Use of AHP in decision-making for flexible manufacturing systems
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Abstract
Purpose – To provide a good insight into the use of analytic hierarchy process (AHP) that is a multiple criteria decision-making methodology in evaluating flexible manufacturing systems (FMSs).

Design/methodology/approach – In this study AHP is used to the decision by a tractor manufacturing plant to implement FMS. Also sensitivity analysis is conducted to see how realistic the final outcome is.

Findings – Information on the use of AHP in assessing advanced manufacturing technologies is provided and an AHP model is proposed to guide the management of tractor manufacturing plant. Most important factors, and their relative importance and influences on the objective of the decision-making model are found. By performing a sensitivity analysis, it is also found that the final outcome remained stable in all cases when the weights of the main criteria affecting the decision are varied up and down by 5 percent in all possible combinations.

Research limitations/implications – When there are dependencies and interactions among the criteria in a decision-making model, analytic network process is more appropriate methodology; yet AHP assumes linear independence of criteria and alternatives.

Originality/value – Proposes a decision-making model to guide managers for assessing advanced manufacturing technologies such as FMS. Also sensitivity analysis conducted in this study is very important for practical decision-making.

Keywords Analytical hierarchy process, Decision making, Flexible manufacturing systems, Advanced manufacturing technologies

Paper type Research paper

Introduction
Flexible manufacturing system (FMS) has received considerable attention in the literature over the last several decades. Hence there is literally a huge amount of published literature on FMS. A dominant theme in these writings is that FMS is a highly automated production system consisting of automated material-handling and transferring machines working together under a comprehensive computer control system (Inman, 1991; Boer and Krabbendam, 1992a, b; Evans and Haddock, 1992; Maccarthy and Liu, 1993; Rao and Deshmukh, 1994; Kaighobadi and Venkatesh, 1994; Maffei and Meredith, 1995; Lee, 1998; Koltai et al., 2000; Mohamed et al., 2001; Shamsuzzaman et al., 2003; Fan and Wong, 2003).

Several studies are devoted to examining the potential benefits of FMS implementation. The common conclusion of these studies is that the advantages associated with the FMS implementation are numerous. Successful implementation of FMS could generate reduced labor costs, increased flexibility and product variety, productivity improvement, improved responsiveness, and increased machinery
utilization (Inman, 1991; Boer and Krabbendam, 1992a, b; Evans and Haddock, 1992; Kaighobadi and Venkatesh, 1994; Maffei and Meredith, 1995). Many firms have installed FMSs and gained such benefits. However, many other firms have failed because of successful FMS implementation require effective operation. A number of studies have addressed the issues related to the success of an FMS installation and implementation, since FMSs are highly capital intensive and installation may take several years. According to those studies, management commitment, people involvement, technological changes, and organizational requirements are critical issues to the success of FMS implementation (Inman, 1991; Boer and Krabbendam, 1992a, b; Evans and Haddock, 1992; Kaighobadi and Venkatesh, 1994; Lee, 1998).

The analytic hierarchy process (AHP) technique is one of the approaches used in determining the relative importance of a set of attributes or criteria. AHP is designed to solve complex multi-criteria problems. Many quantitative methods have been in an attempt to evaluate new technology implementation. The AHP has previously been used in evaluating advanced technology by Shang and Sueyoshi (1995), San and Tabucanon (1994), Albayrakoglu (1996), Shamsuzzaman et al. (2003) and Chan et al. (2000).

In this study, a very comprehensive application of AHP in a real-world case for assessing FMS is presented along with sensitivity analysis. The objective of this paper is to determine whether Turkish Tractor Manufacturing (TTM) should implement FMS throughout the plant by utilizing the AHP. This paper is organized into six sections. First, the research carried out at TTM and then the attributes affecting the decision are presented. The third section introduces the application of the AHP and describes its application in TTM whereas the fourth section introduces the sensitivity analysis and application for checking the authenticity of results obtained by AHP. Finally, the overall conclusion is given in sensitivity analysis section with future scope of further research.

