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Mohammed Ali
Department of Mechanical Engineering, Aligarh Muslim University, Aligarh, India

Mukesh Kumar
Department of Mechanical Engineering, Aligarh Muslim University, Aligarh, India

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AN ANALYTIC HIERARCHY PROCESS (AHP) FRAMEWORK FOR SELECTING FLEXIBLE MANUFACTURING SYSTEM

Dr. Mohammed Ali*
Mukesh Kumar**

Abstract

The main objective of this paper is to propose a structured model for evaluating different Flexible Manufacturing System (FMS) using the Analytic Hierarchy Process (AHP). The paper aims to demonstrate how the model can help in taking correct decisions regarding the type of manufacturing flexibility needed for best FMS. This is because huge amount of money is invested to implement FMS in the industry. Hence, managers need to take judicious decision regarding the type and level of manufacturing flexibility. There are a number of manufacturing flexibility being reported in the literature. In this paper the most fundamental types i.e., machine, routing and product flexibility are examined. The AHP is aimed at integrating different measures into a single overall score for ranking decision alternatives. Its main characteristic is that it is base on pairwise comparison judgment. A usability evaluation of the AHP based model of FMS along with structure of the hierarchy is developed. The framework that is used in this example could serve as one of the tools for making a strategic decision. The effectiveness of our model is demonstrated through numerical examples.

INTRODUCTION

In the last decade a growing number of authors have pointed out the crucial role played by manufacturing in supporting the achievement of the overall business strategy of a company. This role has been summarized in the concept of manufacturing flexibilities that represent the deployment of business strategic objectives at the level of manufacturing. Everyday, manufacturers are investing in Computer Aided Design (CAD), Computer Aided Manufacturing (CAM), Computer Integrated Manufacturing System (CIMS) and a dozen other computer aided technologies. Although the above technologies are diverse, one thing common to all is that they add flexibility to manufacturing operations

**Sr.Lecturer, Dept. of Mechanical Engineering, Aligarh Muslim University, Aligarh, India.*
***M. Tech. Student, Dept. of Mechanical Engineering, Aligarh Muslim University, Aligarh, India.*

(Swamidas, 1998). CIMS tries to integrate all the components of the manufacturing system such as CAD, CAM, FIS, FAS, etc through information technology. FMS is considered at the operational level of CIMS.

In manufacturing and other industries, many researchers turn to decision theory for logical approaches to selection problems. There are number of different decision theory methods reported in literature such as multi-attribute utility theory, vector criterion methods, game theory, and more recently, the Analytic Hierarchy Process (AHP), which was introduced by Saaty. AHP is a multi- criteria decision making tool that allows financial and non-financial quantitative and qualitative measures to be considered and trades offs among them to be addressed. A key feature of multi-criteria decision making is its stress on the judgment of the decision making team, in establishing objectives and criteria, estimating relative importance weights and, to some extent, in judging the contribution of each option to each performance criterion (Lau et al, 2003). The AHP is aimed at integrating different measures into a single overall score for ranking decision alternatives. Its main characteristic is that it is based on pairwise comparison judgment (Rangone, 1996).

Recently the AHP has been applied to several and heterogeneous decision problem, e.g. investment appraisal, project selection, human resources evaluation, vendor rating. However little attention has been given so far to the application of AHP to selecting FMS based on manufacturing flexibility. This paper explores the opportunities and application of AHP in the selection of manufacturing flexibility for a particular FMS.

In this paper, the AHP is used in the selection of flexible manufacturing system. The remainder of the present paper has been organized in the following manner: section 2 deals with literature review to highlight the application of AHP in different areas. The working procedure of AHP has been illustrated in section 3. Then hierarchy is established using the given manufacturing flexibility and key performance metrics and an example is formulated with three FMS in section 4. Finally, industrial implication and conclusions are given in section 5.

LITERATURE REVIEW

Analytic Hierarchy Process (AHP) is a decision aided tool for dealing with complex, unstructured and multiple attribute decisions. It was developed during the 1970s by Thomas L. Saaty. AHP is an analytical tool which enables people to explicitly rank tangible and intangible criteria against each other for the purpose of selecting priorities. The AHP has attracted the interest of many researchers mainly due to the nice mathematical properties of the method and the fact that the required input data are rather easy to obtain and its procedure is simple and comprehensible. It uses a multi-level hierarchal structure of objectives, criteria, sub-criteria, and alternatives (Triantaphyllou and Mann, 1995).

