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Multi-attribute decision model using the analytic hierarchy process for the justification of manufacturing systems

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Abstract

There is a general challenge offered to the field of engineering economics by the introduction of advanced technologies. A survey of the existing literature on evaluation of advanced manufacturing systems indicate that the traditional approaches are inadequate for the purpose. Typically new technologies require very high investments. The traditional approaches do not account for the significant but intangible benefits offered by new technology. In this paper, an attempt has been made to overcome the above deficiencies by presenting an approach to account for the justification of the manufacturing system. This is based on the analytic hierarchy process (AHP) and is capable of taking into account many intangible factors as well. The usefulness of the proposed approach is demonstrated through a case situation. Finally, some research directions for future work are identified.

1. Introduction

Advanced manufacturing systems (AMS) affect product design, fabrication, assembly, material handling systems, inventory management, maintenance, quality control, cost control, and many other activities inside an organization [1]. The introduction of advanced manufacturing systems includes changes in management, organizational culture of a firm, and so on [2]. The willingness of the Japanese to automate and make other risky investments in high technology has given them the competitive edge in the manufacturing world. However, it must be mentioned that, with the installation of AMS, the economic justification problem for the required investment assumes significance, especially in the resource constrained economy.

A recent survey by Mohanty and Parundekar [3] of Indian industries assess the potential for manufacturing automation. Their results indicate that the Indian industries are not coming forward to introduce AMS, partly because of the very high level of investment required by AMS. Most of the companies, even in other countries, also are struggling with their traditional investment justification procedures because they are either misapplied or the information included in the calculations is inadequate for the multifacet problem being tackled. AMS reshape the basic ways in which a firm perceives itself, and hence its objectives are often altered. Decision making in such situations becomes quite complex because manufacturing excellence encompasses quality, flexibility, lead times, customer satisfaction, and many more of such attributes.

Basically the justification problem for manufacturing systems is a very challenging and difficult question to answer [4] because:

(1) Initial commitment of capital is very high and generally a longer gestation period is involved to make the system fully operational.

(2) Cost patterns of new technologies are rarely understood, so that cost estimates and pricing policies for innovative products are fraught with uncertainty.

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(3) Pay-back period is quite substantial and, hence, it is difficult to account through traditional approaches. Traditional methods of accounting do not consider intangible benefits such as quality, reduced lead times, etc.

(4) Capital investment is very high and limited capital is available in countries like India.

(5) Companies frequently set extremely high goals for investment opportunities with the notion that high discount rates insure high returns. Often this may not hold true if a long term perspective is taken.

(6) Cost patterns have changed, manufacturing overheads continue to grow for many companies, and costs such as maintenance, quality control, inventory, material handling, etc. may not be considered on an individual basis to evaluate the manufacturing system.

The above factors necessitate multi-attribute decision techniques for analyzing, communicating, and synthesizing the nature of the problem, and hopefully lead to the best decision for a given case situation.

Thus, it becomes apparent that some type of multi-attribute decision analysis is required to help analyzing the problem of justification of AMS if the benefits offered by AMS are to be properly evaluated.

In this paper, a multi-attribute approach is developed using an analytic hierarchy process (AHP) framework. Section 2 gives a brief overview of the literature. In Section 3, the model is developed followed by a case situation. Section 4 offers a few comments and the sensitivity of the model. Finally, the conclusions are spelt out with future research directions in Section 5.

2. Review of literature

The importance of justification of AMS has led to much research in this field [5–7]. In this Section a brief review of literature is undertaken.

Traditionally pay-back period, return on investment (ROI), internal rate of return (IRR), net present value (NPV), and such economic criteria are used in literature. Burnstein and Talbi [8] compare traditional and dynamics based approaches for justification. Canada and Sullivan [9] discuss various multi-attribute decision models for the economic evaluation. Srinivas and Millen [4] have developed a framework to integrate explicitly a systematic assessment of the strategic impact of FMS investment with the traditional discounted cash flow (DCF) techniques. They have used an AHP framework. Mayer [10] has suggested that the growth opportunities associated with strategic investments should be interpreted as options on the underlying assets analogous to options on securities. The use of an option pricing theory is recommended. However, the drawback of this approach is that it assumes that the growth option is measurable and that the influence of several strategic factors can be aggregated. Suresh and Meredith [11] have analyzed the current problems in justifying machining systems. They have developed an integrated framework in which both strategic and tactical considerations are included. Chandra and Schall [12] have considered an input-output framework for the justification problem. Wabalickis [13] has applied an AHP framework for the FMS justification problem.