Research methodology
TTM was established in 1948 located in Ankara, Turkey as a main tractor manufacturer. It has continued to be the industry leader in the manufacture of tractors in Turkey. In the last six years TTM has invested $100,000,000 in acquiring the latest technologies such as computer aided design (CAD), computer numerically controlled machines (CNC), and FMSs. TTM is currently one of few companies that partially implements FMS in Turkey. Seven flexible manufacturing lines have been established in TTM.

TTM is now considering the implementation of FMS throughout the organization. Although, considerable benefits were gained by having an FMS such as reducing set-up time, increasing customer satisfaction, increasing flexibility, etc. they had also had some difficulties during the FMS implementation. Therefore, the management of TTM wanted to find out whether they should implement FMS in entire plant. We ran an AHP study on the problem in order to provide a systematic approach. We met with the managers of the company for several hours to decide on the best alternative. A team of TTM decision makers consisted of quality control manager, production manager, operations manager, purchasing manager, sales manager and plant manager. First, the AHP methodology was presented to the decision-making team since the decision-making team was not familiar with the approach. Then we
formulated the model and determined the criteria. Thirty-nine criteria were initially identified. However, after further evaluation decision-making team has eliminated insignificant ones to the problem and considered 28 factors as the primary ones. Also, two alternatives were identified:

1. implementing flexible FMS; and
2. not implementing FMS.

After deciding the criteria, pairwise comparisons were performed including all the combinations of criteria/sub-criteria/alternatives relationships by the decision-making team. Since the decision concerns FMS implementation in the entire plant, the criteria were determined based on the decision makers’ experience on partial FMS implementation. Hence, the criteria shown in Table I for evaluating the decision were identified and used in the AHP model.

**Analytic hierarchy process**
The AHP is based on the innate human ability to make sound judgments about small problems. It facilitates decision-making by organizing perceptions, feelings, judgments and memories into a framework that exhibits the forces that influence a decision. The AHP is normally implemented in conjunction with the use of Expert Choice® and it has been applied in a variety of decisions and planning projects in nearly 20 countries (Saaty, 1990).

*Three steps of AHP methodology*
The AHP methodology is explained in Saaty’s (1990) book. Below we give enough of the general approach to enable the reader to follow the paper with ease.

*Step 1 (structuring the hierarchy).* Group related components and arrange them into a hierarchical order that reflects functional dependence of one component or a group of components on another. The approach of the AHP involves the structuring of any complex problem into different hierarchy levels with a view to accomplishing the stated objective of a problem.

