng, "Evaluating naval tactical missile systems by fuzzy AHP based on the grade value of membership function", European Journal of Operational Research 96 (2), 343–350

[46] M. Weck, F. Klocke, H. Schell, E. R. uenauver, "Evaluating alternative production cycles using the extended fuzzy AHP method", European Journal of Operational Research 100 (2), 351–366, 1997

[47] C. Kahraman, Z. Ulukan, E. Tolga, “A fuzzy weighted evaluation method using objective and subjective measures”, In: Proceedings of the International ICSC Symposium on Engineering of Intelligent Systems (EIS’98), 1, University Laguna Tenerife, Spain, pp. 57–63, 1998

[48] H. Deng, “Multicriteria analysis with fuzzy pair wise comparison” International Journal of Approximate Reasoning21 (3), 215–231, 1999

[49] M. Lee, H. Pham, X. Zhang, “A methodology for priority setting with application to software development process”, European Journal of Operation al Research 118,375–389, 1999

[50] C.-H. Cheng, K.-L. Yang, C.-L. Hwang, “Evaluating attack helicopters by AHP based on linguistic variable weight”, European Journal of Operation al Research 116 (2), 423–435, 1999

[51] K.-J. Zhu, Y. Jing, D.-Y. Chang, “A discussion of extent analysis method and applications of fuzzy AHP”, European Journal of Operational Research 116,450–456, 1999

[52] F. T. S. Chan, M. H. Chan, N. K. H. Tang, “Evaluation methodologies for technology selection”, Journal of Materials Processing Technology 107, 330–337, 2000a

[53] F. T. S. Chan, B. Jiang, N. K. H. Tang, “The development of intelligent decision support tools to aid the design of flexible manufacturing systems”, International Journal of Production Economics 65 (1), 73–84, 2000b

[54] L. C. Leung, D. Cao, “On consistency and ranking of alternatives in fuzzy AHP”, European Journal of Operational Research 124, 102–113, 2000

[55] R. J. Kuo, S. C. Chi, S. S. Kao, “A decision support system for selecting convenience store location through integration of fuzzy AHP and artificial neural network”, Computers in Industry 47 (2), 199–214, 2002

[56] Cengiz Kahraman, Ufuk Cebeci, Da Ruan, “Multi-attribute comparison of catering service companiesusing fuzzy AHP: The case of Turkey”, Int. J. Production Economics 87 171–184, 2003

[57] Da-Yong Chang “Applications of the extent analysis method on fuzzy AHP”, European Journal of Operational Research 95, 649-655, 1996

[58] C. L. Hwang, K. Yoon, “Multiple attributes decision making methods and applications” Springer, Berlin, 1980

[59] G. R. Jahanshahloo, F. Hosseinzadeh, M. Lotfi, Izadikhah, “An algorithmic method to extend TOPSIS for decision-making problems with interval data”, Applied Mathematics and Computation, 2005

[60] T. Yang, C. C. Hung, “Multi-attribute decision making methods for plant layout design problem”, Robotics Comput Intregrated Manufacturing 23, 126-137, 2007

[61] Y. J. Wang, H. S. Lee, “Generalizing TOPSIS for fuzzy multiple-criteria group decision-making”, Comput. Math, Appl. 53, 1762-1772, 2007

[62] T. Y. Chen, C. Y. Tsao, “The interval-valued fuzzy TOPSIS method and experimental analysis”, Fuzzy Sets and Systems159, 1410-1428, 2008

[63] C. T. Chen, “Extensions of the TOPSIS for group decision-making under fuzzy environment”, Fuzzy Sets and Systems 114, 1-9, 2000

[64] C. T. Chen, “Extensions of the TOPSIS for group decision-making under fuzzy environment”, Fuzzy Sets and Systems 114, 1-9, 2006