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Fuzzy & Graph Theoretic Approach for the Selection of Advanced Manufacturing System Investments

Sanjeev Goyal[1], Sandeep Grover[2]
[1,2]Mechanical Engineering Department, YMCA University of Science & Technology
Mathura Road, Faridabad-121006, INDIA
Email: goyal.sanjeev@hotmail.com
Email:groversandeep@hotmail.com

***Abstract*—In this paper, a fuzzy graph theoretic approach is proposed to select the most suitable advanced manufacturing system (AMS) from a set of alternatives available. Both tangible and intangible factors like operating cost, product quality, process flexibility etc. affecting the AMS have been considered for the selection among the alternatives. The fuzzy score has been used to convert intangible factors to crisp scores and then graph theoretic approach has been applied to calculate the single numerical index for ranking among the AMS alternatives.**

Index Terms—AMS, Fuzzy Graph Theoretic Approach

1. INTRODUCTION

With the quest of globalization, changing daily prices, increasing labor cost, increasingly sophisticated customer, a record number of companies are looking for advanced manufacturing systems so that they can become flexible, adaptive, responsive and innovative. Extensive literature available on AMS reveals the various facets of AMS covered by various authors and researchers across the globe. The pressure of quality, cost and delivery are the main hurdles for any company to remain competitive in today's scenario [1]. Advanced manufacturing technologies are looked as a tool for gaining competitive advantage for manufacturing industries [2]-[3]. Advanced manufacturing technology provides the manufacturing company a competitive advantage at every level of the operation, if used in proper way. The benefits of advanced manufacturing technologies have been realized and classified into tangible and intangible [4]-[5].

The tangible benefits are reduced inventory, more return on equity, less cost per unit and intangible benefits are flexibility, competitive advantage, enhanced quality and improved delivery. Advanced manufacturing technologies are being touched by progressive firms in developing countries [6]. Advanced manufacturing technologies have enormous benefits but only few companies are able to fully utilize these benefits. Only half of the companies adopting AMT are able to realize their goals [7]. Advanced manufacturing technologies often serve as a double edge sword for the organizations, imposing them challenges while providing competitive advantage [8].

The advanced manufacturing technology can be classified into three main components-hardware, software and brain ware. Hardware relates to the equipments, software to the knowledge of using them and brain ware to the reasons for using the technology in particular way [9]. With increasing globalization, companies are realizing the potential benefits of advanced manufacturing systems to remain in competition [10]-[11].

From the literature survey, it has been found that more and more organizations are adopting advanced manufacturing systems to remain competitive in the ever changing market. Seeking the potential market of AMS, more and more companies are coming which provide advanced manufacturing systems. So, it becomes difficult for a firm to decide which AMS is best suitable for them. As this involves large cost, So, careful decision is must because the wrong choice can even lead the firm to failure. The decision is becoming increasingly complex as it involves many attributes.

Several Authors have used different techniques to provide solution for the decision making problems associated with advanced manufacturing systems [12]-[17]. But the authors have not come across any research work related to the use of fuzzy Graph Theoretic Approach. With the use of this technique, the intangible attributes can be converted into crisp score which further with the use of Graph theoretic Approach give single numerical index. This numerical index is used to compare the different options available visually.

A. Classification of AMS

AMS can be classified into four categories: product design technologies, process technologies, logistics/planning technologies, and information exchange technologies. Product design technologies consist of computer-aided design (CAD), computer-aided engineering (CAE) and automated drafting technologies. Process technologies include flexible manufacturing systems, numerically controlled machines (NC), and programmable controllers. Logistics and planning technologies entail production scheduling systems, shop floor control systems, retrieval systems, and materials requirements planning (MRP) systems. Finally, information exchange technologies are any computer technology that facilitates the storage and exchange of information such as a database, computer networks, or a personal computer [18].

2. METHODOLOGY

A. Converting fuzzy numbers into crisp score

The fuzzy data is in the linguistic form. First convert it into fuzzy numbers. Then the fuzzy numbers are converted into crisp score. The following method is being used here to convert linguistic terms into fuzzy numbers. The method is used here is proposed by Chen and Hwang in 1992 [19].

In fuzzy situation, we don't have the complete information of the system. The system and design range will be used here is "over a number", "around a number" or "between two numbers".

The fuzzy number is converted into crisp score as follows.

