**Flexible Manufacturing System Selection Based on VIKOR and Fuzzy Prioritization Method**

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**Abstract:** Selection of a flexible manufacturing system (FMS) is a challenging task because of the insufficient experience and data about this still-evolving technology. Further, the large investment involved makes the selection process critical. The purpose of this paper is applying a new integrated method to flexible manufacturing system selection. Proposed approach is based on Fuzzy Prioritization Method and VIKOR (VlseKriterijumska Optimizacija I Kompromisno Resenje). Fuzzy Prioritization Method is used in determining the weights of the criteria by decision makers and then ranking of alternative are determined by VIKOR method. In this paper a numerical example demonstrates the application of the proposed method.

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**Keywords:** Fuzzy Prioritization Method (FPM), VIKOR, Fuzzy set, Flexible Manufacturing System

**1. INTRODUCTION**

Flexible manufacturing systems (FMS) have extensively been studied over the past fifteen years. Selection of FMS is a challenging task because of the insufficient experience and data about this still-evolving technology. Further, the large investment involved makes the selection process critical. An FMS is an integrated manufacturing system that consists of one or several work stations linked by a computerized inventory system, making it possible for jobs to follow diverse routes through the production system. An advantage of FMS is that it can simultaneously meet several goals: small batch sizes, high quality standards and efficiency of the production process. Boththe industrial and the academic community (Kuula, 1993., Buzacott et al, 1986., Jaikumar, 1986., Ranta et al, 1988) have been interested in the design of flexible manufacturing systems. The rest of the paper is organized as follows: The following section presents a concise treatment of the basic concepts of fuzzy set theory. Section 3 presents the methodology of Fuzzy Prioritization Method and VIKOR. The application of the proposed framework to FMS selection is addressed in Section 4. Finally, conclusions are provided in Section 5.

**2. Fuzzy sets and fuzzy numbers**

Fuzzy set theory, which was introduced by Zadeh (1965) to deal with problems in which a source of vagueness is involved, has been utilized for incorporating imprecise data into the decision framework. A fuzzy set can be defined mathematically by a membership function , which assigns each element x in the universe of discourse X a real number in the interval [0,1]. A triangular fuzzy number can be defined by a triplet (a, b, c) as illustrated in Fig 1.

1.0

a

0.0

c

b

Fig1**.** A triangular fuzzy number .

The membership function  is defined as

= (1)

Where l, m, and u are also considered as the lower bound, the mean bound, and the upper bound, respectively. The triangular fuzzy number is often represented as (l,m,u). According to Table 1, criteria compare with each other. After pairwise comparisons, are finished at a level, a fuzzy reciprocal judgment matrix can be established as

|  |
| --- |
|  = = (2) |

Table 1. Linguistic variables for important of each criteria

|  |  |
| --- | --- |
| linguistic variables | triangular fuzzy numbers |
| very low | (0.00,0.00,0.00) |
| low | (0.10,0.20,0.30) |
| medium low | (0.20,0.35,0.50) |
| medium | (0.40,0.50,0.60) |
| medium high | (0.50,0.65,0.80) |
| high | (0.70,0.80,0.90) |
| very high | (0.80,1.00,1.00) |

Where n is the number of the related elements at this level, and aij =1/ aij. Basic arithmetic operations on triangular fuzzy numbers A1 = (l1,m1,u1), where l1 ≤ m1 ≤ u1, and A2 = (l2,m2,u2), where l2 ≤ m2 ≤ u2, can be shown as follows:

|  |
| --- |
| Addition:A1 A2 = (l1 + l2 ,m1 + m2,u1 + u2) (3) |
| Subtraction:A1 A2 = (l1 - u2 ,m1 - m2,u1 – l2) (4) |

Multiplication: if K is a scalar

K A1 =

|  |
| --- |
| A1 A2 ≈ (l1l2 ,m1m2,u1u2) , if l1 0 , l2 0 (5) |
| Division: A1 Ø A2 ≈ ( ,if l1 0 , l2 0 (6)  |

Although multiplication and division operations on triangular fuzzy numbers do not necessarily yield a triangular fuzzy number, triangular fuzzy number approximations can be used for many practical applications (Kaufmann and Gupta, 1988). Triangular fuzzy numbers are appropriate for quantifying the vague information about most decision problems including Facility location selection. The primary reason for using triangular fuzzy numbers can be stated as their intuitive and computational-efficient representation (Karsak, 2002). A linguistic variable is defined as a variable whose values are not numbers, but words or sentences in natural or artificial language. The concept of a linguistic variable appears as a useful means for providing approximate characterization of phenomena that are too complex or ill-defined to be described in conventional quantitative terms (Zadeh, 1975).