After carefully reviewing the present literature and problems with the traditional approaches, it appears that the justification problem of manufacturing systems requires a comprehensive analysis. In this context, it may therefore be useful to adopt a multi-attribute decision framework. The next Section discusses the development of a multi-attribute decision model using AHP.

3. Development of the model

The analytic hierarchy process [14,15] has been well received in literature. Applications of this methodology have been reported in numerous fields. The general approach of the AHP is to decompose the problem and to make pairwise comparisons of all elements on a given level with respect to the related elements in the level just above. Herein a highly user friendly computer model is developed which assists the user in evaluating his choices. The schematic of the model is shown in Fig. 1.

3.1. Description of the model

3.1.1. Attributes

The attributes are the main components defined by a company when it has to take a decision

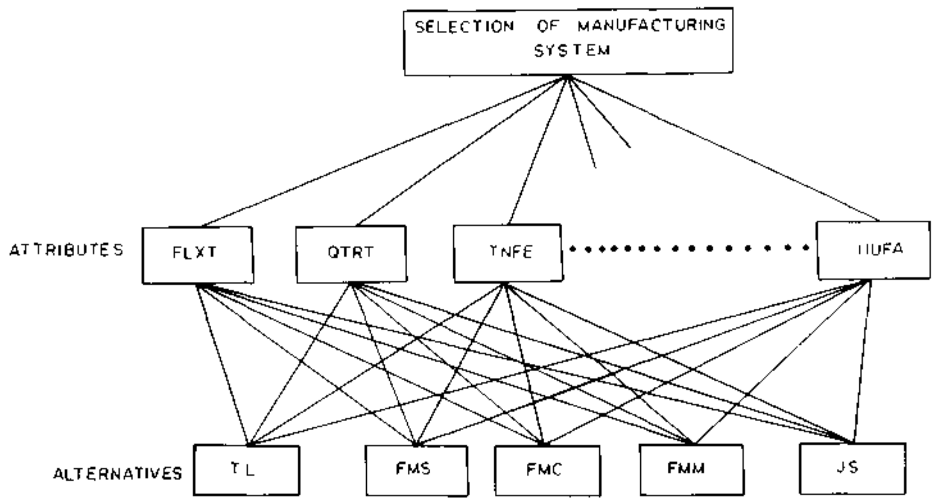

Fig. 1. Schematic of the AHP model.

Table 1
Attributes used in AHP

[FLXT]	**Flexibility**: This covers design flexibility, volume flexibility, routing flexibility, machine flexibility, process flexibility and operation flexibility. Can the system handle variations in part sizes and geometry, batch size and product types?
[QTRT]	**Quality & Reliability**: This is an indicator of the quality of the product. Will it conform to the required specifications and tolerances? and an indicator of meantime to failure and average downtime i.e. how often the system breaks down, to what extent a break down affects the whole system and how long it takes to repair the system?
[TNFE]	**Technical Feasibility**: Is the system capable of producing the product to the required specifications? Can it handle the large variety of jobs precisely?
[MKPO]	**Market position**: This is an indicator of the competition faced, the price sensitivity, the customer requirements and the productmix.
[TGPO]	**Technology Position**: This is an indicator of the company's policy towards modernization, integration and innovation. Is the system such that it facilitates these policies?
[INVS]	**Investment**: Is the company in a position to make the required investment? Does this investment fit in with the company's overall corporate strategy?
[THPT]	**Throughput**: This is an indicator of the lead-time, cycle time and delivery time of the system.
[INVE]	**Inventory**: This includes inventory of raw materials, work-in-process materials and finished goods. To what extent does the system help in reducing inventory costs?
[INFO]	**Information**: How efficiently information and statistics regarding the state of production and requirements are processed and supplied to the management?
[CPUT]	**Capacity utilization**: To what extent is the idle time of the system reduced? Does the system facilitate greater utilization with production and process planning?
[EMRL]	**Employee relations**: How much emphasis does the company place on the worker's attitudes, morale and problems? How will the system effect the same?
[HUFA]	**Human factors**: How does it compare with other system in terms of safety and ergonomics i.e. in terms of efficiency and convenience of the workers?

on which manufacturing system to use. The selection of attributes was determined through literature survey, discussion and consultation with the industry personnel. These attributes are explained in Table 1.