*Step 2 (performing paired comparisons between elements/decision alternatives).* Construct a matrix of pairwise comparisons of elements where the entries indicate the strengths with which one element dominates another using a method for scaling of weights of the elements in each of the hierarchy levels with respect to an element of the next higher level. Use these values to determine the priorities of the elements of the hierarchy reflecting the relative importance among entities at the lowest levels of the hierarchy that enables the accomplishment of the objective of the problem (Albayrakoglu, 1996; Chan et al., 2000). The scale used for comparisons in AHP enables the decision maker to incorporate experience and knowledge intuitively (Harker and Vargas, 1990) and indicates how many times an element dominates another with respect to the criterion. The decision maker can express his preference between each pair of elements verbally as *equally important*, *moderately more important*, *strongly more important*, *very strongly more important*, and *extremely more important*. These descriptive preferences would then be translated into numerical values 1, 3, 5, 7, 9, respectively, with 2, 4, 6 and 8 as intermediate values for comparisons between two successive qualitative judgments. Reciprocals of these values are used for the corresponding transposed judgments.
<table>
<thead>
<tr>
<th>Criteria</th>
<th>Definition</th>
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<tbody>
<tr>
<td>Quality improvement</td>
<td>Because of the ability to make things that could not be made by hand (e.g. microprocessors) and because of improved inspection capabilities, quality is improved</td>
</tr>
<tr>
<td>Faster delivery</td>
<td>The managers pointed out that the firm delivered its products to the market just in time. On-time delivery frequency is increased remarkably</td>
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<tr>
<td>Product variety</td>
<td>Product variety is increased due to scope economies as a result of implementing FMS</td>
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<tr>
<td>Customer satisfaction</td>
<td>Because of product variety, improved quality, and the ability to produce in small quantities, customer satisfaction is also increased</td>
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<tr>
<td>Set-up time</td>
<td>The managers pointed out that they have achieved zero set-up time</td>
</tr>
<tr>
<td>Cutting speed</td>
<td>The managers emphasized that cutting speed, which reduces cutting times, is much better than before. They increased cutting speed 1,000 percent</td>
</tr>
<tr>
<td>Production time</td>
<td>Because machining times went down from 410,240 to 352,402 minutes, reduction in production times was achieved</td>
</tr>
<tr>
<td>Labor cost</td>
<td>The managers pointed out that they have been provided with a significant cost reduction because of decrease in the number of operators</td>
</tr>
<tr>
<td>Number of operators</td>
<td>Since both machining and material-handling are under computer control, operators are needed only to perform necessary loading and unloading operations. The managers reported that the number of operators went down from 23 to 12</td>
</tr>
<tr>
<td>Number of operations</td>
<td>The managers pointed out that the number of operations went down from 30 to 10 after FMS implementation</td>
</tr>
<tr>
<td>Number of machine tools</td>
<td>The managers pointed out that the number of machine tools went down from 32 to 12 after FMS implementation</td>
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<tr>
<td>Productivity</td>
<td>Productivity is increased by reducing the non-productive time on a part spent on the shop floor</td>
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<tr>
<td>Machine utilization</td>
<td>They have achieved higher machine utilization because of reduced set-up times, efficiently handled parts, and simultaneously produced several parts</td>
</tr>
<tr>
<td>Profitability</td>
<td>All these advantages achieved in TTM Plant may help to increase profitability in the long-term</td>
</tr>
<tr>
<td>Long-term competitive power</td>
<td>All these advantages achieved in TTM Plant may help to increase its competitive power in the long-term</td>
</tr>
<tr>
<td>Top management commitment</td>
<td>The managers pointed out that FMS begins with top management’s commitment and involvement. FMS requires a high degree of management commitment and effort. Many problems on the managerial side result from a lack of top management support. Management may not be willing to adopt new technology. On the other hand, managers may quickly abandon the current technology when there are short-term failures</td>
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(continued)
Step 3 (synthesizing results). Synthesize these priorities to obtain the each alternative’s overall priority. Select the alternative with the highest priority.

AHP in TTM
In this section, the work carried out to use AHP for assessing importance priority of “implementing FMS” over “not implementing FMS” in TTM is briefed.

Structuring the hierarchy
In using AHP to model a decision problem, the first step is to structure the hierarchy. The goal of our model was to determine whether TTM should implement FMS in the entire plant. We placed this goal at the top of the hierarchy. The hierarchy descended