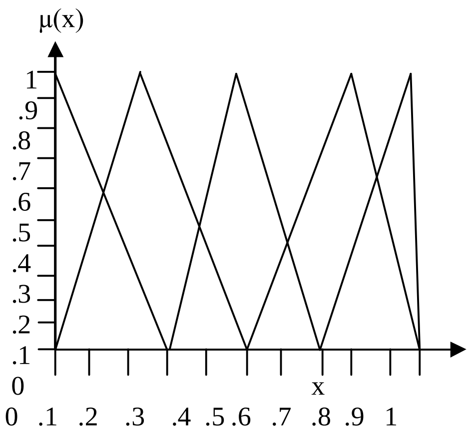

Figure1 Linguistic form into fuzzy numbers (5 point) [19]

$$\mu_{\max}(x) = \begin{Bmatrix} x, 0 \le x \le 1 \\ 0, otherwise \end{Bmatrix} \quad 1$$

$$\mu_{\min}(x) = \begin{Bmatrix} 1-x, 0 \le x \le 1 \\ 0, otherwise \end{Bmatrix} \quad 2$$

The maximum and minimum fuzzy numbers should be selected in a manner that they can be fitted automatically into comparison scale. The left score of the fuzzy number is calculated as below:

$$\mu_L(W_i) = Sup_x[\mu_{\min}(x)^{\mu_{w_i}(x)}] \quad 3$$

By using the above formula the left score is converted into crisp number between 0 & 1.It is the maximum value of the intersection of fuzzy number W_i and the minimum fuzzy number. Similarly the right score can be converted into crisp number by using the following formula.

$$\mu_R(W_i) = Sup_x[\mu_{\max}(x)^{\mu_{w_i}(x)}] \quad 4$$

The total score of the equation 3 & 4 is given below:

$$\mu_T(W_i) = [\mu_R(W_i) + 1 - \mu_L(W_i)]/2 \quad 5$$

A five point scale is used here to demonstrate the conversion of fuzzy numbers into crisp numbers.

Intangible Factors	**Fuzzy Numbers**
Poor	W_1
Fair	W_2
Good	W_3
Very Good	W_4
Excellent	W_5

By using the equations 1-5, the crisp score can be computed which is shown below

TABLE 1
Conversion of Fuzzy Numbers Into Crisp Numbers [19]

Intangible Factors	Fuzzy Number	Crisp Score
Poor	W_1	0.115
Fair	W_2	0.295
Good	W_3	0.495
Very Good	W_4	0.695
Excellent	W_5	0.895

TABLE 2
Conversion of Fuzzy Numbers Into Crisp Numbers (Relative Importance Among Facors) [19]

Intangible Factors	Fuzzy Number	Crisp Score
One Factor is very less important than the other	W_1	0.115
One factor is less important than the other	W_2	0.295
Two Attributes are equally important	W_3	0.495
One Attribute is more important than the other	W_4	0.695
One Attribute is much more important than the other	W_5	0.895

C. Graph Theoretic Approach

Graph theoretic and matrix model consists of digraph representation, matrix representation and permanent representation. It is a powerful technique that can be applied in various fields [20]-[29]. Main objectives of the graph theoretic approach

- It is a tool which is used to calculate the single numerical index of any issue
- It converts the intangible issues into tangible i.e. it quantify the subjective issues.
- It also finds the interdependencies of the various subfactors in numerical way.
- It helps to compare the different options available on the basis of the single numerical index.

First of all digraph of factors is made. Then with the help of matrices these digraph will be converted into mathematical form and then a permanent function will be calculated which will represent the single numerical index for the AMS selection model.

3. CASE STUDY

To demonstrate the proposed methodology for the selection of AMS, a case study has been conducted in an organisation. This organisation is engaged in the manufacture of sheet metal components, having a turnover of US$1.3 million and employing 750 employees. This company manufactures 15–20 models of their products and change overtime of 60–90 min from one model to another has been reported. The organisation has taken decision to install advanced manufacturing systems for improving the delivery time, reducing cost to manufacture product, launching new products with less time as compared to competitors. Several rounds of discussions were held with senior managers, job shop floor workers to identify the critical attributes for selecting the advanced manufacturing system. The past available literature was also taken care of while selecting the critical factors. The attributes chosen here can be divided into tangible and intangible. The tangible attributes are those which are available in numerical form like Initial Cost, Maintenance Cost and Operating Cost and intangible factors are those which cannot be quantified like flexibility, product quality etc.