**3. RESEARCH METHODOLOGY**

In this paper, the weights of each criterion are calculated using FPM. After that, VIKOR is utilized to rank the alternatives. Finally, we select the best FMS based on these results.

**3.1. Fuzzy Prioritization Method (FPM)**

Fuzzy prioritization method is described by Wang et al (2006) as follow: suppose that a fuzzy judgment matrix is constructed as Eq. (2) in a prioritization problem, where n elements are taken into account. Among this judgment matrix A, the triangular fuzzy number aij is expressed as (lij,mij,uij), i and j=1,2,…,n, where [l](http://www.sciencedirect.com/science?_ob=MathURL&_method=retrieve&_udi=B6VF8-4MFJT98-1&_mathId=mml279&_user=1400009&_cdi=6004&_pii=S0925527306002180&_rdoc=1&_issn=09255273&_acct=C000052577&_version=1&_userid=1400009&md5=fca9b0b037b5ec340c4a47cf6576c112" \o "Click to view the MathML source)[ij](http://www.sciencedirect.com/science?_ob=MathURL&_method=retrieve&_udi=B6VF8-4MFJT98-1&_mathId=mml279&_user=1400009&_cdi=6004&_pii=S0925527306002180&_rdoc=1&_issn=09255273&_acct=C000052577&_version=1&_userid=1400009&md5=fca9b0b037b5ec340c4a47cf6576c112" \o "Click to view the MathML source), mij, and [u](http://www.sciencedirect.com/science?_ob=MathURL&_method=retrieve&_udi=B6VF8-4MFJT98-1&_mathId=mml281&_user=1400009&_cdi=6004&_pii=S0925527306002180&_rdoc=1&_issn=09255273&_acct=C000052577&_version=1&_userid=1400009&md5=94e32f11c6d27429b597e685433c6ebe" \o "Click to view the MathML source)[ij](http://www.sciencedirect.com/science?_ob=MathURL&_method=retrieve&_udi=B6VF8-4MFJT98-1&_mathId=mml281&_user=1400009&_cdi=6004&_pii=S0925527306002180&_rdoc=1&_issn=09255273&_acct=C000052577&_version=1&_userid=1400009&md5=94e32f11c6d27429b597e685433c6ebe" \o "Click to view the MathML source) are the lower bound, the mean bound, and the upper bound of this fuzzy triangular set, respectively. Furthermore, we assume that lij<mij<uij when i≠j. If i=j, then aij= aji = (1, 1, 1). Therefore, an exact priority vector w = (w1, w2,…,wn)T derived from A must satisfy the fuzzy inequalities:

|  |
| --- |
| lijmij (7) |

Where wi> 0, wj> 0, i≠j, and the symbol means “fuzzy less or equal to”.To measure the degree of satisfaction for different crisp ratios wi/ wj with regard to the double side inequality (7), a function can be defined as:

|  |
| --- |
| µij= (8) |

 Where i≠j. Being different from the membership function (1) of triangular fuzzy numbers, the function value of μij (wi/ wj) may be larger than one, and is linearly decreasing over the interval (0,mij] and linearly increasing over the interval [mij,∞), as shown in Fig. 2. The less value of μij (wi/ wj) indicates that the exact ratio wi/ wj is more acceptable.

1

lij

mij

uij

Fig 2. Function for measuring the satisfaction degree of wi/ wj

 To find the solution of the priority vector (w1,w2,…,wn)T, the idea is that all exact ratios wi/ wj should satisfy n(n-1) fuzzy comparison judgments (lij,mij,uij) as possible as they can, i and j=1,2,…,n, i≠j. Therefore, in this study, the crisp priorities assessment is formulated as a constrained optimization problem:

Min J (w1 ,w2 ,…,wn)

= min

= min

Subject to

,wk >0 , k=1,2,…,n.