<table>
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<td>Training employees</td>
<td>Owing to timing delays for comprehensive training program including programming, technical, operating training, there were some difficulties in training personnel as to how to use new machine tools</td>
</tr>
<tr>
<td>Unstable conditions</td>
<td>Turkey is a dynamic country with ups and downs in its economy. The managers emphasized that because of these unstable conditions, they are very afraid to try new things</td>
</tr>
<tr>
<td>Workers involvement</td>
<td>The managers pointed out that there might be silent resistance from the workers against the new system. Even if there is support from the workers initially, workers support might be lost later on as the study progresses</td>
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<tr>
<td>Delivery dependability</td>
<td>Until there is some experience in how to maintain machine tools, they had to work with the service team of the supplier company. As a result of this, there were delays in delivering parts and materials</td>
</tr>
<tr>
<td>Material availability</td>
<td>Since they did not have sufficient information about the material they will need, they had some difficulties to procure such materials</td>
</tr>
<tr>
<td>Delays in the entire production process</td>
<td>There were certain shortcomings occurring during the implementation of synchronized activities of FMS. These shortcomings caused delays in the entire production process</td>
</tr>
<tr>
<td>High initial costs</td>
<td>The managers pointed out that FMS required large capital investments that exceed $10 million</td>
</tr>
<tr>
<td>Necessity of developing company-specific models</td>
<td>FMS must be custom-designed to a company’s specific needs. The managers emphasized that they had difficulties when they were developing their own model</td>
</tr>
<tr>
<td>Space requirements</td>
<td>The managers pointed out that installing FMS increased space requirements in the entire plant</td>
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<tr>
<td>Long implementation lead-time</td>
<td>The managers emphasized that installing and running FMS took several years</td>
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<tr>
<td>Labor requirements</td>
<td>The managers pointed out that the company needed experts and qualified employees during the implementation process of FMS</td>
</tr>
<tr>
<td>Central computer control</td>
<td>Since a comprehensive computer control system is used to run the entire system, if the computer breaks down, the production line would stop and delays and errors would occur in the production process</td>
</tr>
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Table I.
from the more general criteria in the second level to sub-criteria in the third level to tertiary sub-criteria in the fourth level on to the alternatives at the bottom or fifth level. The general criteria level involved four major criteria: advantages, opportunities, risks and disadvantages. We located advantages to customer and advantages to company under advantages criterion in the third level of the hierarchy. Each of these in turn needed further decomposition into specific items in the fourth level. As an example, advantages to customer were decomposed into four criteria, which are quality improvement, faster delivery, product variety and customer satisfaction. We also located profitability and long-term competitive power in the third level of the hierarchy under opportunities. The seven sub-criteria were included for risks in the third level. These are top management commitment, training employees, unstable conditions, workers involvement, delivery dependability, materials availability and delays in the entire production process. The decision-making team decomposed disadvantages into six criteria: high initial costs, necessity of developing country specific models, space requirements, long implementation lead-time, labor requirements and central computer control. The decision-making team considered two decision alternatives, and located them on the bottom level of the hierarchy. Figure 1 shows a hierarchical representation of the selecting best production system decision-making model.

Performing pairwise comparisons
Pairwise comparisons were performed systematically to include all the combinations of criteria/sub-criteria/tertiary sub-criteria/alternatives relationships. The decision-making team compared the criteria and sub-criteria according to their relative importance with respect to the parent element in the adjacent upper level. We have first entered the judgments for four major criteria in level 2. We concluded that advantages are the most important factor of assessing the FMS implementation with a priority of 0.328. Disadvantages are also a major factor with an importance priority of 0.248. Figure 2 shows the pairwise comparison matrix for the major criteria.

After comparing the major criteria, we have evaluated the sub-criteria and tertiary sub-criteria. As an example, for advantages to customer criterion customer satisfaction received the highest priority with 0.436, followed by quality improvement with 0.247.
Figure 3 shows the judgments obtained and importance matrix for **advantages to customer**.

The Figure 4 shows the priorities of all criteria under advantages hierarchy.

Finally, we compared each pair of alternative with respect to each criterion. In comparing the two alternatives, we asked which alternative decision-making team preferred with respect to each of the main criterion in level 2, each sub-criterion in level 3, each tertiary sub-criterion in level 4. For example, for the sub-criterion competitive power (located under opportunities), we obtained a matrix of paired comparisons (Figure 5) in which alternative 1 (**implementing FMS**) is preferred over alternative 2 (**not implementing FMS**). As a result of it, implementing FMS came out as the top choice with a preference rating of 0.890.

**Synthesizing the results**

After deriving the local priorities for the criteria and the alternatives through pairwise comparisons, the priorities of the criteria were synthesized to calculate the overall priorities for the decision alternatives. As shown in Figure 6, **implementing FMS** received the highest ranking with 54.6 percent, indicating that the organization should install and implement FMS in entire plant.
Sensitivity analysis

A series of sensitivity analyses were conducted to investigate the impact of changing the priority of the criteria on the alternatives’ ranking. Dynamic sensitivity of Expert Choice® was performed to see how realistic the final outcome is. Dynamic sensitivity analysis is used to dynamically change the priorities of the criteria to determine how these changes affect the priorities of the alternative choices (Saaty, 2001). We investigated the impact of changing the priority of four main criteria on overall results. As shown in Figures 7-10, the results indicated that the alternatives’ ratings are not sensitive to changes in the importance of the advantages, while it is sensitive to...
changes in the importance of disadvantages and risks and a little sensitive to changes in the importance of opportunities. When the importance of advantages was increased up to 0.623, overall rank of the final outcome was preserved. When the importance of disadvantages was increased from 0.248 to 0.461, not implementing FMS became the best alternative. We performed a third sensitivity analysis where the relative importance of risks was increased to 0.438. Similarly in this analysis, not implementing