3.1.2. Alternatives

The alternatives are the manufacturing systems chosen to be compared and evaluated. From the given set of alternatives, the model evaluates the best manufacturing system for the applica-

Table 2
Case situation

Product	:	Small car (1000 cc)
Market changes	:	Medium (expect minor changes in design every 6 months and major changes every 2 years)
Production volume	:	In the beginning 10000 cars to be increased to 40000 cars (over a period of 5 years)
Company goals	:	Maintain competitive edge by introducing of new products
Quality	:	High
Market location	:	Metropolitan area
Market segment	:	Family car and luxury car targeted at upper income level
Production location	:	Where trained manpower and raw materials etc. are available
Distribution network	:	All major metro cities

Table 3
Weightages and consistency for different attributes

Number	Attribute	Weightage	Consistency
[01]	FLEXIBILITY	0.202	0.069
[02]	QUALITY & RELIABILITY	0.214	0.091
[03]	TECHNICAL FEASIBILITY	0.026	0.049
[04]	MARKET POSITION	0.042	0.061
[05]	TECHNOLOGY POSITION	0.038	0.073
[06]	INVESTMENT	0.068	0.077
[07]	THROUGHPUT	0.129	0.054
[08]	INVENTORY	0.110	0.068
[09]	INFORMATION	0.014	0.070
[10]	CAPACITY UTILIZATION	0.123	0.058
[11]	EMPLOYEE RELATIONS	0.017	0.086
[12]	HUMAN FACTORS	0.017	0.088

The consistency ratio for the attribute matrix is 0.090.

Table 4
Weightages of attributes for alternative manufacturing systems

Number	Attribute	TL	FMS	FMC	FMM	JS
[01]	FLXT	0.036	0.499	0.239	0.149	0.077
[02]	QTRT	0.141	0.491	0.243	0.086	0.039
[03]	TNFE	0.149	0.483	0.218	0.107	0.044
[04]	MKPO	0.146	0.537	0.193	0.081	0.043
[05]	TGPO	0.150	0.506	0.210	0.091	0.042
[06]	INVS	0.130	0.493	0.242	0.098	0.036
[07]	THPT	0.445	0.284	0.151	0.079	0.041
[08]	INVE	0.462	0.297	0.126	0.079	0.037
[09]	INFO	0.118	0.503	0.252	0.087	0.039
[10]	CPUT	0.505	0.261	0.132	0.067	0.035
[11]	EMRL	0.027	0.069	0.136	0.266	0.502
[12]	HUFA	0.115	0.482	0.261	0.100	0.042

tion. To allow a complete comparison, the chosen alternatives are such that they cover the range of normal production requirements of volume, quality, etc. These alternative manufacturing systems are:

(1) Transfer line (TL): Used for mass production.

Table 5
Final evaluation of the manufacturing system

Number	Attribute	TL	FMS	FMC	FMM	JS
[01]	FLXT	0.007	0.101	0.048	0.030	0.016
[02]	QTRT	0.030	0.105	0.052	0.018	0.008
[03]	TNFE	0.004	0.012	0.006	0.003	0.001
[04]	MKPO	0.006	0.023	0.008	0.003	0.002
[05]	TGPO	0.006	0.019	0.008	0.003	0.002
[06]	INVS	0.009	0.034	0.016	0.007	0.002
[07]	THPT	0.057	0.037	0.019	0.010	0.005
[08]	INVE	0.051	0.033	0.014	0.009	0.004
[09]	INFO	0.002	0.007	0.004	0.001	0.001
[10]	CPUT	0.062	0.032	0.016	0.008	0.004
[11]	EMRL	0.000	0.001	0.002	0.005	0.009
[12]	HUFA	0.002	0.008	0.005	0.002	0.001
Total score of alternative		0.236	0.412	0.198	0.099	0.054

Ranking: FMS > TL > FMC > FMM > JS.
Best Alternative is FMS (0.412).