Where ij ,P є N , and

δ(x) = (9)

The power index P is fixed, and chosen by decision makers in a specific MCDM problem. A larger P is suggested, e.g. 10, as illustrated briefly in the next section. The function J (w1,w2,…,wn) is non-differentiable. In some cases, decision-makers are unable or unwilling to give all pairwise comparison judgments of n elements. However, provided that the known fuzzy set of pairwise comparisons involves n elements, such as F={aij} ={a12 ,a13 ,…,an1} or {a21 ,a31 ,…,an1}, the solution of priority vector (w1,w2,…,wn)T will be still able to be derived based on the optimization problem above. In order to measure the consistency degree of the fuzzy comparison judgment matrix A as Eq. (2), an index γ can be defined after the optimal crisp priority vector  is obtained:

[γ](http://www.sciencedirect.com/science?_ob=MathURL&_method=retrieve&_udi=B6VF8-4MFJT98-1&_mathId=mml328&_user=1400009&_cdi=6004&_pii=S0925527306002180&_rdoc=1&_issn=09255273&_acct=C000052577&_version=1&_userid=1400009&md5=ccb674e961c970b32ff2f5ad5435c9ba) = exp (10)

Where µij( is the function of (8). The value of γ satisfies 0 < γ ≤1 always. If it is larger than e-1=0.3679, all exact ratios satisfy the crisp inequalities iij ≤ ≤ mij, i and j=1,2,…,n, i≠j, and the corresponding fuzzy judgment matrix has good consistency. γ=1 indicates that the fuzzy judgment matrix is completely consistent. In conclusion, the fuzzy judgment matrix with a larger γ value is more consistent. For solving this optimization problem that has non-linear constraints, we used the genetic algorithm.

**3.2. The VIKOR Method**

The VIKOR method is a compromise MADM method, developed by Opricovic .S and Tzeng (Opricovic, 1998; Opricovic, S. and Tzeng, G. H., 2002) started from the form of Lp-metric:

The VIKOR method can provide a maximum ‘‘group utility’’ for the “majority’’ and a minimum of an individual regret for the ‘‘opponent’’ (Opricovic, 1998; Opricovic, S; Tzeng, G. H., 2002; Serafim Opricovic & Gwo-Hshiung Tzeng, 2004).

**3.2.1. Working Steps of VIKOR Method**

1) Calculate the normalized value

Assuming that there are m alternatives, and n attributes. The various I alternatives are denoted as xi. For alternative xj, the rating of the jth aspect is denoted as xij, i.e. xij is the value of jth attribute. For the process of normalized value, when xij is the original value of the ith option and the jth dimension, the formula is as follows:

 (11)

2) Determine the best and worst values

For all the attribute functions the best value was and the worst value was, that is, for attribute J=1-n, we get formulas (12) and (13)

 (12)

 (13)

Where the positive ideal solution for the jth criteria is, is the negative ideal solution for the jth criteria. If one associates all, one will have the optimal combination, which gets the highest scores, the same as.

3) Determine the weights of attributes

The weights of attribute should be calculated to express their relative importance.

4) Compute the distance of alternatives to ideal solution

This step is to calculate the distance from each alternative to the positive ideal solution and then get the sum to obtain the final value according to formula (14) and (15).

 (14)

 (15)

Where Si represents the distance rate of the ith alternative to the positive ideal solution (best combination), represents the distance rate of the ith alternative to the negative ideal solution (worst combination). The excellence ranking will be based on values and the worst rankings will be based on values. In other words,, indicate and of -metric respectively.

5) Calculate the VIKOR values for i=1,2, … ,m, which are defined as

 (16)

Where , , and v is the weight of the strategy of “the majority of criteria’’ (or ‘‘the maximum group utility’’). represents the distance rate from the positive ideal solution of the ith alternative’s achievements In other words, the majority agrees to use the rate of the ith. represents the distance rate from the negative ideal solution of the ith alternative; this means the majority disagree with the rate of the ith alternative. Thus, when the v is larger (> 0.5), the index of will tend to majority agreement; when v is less (< 0.5), the index will indicate majority negative attitude; in general, v = 0.5, i.e. compromise attitude of evaluation experts.

6) Rank the alternatives by values

According to the values calculated by step (4), we can rank the alternatives and to make-decision.

**4. A NUMERICAL APPLICATION OF PROPOSED APPROACH**

 The criteria for this example are taken from Shamsuzzaman et al (2003). These criteria are including: Flexibility (C1), Cost (C2), Risk (C3), Production rate (C4), and Throughput time (C6). In addition, there are six alternatives include A1, A2, A3, A4, A5 and A6.In this paper, the weights of criteria are calculated by using FPM, and these calculated weight values are used as VIKOR inputs. Then, after VIKOR calculations, evaluation of the alternatives and selection of Flexible Manufacturing System is realized.