A Flexible Manufacturing System (FMS) is an automated manufacturing system that consists of machining centers with automated loading and unloading of parts, an automated guided vehicles system for moving parts between machines, and other automated elements to allow unattended production of parts. FMS is an important element in CIMS. The role of flexibility can be viewed as one that provides alternative decision solutions to certain discrete events, which the system should evolve (Groover, 2002). According to Upton (1994), flexibility in a generic sense can be defined as a quality to change react with little penalty in time, effort, cost or performance. Wadhwa and Rao (2002) propose a flexibility maturity model to help the practitioner to navigate through the flexibility web. They suggested that flexibility could resolve conflicts between organizational objectives. They emphasized that some of the organizational objectives like faster delivery at lower cost, lower cost with greater variety, greater variety with higher quality, faster delivery and higher quality, lower cost and higher quality can be resolved by providing flexibility in the organization. Manufacturing flexibility remains a key strategic objective of many manufacturing companies. Browne et al. (1984) state eight different types of manufacturing, i.e., machine, routing, product, operation, expansion volume, process and production flexibility. The manufacturing flexibility in the form of routing and machine flexibility could be judiciously exploited towards lead-time reduction in multi-product manufacturing system (Wadhwa and Bhagwat, 1998, Mohammed and Wadhwa, 2005). Product flexibility helps organizations to make products that best serve the needs of customers at a reasonable cost, and volume flexibility provides the companies with near mass production capacity and efficiency (Zhang et al. 2003).

Researchers who have used AHP on various manufacturing related problems include Partovi (1992) and Mohanty and Deshmukh (1997). Chick, et al. (2000) applied AHP for selection of preferred suppliers and machining systems. Abdul-Hamid, et al. (1999) use AHP to select between three plant layouts, with respect to flexibility, production volume, and cost criteria. Some of the industrial engineering applications of the AHP include its use in integrated manufacturing (Putrus, 1990); layout design, (Cambron and Evans, 1991). According to Chan et al. (2000) AHP is one of the useful methodologies and plays an important role in selecting alternatives. For evaluating the numerous criteria, AHP has become one of the most widely used methods for the practical solution of multi-criteria decision making problems (Liu et al., 1999).

Hence from the literature review we observe that AHP has been used as a decision tool for evaluating aspect of manufacturing system. However, little attention has been given so far to the application of the AHP to selection FMS based on manufacturing flexibility.

ANALYTICAL HIERARCHY PROCESS (AHP)

The AHP is a decision support tool which can be used to solve complex decision problems. It uses a multi-level hierarchical structure of objectives, criteria, sub-criteria, and alternatives. The pertinent data are derived by using a set of pairwise comparison. These comparisons are used to obtain the important weights of the decision criteria, and the relative performance measures of the alternatives in terms of each individual's decision criterion.

There are three basic steps in using AHP: the description of the problem as a hierarchy, the prioritization of procedure, and calculation of the results. The first step is formulating the problem in structured manner and then arranging them in a hierarchical order. The structure of the typical decision problem considered in this study of a number, say M, of alternatives and a number, say N, of decision criteria can be estimated. Let a_{ij} (i = 1,2,3......M, and N = 1,2,3........N) denote the performance value of the i-th alternative (i.e., Ai) in terms of the j-th criterion (i.e., Cj). Also denote as Wj the weight of the criterion Cj. Then, the core of the typical multi-criteria decision making problem can be represented by the following decision matrix:

		Criterion	
	C_1	C_2	C_3.........C_N
	W_1	W_2	W_3.........W_N
A_1	a_{11}	a_{12}	a_{13}........a_{1N}
A_2	a_{21}	a_{22}	a_{23}........a_{2N}
-	-	-	-
A_M	a_{M1}	a_{M2}	a_{M3} ....a_{MN}

Given the decision matrix, the decision problem considered in this study is how to determine which the best alternative is. In other words the problem is to determine the relative significance of the M alternatives when they are examined in terms of the N decision criteria combined.