TABLE 3
AMS Selection Attributes

AMS	IC ($) million	MC($) million	AOC($) million	RFA %age	PF	PQ
I	0.56	0.19	0.08	25	VG	F
II	0.76	0.10	0.04	15	VG	VG
III	0.70	0.13	0.05	30	G	G

Where, IC=Initial Cost, MC=Maintenance Cost (5 years), AOC= Annual Operating Cost, RFA= Reduction in floor area, PF= Product Flexibility, PQ= Product Quality, G= Good, VG= Very Good, F= Fair, E= Excellent.

Here fuzzy data is given in the column of PF and PQ by discussing with the practitioners.

4. AMS SELECTION THROUGH FUZZY MADM AND GTA

By using table 1, crisp scores were provided to PF and PQ as shown in table 4.

TABLE 4
AMS Selection Attributes Having Crisp Score

AMS	IC ($) million	MC($) million	AOC($) million	RFA %age	PF	PQ
I	0.56	0.19	0.08	25	0.695	0.295
II	0.76	0.10	0.04	15	0.695	0.695
III	0.70	0.13	0.05	30	0.495	0.495

The values of the table 4 have to be normalized before being compared as all the values have different units. Some of the values (RFA, PF, PQ) shown in the table 4 are in favourable condition while other (IC, MC, AOC) are unfavourable. For Normalizing the two formulas being used here are as follows:

Favourable Condition = B_{ii}/B_{iu} 6

Unfavourable Condition= B_{il}/B_{ii} 7

Normalized table is shown below.

TABLE 5
Normalized AMS Selection Attributes

AMS	IC	MC	AOC	RFA	PF	PQ
I	1	0.52	0.5	0.83	1	.42
II	0.73	1	1	0.50	1	1
III	0.8	0.77	0.8	1	0.71	0.71

By using table 2, the interrelations among the AMS selection factors can be found.

TABLE 6
Relative Importance among Attributes

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	IC	MC	AOC	RFA	PF	PQ
IC	-	0.495	0.695	0.695	0.695	0.495
MC	0.495	-	0.695	0.695	0.495	0.295
AOC	0.295	0.295	-	0.295	0.295	0.295
RFA	0.295	0.295	0.695	-	0.295	0.115
PF	0.295	0.495	0.695	0.695	-	0.295
PQ	0.495	0.695	0.695	0.895	0.695	-

Furthermore to find the interrelations among the various factors graph theoretic approach is being used. For that in the first step a digraph has been constructed as shown in Fig. 2 with the discussions held with decision makers at the organisation.

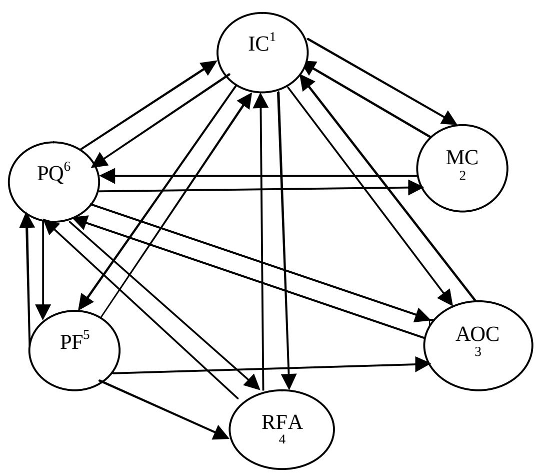

Figure 2. AMS selection digraph

In the step 2 of graph theoretic approach permanent matrix for AMS selection is formed.

	IC	MC	AOC	RFA	PF	PQ
IC	F_1	a_{12}	a_{13}	a_{14}	a_{15}	a_{16}
MC	a_{21}	F_2	a_{23}	a_{24}	a_{25}	a_{26}
AOC	a_{31}	a_{32}	F_3	a_{34}	a_{35}	a_{36}
RFA	a_{41}	a_{42}	a_{43}	F_4	a_{45}	a_{46}

PF	a_{51}	a_{52}	a_{53}	a_{54}	F_5	a_{56}
PQ	a_{61}	a_{62}	a_{63}	a_{64}	a_{65}	F_6

Here the F_i and a_{ij} represents the ams selection attribute and comparison among attributes respectively. The value of F_i and a_{ij} will be taken from table 5 &6.