(2) Flexible manufacturing system (FMS): NC machines, material handling equipments are linked, controlled, and monitored by a central computer.

(3) Flexible manufacturing cell (FMC): Consists of a group of flexible manufacturing modules placed together. There is computer control manufacturing within the group but not between the groups.

(4) Flexible manufacturing module (FMM): One or two NC machines are placed together being serviced by a material handling system.

(5) Job shop (JS): Machines are grouped together based on the operation (function), there is no control on the sequence of production.

3.1.3. Methodology

The attributes are compared with each other on a pairwise comparison. The relative weights or priorities are obtained. Highly user-friendly software, the multi-attribute decision model (MADM), has been developed in PASCAL for the aid to the user for pair-wise comparison of the attributes as well as for the alternatives and for analyzing the user inputs.

A questionnaire was developed with respect to the case situation described in Table 2. A cross-section of users (sample size = 15) were asked to respond to this questionnaire for selection of the appropriate manufacturing system. These responses were used as an input to the AHP model. Using the developed program, the data were processed for 15 user responses. The user responses have finally been aggregated for final results. The relative importance and consistency of each of these attributes are given in Table 3. Similarly, from the analysis, it appears that the flexible manufacturing system (FMS) option is the best under the circumstances of the developed case situation (Table 4–5). Thus, it appears that otherwise the justification for FMS would have been very difficult for the AHP framework developed here.

4. Usefulness of MADM

The model developed is able to solve the justification problem for the case situation taking the intangible benefits into account. The inputs to the model help clarifying the goals of the organization as it requires insights for constructive discussion. The salient features of the multi-at-

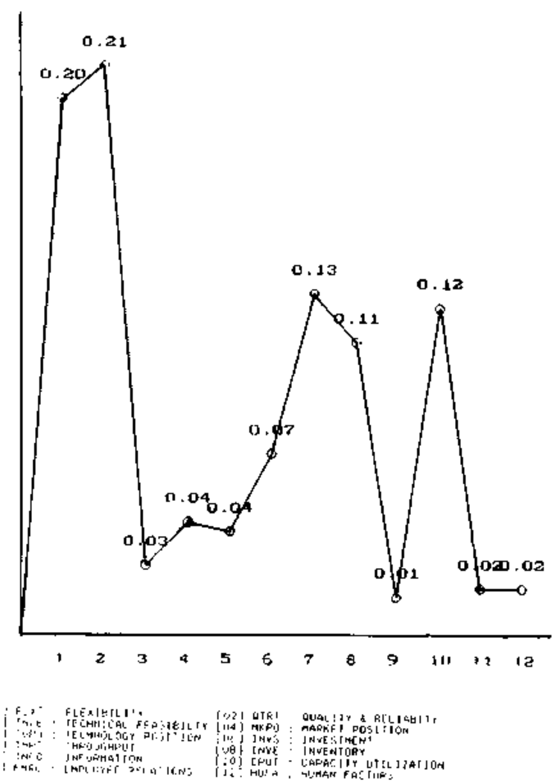

Fig. 2. Graphical estimation of the input data for attributes.

	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]
[1]	1.000	0.333	7.000	5.000	6.000	4.000	3.000	4.000	9.000	3.000	8.000	7.000
[2]		1.000	6.000	5.000	5.000	4.000	2.000	4.000	8.000	3.000	6.000	5.000
[3]			1.000	0.500	0.333	0.200	0.167	0.143	3.000	0.143	4.000	3.000
[4]				1.000	2.000	0.333	0.250	0.167	4.000	0.200	5.000	4.000
[5]					1.000	0.333	0.200	0.333	5.000	0.167	4.000	3.000
[6]						1.000	0.333	0.167	7.000	0.500	5.000	4.000
[7]							1.000	2.000	8.000	1.000	6.000	4.000
[8]								1.000	5.000	1.000	6.000	5.000
[9]									1.000	0.143	0.500	1.000
[10]										1.000	7.000	6.000
[11]											1.000	2.000
[12]												1.000

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ATTRIBUTES

[01] FLXT : FLEXIBILITY
[02] QTRT : QUALITY & RELIABITY
[03] TNFE : TECHNICAL FEASIBILTY
[04] MKPO : MARKET POSITION
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Fig. 3. Input screen for comparing the attributes.