Once the hierarchy has been constructed the next step is prioritization procedure to determine the relative importance of the criteria in each level. Criteria in each level are compared pairwise with respect to their importance to criteria in the next higher level. Then number of square matrices is developed by comparing criteria in each level to criteria in the next higher level. The preferences are made between every two criteria as equally important, moderately more important, strongly more important or extremely more important. These descriptive preferences are then translated into numerical ratings on a scale of 1 to 9 where 1 represents equally preferred options and 9 extremely preferred options vis-à-vis other. The nominal scale used in AHP enables the decision maker to incorporate decision and knowledge in an intuitive and natural manner.

The next step is deriving relative weights for the various criteria; the relative weights of the criteria of each level with respect to criteria in the next higher level are computed as the components of the normalized eigenvectors associated with the largest eigenvalue of their comparison matrices. The composite weights of the decision alternative are then determined by aggregating the weights throughout the hierarchy. The outcome of this aggregation is a normalized vector of the overall weights of the options (Partovi, 1994).

PROBLEM DEFINITION

In this section a model for evaluating different FMS is presented. The model is in the form of hierarchy which includes different manufacturing flexibility and performance measures. It is possible to access each level's priority in this hierarchy using AHP. In particular, referring to FMS the AHP can help managers to assess and compare the overall support provided by each manufacturing flexibility to the achievement of the required performance of the system under consideration. Figure 1 depicts the decision hierarchy structure of criteria and alternative.

As explained earlier the first step of the AHP consists of developing a hierarchical structure of the assessment problem. In the case of the present problem the goal is the selection of best FMS; the criteria are the manufacturing flexibilities; the sub-criteria are the performance measures of different manufacturing flexibility (i.e., machine flexibility, routing flexibility and product flexibility), the alternatives are the selection of best FMS.

At the first level of hierarchy there are the three manufacturing flexibility (criteria) i.e., machine, routing and product flexibility. The explanation of different flexibility types are as follows:

- Machine flexibility: the ease of making the change required to produce a given set of part types.
- Routing flexibility: the ability to handle breakdowns and to continue producing the given set of part types.
- Product flexibility: the ability to changeover to produce new products very economically and quickly.

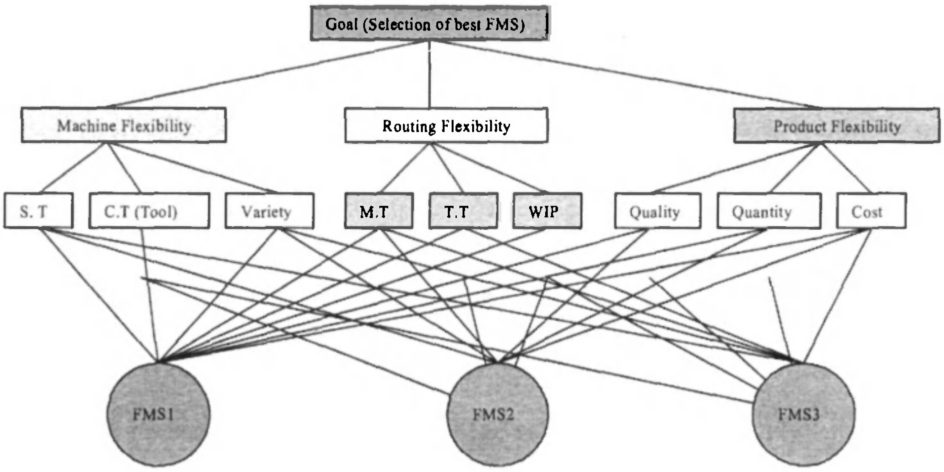

Figure 1: The Decision Hierarchy Structure of Criteria and Alternative of FMS

At the second level there are operating measures (sub-criteria) for each flexibility type.

- Machine Flexibility (MF)
  - Setup time (S.T) is the time in which the job is set up on the machine.
  - Changing time of tool (C.T) is the time to change the tool for performing different operations.

    - The ability of the plant to manufacture a range of product is known as variety.