**Fuzzy Prioritization Method:**

After forming the decision hierarchy for flexible manufacturing system selection problem, the criteria to be used in evaluation process are assigned weights by using FPM method. Geometric means of these values are found to obtain the pairwise compassion matrix on which there is a consensus (Table 2).

Table 2**.** Fuzzy comparison matrix

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **D** | C1 | C2 | C3 | C4 | C5 |
| L | m | u | L | m | u | L | m | u | L | m | u | L | m | u |
| C1 | 1.00 | 1.00 | 1.00 | 1.00 | 2.33 | 3.00 | 3.00 | 5.00 | 7.00 | 0.20 | 2.47 | 7.00 | 0.33 | 3.44 | 7.00 |
| C2 | 0.33 | 0.56 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 3.25 | 5.00 | 0.14 | 1.83 | 5.00 | 0.20 | 2.07 | 3.00 |
| C3 | 0.14 | 0.23 | 0.33 | 0.20 | 0.51 | 1.00 | 1.00 | 1.00 | 1.00 | 0.20 | 1.18 | 3.00 | 0.14 | 0.23 | 0.33 |
| C4 | 0.14 | 3.38 | 5.00 | 0.20 | 3.40 | 7.00 | 0.33 | 0.85 | 5.00 | 1.00 | 1.00 | 1.00 | 0.33 | 2.11 | 3.00 |
| C5 | 0.14 | 1.16 | 3.00 | 0.33 | 1.89 | 5.00 | 3.00 | 1.00 | 7.00 | 0.33 | 1.22 | 3.00 | 1.00 | 1.00 | 1.00 |

 After that we formulate the fuzzy comparison matrix as a constrained optimization problem and we solve this optimization problem using Genetic algorithm. In order to employ Genetic algorithm, we use the MATLAB toolbox. Some settings that are used: Population Size equal to 100, the number of direct transfer to the next generation (Elite count) equal to 2, crossover fraction equal to 0.8 and the stopping conditions are described as follow: transfer from 100 generation and a lack of improvement in 50 generation. The results obtained from solving optimization problem using of Genetic algorithm are presented in Table 3.

Table 3.The weight of criteria

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| W1 | W2 | W3 | W4 | W5 |
| 0.280883 | 0.175129 | 0.06327 | 0.240667 | 0.240052 |

Then, weighted normalized matrix is formed by multiplying each value with their weights. After that we formed the Total weighted values of criteria as shown in Table 4.

Table 4. Total weighted values of main criteria

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Ai - Cj | C1 | C2 | C3 | C4 | C5 |
| A1 | 0.26 | 0.18 | 0.01 | 0.26 | 0.11 |
| A2 | 0.26 | 0.12 | 0.02 | 0.24 | 0.13 |
| A3 | 0.28 | 0.01 | 0.05 | 0.04 | 0.19 |
| A4 | 0.00 | 0.08 | 0.04 | 0.12 | 0.04 |
| A5 | 0.17 | 0.02 | 0.05 | 0.00 | 0.18 |
| A6 | 0.18 | 0.09 | 0.02 | 0.03 | 0.20 |

The ranking of alternatives are shown in Table 5.

According to result, if the best one is needed to be selected, then the alternative A4 must be chosen.

Table 5. Rankings of alternatives according to Qi values

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Ei=Ʃei | Fi=Max (ei) | Qi | Ranking |
| A1 | 0.796574 | 0.278979 | 0.929987 | 5 |
| A2 | 0.845344 | 0.288269 | 1 | 6 |
| A3 | 0.51279 | 0.274223 | 0.675601 | 4 |
| A4 | 0.253205 | 0.127156 | 0 | 1 |
| A5 | 0.408987 | 0.16989 | 0.264161 | 2 |
| A6 | 0.543172 | 0.192014 | 0.446127 | 3 |
| Min | 0.253205 | 0.127156 |  |
| Max | 0.845344 | 0.288269 |

**5. CONCLUSIONS**

Selection of a flexible manufacturing system (FMS) is a challenging task because of the insufficient experience and data about this still-evolving technology. Further, the large investment involved makes the selection process critical. This paper illustrates an application of FPM along with VIKOR in selecting FMS. Fuzzy set theory is incorporated to overcome the vagueness in the preferences. Two steps FPM and VIKOR methodology is structured here that FPM uses VIKOR result weights as input weights. According to this methodology, A4 are selected as the best FMS.

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