ATTRIBUTES

[01] FLXT : FLEXIBILITY
[02] QTRT : QUALITY & RELIABITY
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[11] EMRL : EMPLOYEE RELA
[12] HUFA : HUMAN FACTORS

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ALTERNATIVES

Transfer Line (T.L.)
Flexible Manufaturing system (F.M.S.)
Flexible Manufaturing cells (F.M.C.)
Flexible Manufaturing Module (F.M.M.)
Job Shop (J.S.)

[01] FLXT : FLEXIBILITY

	T.L.	F.M.S.	F.M.C.	F.M.M.	J.S.
T.L.	1.000	0.143	0.166	0.200	0.250
F.M.S.		1.000	3.000	5.000	6.000
F.M.C.			1.000	2.000	4.000
F.M.M.				1.000	3.000
J.S.					1.000

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Fig. 4. Input screen for comparing the alternatives with respect to the attribute "flexibility".

tribute decision model (MADM) are:

(1) A user-friendly, interactive software which is menu driven.

(2) Options are offered to the user to define his mode of input, i.e., (a) from a file, and (b) by direct input on the screen.

(3) The screen input and editing are done on a clearly defined matrix. The editing can be carried out on the screen itself, thus on-line changes are possible.

(4) To see the results of the calculations and editing there are two options, i.e., (a) on the screen, and (b) on an output file, so as to get hard copy.

(5) A help menu explicitly gives examples of how to enter pairwise comparisons and information on the constituent elements of each of the attribute and alternatives. The user can access the help menu at any stage.

(6) The validity of the input data is checked through a consistency criteria. The consistency ratio (CR) is an approximate mathematical indicator of the consistency of pairwise comparisons.

(7) Graphic display of the calculated weigh-

tages for each of the attribute and alternatives allows a visual estimation of the data entered by the user (Fig. 2). In case of a discrepancy, the user can immediately enter the edit mode, change the data and return to see the result of the changes.

4.1. Comments on the model

As with all such models that attempt to solve the challenging question of justification, the present model also has few limitations:
(1) The pairwise comparisons make the input time large and cumbersome.
(2) It requires that the user is clear on his goals and objectives.
(3) The developed software is highly menu driven and user friendly. It requires no difficulty to enter the data, as editing and graphical representations were provided (Figs. 3 and 4).
(4) The number of attributes and alternatives cannot be too large in number, as the number of comparisons to be made will increase sharply.
(5) The model will give a decision based on a single user input. It does not account for multi-user responses. However, these responses could be adequately aggregated to get the final ranking.

5. Conclusions

In this paper, an attempt is made to develop a multi-attribute decision model using AHP for the justification problem. A highly user-friendly, menu-driven software was developed to aid in this analysis. The usefulness of this approach was highlighted using a case situation. The model developed is able to solve the problem reasonably well. In fact, just giving the inputs to the model helps clarify goals of the organization as it requires deep thought and constructive discussions. As with all models for the justification problem, the present model also has certain limitations:

(a) The pairwise comparisons make the input time large and difficult.

(b) It requires the user to have the necessary experience although the graphic menus helps him in the analysis.

(c) It requires that the user is clear on his goals and objectives.

Thus, the AHP basically addresses the strategic issue of justification. In case this decision is to be evolved by a panel of experts, say consisting of the managing director, chairman, financial director, etc., then each person's opinion can be consolidated by appropriate weights and then final decisions can be evolved. This would involve extending the logic of the model to one more hierarchy or level. It may also be worthwhile to incorporate other multi-attribute decision frameworks to cross check the strategic implications of the results of the AHP model.

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