- Routing Flexibility (RF)
    - Make-span time (M.T) is the time taken to complete all the operations on the part.
    - Transportation time (T.T) is the time taken to move the part from one machine to another.
    - Work in progress (WIP) is the total part in the system.
- Product Flexibility (PF)
    - Quality is the degree to which the product or service meets customer and organization expectations.
    - Quantity is the total amount of parts to be manufactured by the system.
    - Cost is the total investment required to manufacture the required quantity of parts.

Finally, at the third level (alternative) of the hierarchy, there are the three different types of FMS i.e., FMS1, FMS2 and FMS3, that must be assessed and compared and the best among them selected. After developing the performance hierarchy, we have to determine the relative weights of manufacturing flexibilities and, for each flexibility, the performance measures. With respect to manufacturing flexibilities the relative weights assess their importance in providing support to implementation of the business strategy. As far as performance measures are concerned, the relative weights express their importance in contributing to the corresponding manufacturing flexibility.

Once the hierarchy has been structured, the next step is to determine the priorities of criteria at each level. A set of comparison matrices of all criteria in a level of the hierarchy with respect to criteria of the immediately higher level are constructed so as to prioritise and convert individual comparative judgments into ratio scale measurements. The preferences are quantified by using a nine-point scale. The meaning of each scale measurement is explained in Table 1 above. The pair-wise comparisons are given in terms of how much criteria A are more important than criteria B. As the AHP approach is a subjective methodology (Cheng and Li, 2001), information and the priority weights of criteria is being from a decision-maker of the company using direct questioning or a questionnaire method.

The pairwise comparison data are organized in the form of a matrix and are summarized on the basis of Saaty's eigenvector procedure, in the absolute priorities weights that will be used to calculate the overall score of each FMS (Rangone, 1996).

The pairwise comparison data are translated into the absolute values by solving the following matrix equation:

$$A^{*}AW = k^{*}AW$$

Where

A = the pairwise comparison matrix;

AW = the vector of the absolute values;

k = the highest of the eignvalues of the matrix A.

Table 1-4 reports the paired comparison data and the absolute weights of the manufacturing flexibilities and of the performance measures of the problem in the example. It should be noted that the machine flexibility of the output of the AHP, i.e. the calculation of the overall support of flexible manufacturing system to the manufacturing strategy, is strictly to the consistency of the pairwise comparison judgments.

	S.T	C.T (Tool)	Variety	Absolute Weights
S.T	1	6	3	0.667
C.T (Tool)	1/6	1	1/2	0.111
Variety	1/3	2	1	0.222

Table 1: The pairwise comparison judgments and the absolute weights of the manufacturing flexibilities

	MF	RF	PF	Absolute Weights
MF	1	1/7	5	0.315
RF	7	1	1/3	0.382
PF	1/5	3	1	0.302

Table 2: The pairwise comparison judgments and the absolute weights of the MF

	M.T	T.T	W.I.P	Absolute Weights
M.T	1	2	5	0.581
T.T	1/2	1	3	0.309
W.I.P	1/5	1/3	1	0.110

Table 3: The pairwise comparison judgments and the absolute weights of the RF

	Quality	Quantity	Cost	Absolute Weights
Quality	1	7	3	0.681
Quantity	1/7	1	1/2	0.103
Cost	1/3	2	1	0.266

Table 4: The pairwise comparison judgments and the absolute weights of the PF

The AHP allows the judgments of several people to be considered in the assessment process. This is a critical issue, since determining the relative importance of the competitive priorities and the performance measures is normally a collective process that may involve several managers. The same pairwise comparison procedure described in the previous paragraph is used to assess the FMS with respect to each performance measures. For example, if with respect to set up time the performance of FMS1 is judged to be "moderately better" than the performance of FMS, a rating of 3 is attributed. The pairwise data are translated into absolute ratings on the basis of the Satty's eigenvector procedure. Such absolute ratings represent the importance of the corresponding performance relative to achieving a competitive priority. The pairwise comparison procedure is shown in Table 5 to 13.