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**Figure 7.**
First scenario

**Figure 8.**
Second scenario

**Figure 9.**
Third scenario

**Figure 10.**
Fourth scenario
FMS became the most preferable one. In the fourth scenario, only when the importance of opportunities was increased from 0.207 to 0.567, not implementing FMS turned out to be the best one.

The sensitivity analysis indicated that when the importance of the main criteria was changed up and down by 5 percent in all possible combinations, the ranks of the alternatives remained stable in all cases. In this respect TTM should choose implementing FMS as the best alternative for the decision.

**Conclusion**

Since FMSs are highly capital intensive and installation may take several years, only a limited percentage of companies have made a serious attempt to install FMS in Turkey. TTM is one of the companies which have achieved a successful partial implementation of FMS. In this study, we proposed an AHP model to guide the management of TTM who are contemplating a decision about whether FMS should be implemented in the entire plant. We found most important factors, and their relative importance and influences on the objective of our decision-making model. To invest in FMS is a complex decision involving many criteria. The AHP enabled us to incorporate 28 factors that were both qualitative and quantitative to assess the FMS implementation. We concluded that implementing FMSs is the most preferable alternative with an overall priority score of 0.546. This alternative is not as overwhelmingly preferable to other alternative as we expected prior to our study, which was a surprising outcome. In our judgment the main reason for this is, in spite of advantages and opportunities to be gained by implementing FMS, there are numerous risks and disadvantages.

**Further discussion**

Our literature search indicated that most studies found the best solution and ignored sensitivity analysis. The sensitivity analysis is very important for practical decision-making. We performed sensitivity analysis to see how realistic the final outcome is. The sensitivity analysis indicated that when we varied the weights of the main criteria up and down by 5 percent in all possible combinations, the ranks of the alternatives remained stable in all cases. It also indicated that the alternatives’ ratings are not sensitive to changes in the importance of the advantages; while it is sensitive to changes in the importance of disadvantages and risks and a little sensitive to changes in the importance of opportunities. When we increased or decreased the importance of disadvantages and risks, not implementing FMS became the most preferable alternative. We attribute this result to FMS’s high risks and disadvantages.

The actual process of conducting this analysis helped us prioritize the criteria in a manner that otherwise might not be possible. The decision-making team was far more confident with their decision as this study showed them, even if the importance of certain criteria changes, overall ranking does not change; even though the degree of preference rating is strengthened or weakened. Bounded rationality and limited cognitive processes make it impossible for the decision maker to adequately consider all of the factors involved in a complex screening decision. Without decision support methodologies such as AHP, managers might base their decisions on only a subset of important criteria while not understanding their relative importance and interactions.

AHP has some limitations. AHP assumes linear independence of criteria and alternatives. If there is dependence among the criteria, analytic network process (ANP)
(Saaty, 2001) is more appropriate; yet ANP requires far more comparisons which may be formidable in practical decision environment. We were able to acquire the cooperation of the decision-making team to structure the model and apply it. We attribute our success mainly to the ease of use of AHP and the existence of easy-to-use commercial software **Expert Choice**.

We needed a methodology that is well supported with powerfully developed software conducive to real-life applications easily understandable by the managers. AHP would be appropriate whenever a goal is clearly stated and a set of relevant criteria and alternatives are available. When there are numerous criteria involved, AHP is one of the very few multiple criteria approaches capable of handling so many criteria, especially if some of the criteria are qualitative. With **Expert Choice** software, AHP enables sensitivity analysis of results which is very important in practical decision-making. This study showed the researchers that AHP can be used to manage complex problems to evaluate advanced manufacturing technologies. For future research it would be interesting to see comparative evaluations of ANP and AHP.

**References**