The solution of the permanent matrix is given below:

$$\begin{aligned}
VPF-T = perT = & \prod_{i=1}^{6} F_i + \sum_i\sum_j\sum_k\sum_l\sum_m\sum_n (a_{ij}a_{ji})F_kF_lF_mF_n \\
& + \sum_i\sum_j\sum_k\sum_l\sum_m\sum_n (a_{ij}a_{jk}a_{ki} + a_{ik}a_{kj}a_{ji})F_lF_mF_n \\
& + [(\sum_i\sum_j\sum_k\sum_l\sum_m\sum_n (a_{ij}a_{ji})(a_{kl}a_{lk})F_mF_n \\
& + \sum_i\sum_j\sum_k\sum_l\sum_m\sum_n (a_{ij}a_{jk}a_{kl}a_{li} + a_{il}a_{lk}a_{kj}a_{ji})F_mF_n)] \\
& + [\sum_i\sum_j\sum_k\sum_l\sum_m\sum_n (a_{ij}a_{ji})(a_{kl}a_{lm}a_{mk} + a_{km}a_{ml}a_{lk})F_n \\
& + \sum_i\sum_j\sum_k\sum_l\sum_m\sum_n (a_{ij}a_{jk}a_{kl}a_{lm}a_{mi} + a_{im}a_{ml}a_{lk}a_{kj}a_{ji})F_n] \\
& + [\sum_i\sum_j\sum_k\sum_l\sum_m\sum_n (a_{ij}a_{ji})(a_{kl}a_{lm}a_{mn}a_{nk} + a_{kn}a_{nm}a_{ml}a_{lk}) \\
& + \sum_i\sum_j\sum_k\sum_l\sum_m\sum_n (a_{ij}a_{jk}a_{kl})(a_{lm}a_{mn}a_{nl}) \\
& + \sum_i\sum_j\sum_k\sum_l\sum_m\sum_n (a_{ij}a_{ji})(a_{kl}a_{lk})(a_{mn}a_{nm}) \\
& + \sum_i\sum_j\sum_k\sum_l\sum_m\sum_n (a_{ij}a_{jk}a_{lm}a_{mn}a_{ni} + a_{in}a_{nm}a_{ml}a_{lk}a_{kj}a_{ji}]
\end{aligned}$$

8

In this total (n+1) 1.e (6+1) groupings have been made. These groups represent the measure of attributes and the relative importance. Here total 7 groups have been made and their importance is discussed below.

In this total (n+1) 1.e (6+1) groupings have been made. These groups represent the measure of attributes and the relative importance. Here total 7 groups have been made and their importance is discussed below.

i. The first grouping represents the measures of inheritance level of gripper selection factors.
ii. The second grouping is absent as there is no self loop in the digraph.
iii. The third grouping contains interrelationships between the subfactors (i.e. $a_{ij}a_{ji}$)and measures of four remaining factors.
iv. The fourth grouping represents a set of three factors relative importance loop and measure of three factors.
v. The fifth grouping contains two sub groups. The terms of the first subgroup represents the relative importance among the two factors and the measure of two factors. The second subgroup contains the relative importance among the four factors and the measure of the two factors.
vi. The sixth grouping contains two sub groups. The first subgrouping is a set of 2 factor interdependence, i.e. $a_{ij}a_{ji}$, a set of 3 factor interdependence, i.e. $a_{kl}a_{lm}a_{mk}$ or its pair $a_{km}a_{ml}a_{lk}$ and measure of remaining factor. The second sub-grouping is a set of five factors interdependence, i.e. $a_{ij}a_{jk}a_{kl}a_{lm}a_{mi}$or its pair $a_{im}a_{ml}a_{lk}a_{kj}a_{ji}$and measure of remaining factor.
vii. Similarly seventh grouping analyses sub-grouping in terms of a set of two and four factor interdependence, 2 – three factor interdependence, 3 – two factor interdependence and six factors interdependence.

The permanent matrix for the AMS selection problem is rewritten according to the digraph shown in fig.2

	IC	MC	AOC	RFA	PF	PQ
IC	F_1	a_{12}	a_{13}	a_{14}	a_{15}	a_{16}
MC	a_{21}	F_2	0	0	0	a_{26}
AOC	a_{31}	0	F_3	0	0	a_{36}
RFA	a_{41}	0	0	F_4	0	a_{46}
PF	a_{51}	0	a_{53}	a_{54}	F_5	a_{56}
PQ	a_{61}	a_{62}	a_{63}	a_{64}	a_{65}	F_6

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In step 3, the values will be set into equation 9 from table 5 &6. Then by using equation 8, the overall numerical index will be found out for individual AMS. Overall numerical index for each AMS is shown below.

AMS I: 11.549

AMS II: 16.359

AMS III: 14.358

So, the obvious choice is AMS II, because it is having the maximum overall index.

5. CONCLUSION

By using the above technique, AMS selection process becomes objective. By knowing the overall numerical index the organisation can make objective decision. This technique can further be extended to multi attribute problems.

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