	FMS1	FMS2	FMS3	Absolute rating
FMS1	1	1/9	3	0.267
FMS2	9	1	1/2	0.434
FMS3	1/3	2	1	0.299

Table 5: The pairwise comparison judgments and the absolute ratings with respect to setup time

	FMS1	FMS2	FMS3	Absolute rating
FMS1	1	1/3	1/7	0.110
FMS2	3	1	4	0.561
FMS3	7	¼	1	0.329

Table 6: The pairwise comparison judgments and the absolute ratings with respect to changing time (Tool)

	FMS1	FMS2	FMS3	Absolute rating
FMS1	1	1/2	1/4	0.143
FMS2	2	1	1/2	0.286
FMS3	4	2	1	0.571

Table 7: The pairwise comparison judgments and the absolute ratings with respect to variety

	FMS1	FMS2	FMS3	Absolute rating
FMS1	1	1/4	1/2	0.159
FMS2	4	1	1/8	0.252
FMS3	2	8	1	0.438

Table 8: The pairwise comparison judgments and absolute ratings with respect to make-span time

	FMS1	FMS2	FMS3	Absolute rating
FMS1	1	1/5	2	0.158
FMS2	5	1	9	0.760
FMS3	½	1\9	1	0.313

Table 9: The pairwise comparison Judgments and the absolute ratings with respect to transportation time

	FMS1	FMS2	FMS3	Absolute rating
FMS1	1	1/6	1/4	0.111
FMS2	6	1	1/2	0.477
FMS3	4	2	1	0.352

Table 10: The pairwise comparison judgments and the absolute ratings with respect to work in process

	FMS1	FMS2	FMS3	Absolute rating
FMS1	1	3	1/5	0.259
FMS2	1/3	1	1/2	0171
FMS3	5	2	1	0.571

Table 11: The pairwise comparison judgments and the absolute ratings with respect to quality

	FMS1	FMS2	FMS3	Absolute rating
FMS1	1	1/3	1/4	0.123
FMS2	3	1	1/2	0.320
FMS3	4	2	1	0.557

Table 12: The pairwise comparison judgments and the absolute ratings with respect to quantity

	FMS1	FMS2	FMS3	Absolute rating
FMS1	1	1/5	1/2	0.149
FMS2	5	1	1/3	0.348
FMS3	2	3	1	0.503

Table 13: The pairwise comparison judgments and the absolute ratings with respect to cost

Weighing the absolute ratings with the absolute priority weights of performance measures, we can calculate the overall ratings of different FMS with respect to each competitive priority (Tables 14, 15 and 16). Averaging these values with the absolute weights of the competitive priorities, it is possible to determine the overall support provided by each FMS. On the basis of this score, the three FMSs are ranked (see Table 17). It is seen that FMS3 is the best option.

	FMS1	FMS2	FMS3
MF	0.221	0.414	0.362

Table 14: The ratings of MF

	FMS1	FMS2	FMS3
RF	0.153	0.434	0.390

Table 15: The ratings of RF

	FMS1	FMS2	FMS3
PF	0.229	0.242	0.579

Table 16: The ratings of PF

FMS	FMS1	FMS2	FMS3
Overall Rating	0.066	0.120	0.146
Rank	3	2	1

Table 17: The overall ratings and the corresponding rank of FMS

CONCLUSION:

The AHP is a flexible tool, as it can be applied to prioritize various performance measures. The framework that was used in this example could serve as one of the tools for making a strategic decision. It can improve the quality of decision making of the managers regarding the selection of different flexible manufacturing system. The criteria and attributes that were used in the model focused on the selection of best flexible manufacturing system. Since different types of flexible manufacturing system that is selected or recommended by the initial model will impact other functional strategies, this framework requires integration with other models for strategic decision-making. AHP can further help managers to communicate the manufacturing competitive priorities and the relative importance of performance measures to all level of organizational structure by translating mangers subjective judgments into quantitative terms. Yet, when seeking to invest in systems that are very costly, a structured analysis, which is provided by this model, can help to reduce the risk of poor investment decisions. A major contribution of the paper lies in the development of framework for selecting the best flexible manufacturing system with the help of AHP decision tool. The framework that is used in this example could serve as one of the tools for making a strategic decision. Finally, this paper enriches the exploratory evaluation of an analytical approach for managerial decision-making through a modeling technique that will be helpful to researchers and managers in the selection of advanced manufacturing system such as flexible manufacturing system. Hence AHP provides a convenient approach for solving complex multi criteria decision method problems in manufacturing domains.

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