DECISION-MAKING FOR FLEXIBLE MANUFACTURING SYSTEMS’ TECHNOLOGY CHOICE

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Abstract
The purpose of this paper is to present a method for decision-making support for technology’s choice in Flexible Manufacturing Systems (FMS). The object of the research is an automated manufacturing cell of the automotive industry. The research method is the qualitative-quantitative modeling. In the qualitative part, specialists in automation engineering created three technological scenarios for the implementation of the FMS. In the quantitative part of the research, six members of the management team used a multicriteria decision support method to distribute importance among competitive priorities and to assess how much each technological scenario can influence each competitive priority. The research also proposes two calculation methods for the final merit of the scenarios. According to both methods, the best scenario was the third one, based on the use of robots. The study also concluded that the adoption of the third scenario is better than doing nothing, i.e., continuing with the current manual installation.

Keywords:
Flexible manufacturing system, FMS, automation, multicriteria, decision-making, robots.

1 INTRODUCTION
Competition in the manufacturing market intensified since the 1960s when cost and quality became the main concerns of manufacturers. Until then, the only concern was to guarantee the volume of production demanded by the market. Later, flexibility and dependability also became critical dimensions of competition for the manufacture [1], which allowed operating in the current business environments, uncertain and turbulent [2].

Manufacturing companies have introduced the so-called Flexible Manufacturing System (FMS) to gain flexibility and dependability. FMS’s break the classic trade-off between dependability and quality, because FMS reduces variability in production and at the same time increases the reliability of deliveries [3]. Although it requires high initial investment, which raises the cost, the FMS can contribute to the competitiveness of a company in turbulent markets, since it adds other dimensions of competition that can compensate and surpass the cost increase [4]. In short, FMS’s increase manufacturing competitiveness in the industry, not only with improvements in overall productivity and final product quality but also by reducing vulnerabilities due to variations in demand and product mix and shorter lead times required by customers [5].

An FMS is a manufacturing system with the ability to react to changes, predicted or not. FMS’s provide various types of flexibilities. Among other types, the machine flexibility is the capacity to modify the system to produce new products and new combinations of products; the routing flexibility is the ability to use multiple devices to perform the same operation; and the volume flexibility is the capacity to change the lot size without changing the cost [6].

The implementation of an FMS involves a high capital investment. To justify the investment, techniques based on principles of economic engineering are insufficient. Other methods, based on qualitative strategic assessment, should be used to justify the adoption of FMS. In general, a corporate strategy plan is more concerned with productivity gains, not just with economic factors. The evaluation of an FMS is a strategic decision based on multicriteria, not just on a single cost reduction [7]. The decision involves multiple strategic dimensions, such as cost, quality, flexibility, and dependability [8]. Among many other strategic advantages, reducing the variability of the automated process, or ensuring timely delivery can bring more significant gains than just reducing costs. Authors [5, 7, 9, 10, 11, 12] argue that the economic justifications for FMS investments alone cannot make the investment feasible. Usually, only financial reasons hide many of the benefits that the FMS technology can provide.

The purpose of this article is to present a method to support the decision to choose the technology for the implementation of an FMS. The research question is: how to evaluate options for choosing the technology for an FMS? The research method is the quantitative modeling. The specific objectives are: among the competitive dimensions in manufacturing presented in the literature, to choose and prioritize the most important for the case; formulate a method to evaluate options for technology choice in FMS, and apply the method in a real case.

2 FMS
An FMS is usually composed of computer-controlled machine tools that can simultaneously process average volumes of an intermediate variety of parts supported by automated material handling devices. FMS technology shows more efficiency in balancing volume and variety of parts [13]. Another definition for FMS is an arrangement of automated machines interconnected by an automatic material conveying and handling system, controlled by a central computer. A central computer controls devices operations, materials transport, communication, and transfer systems, including the inspection [4]. An FMS can also be understood as an automated manufacturing cell, composed of processing stations (usually machine tools), interconnected by an automated material handling and storage system and controlled by a distributed industrial computing system. The automated cell can process various types of parts simultaneously in the different workstations, adjusting automatically to the mix and the variations of the market demand [14].

Cellular layouts are best suited for mid-volume and mid-variety range operations. Below the mid-range, it is worth a job-shop type system. Above, a flow-shop type system [14]. For high variety and low volume, a discrete automation fits better, as in job-shop applications. For high volume and low variety, as in flow-shop applications, transfer automation fits better. Finally, in compromising situations, as in cellular manufacturing, an FMS provides better the production requirements [4].
Reciprocals

2, 4, 6

7

5

3

1

Intensity of studies showed that the dimensions of cost, quality, called strategic dimensions in manufacturing. Empirical sorting, which defines the possible configurations; and the internal rate of return. The decision requires two steps: the methods, such as calculations of return periods and intangible and cannot be estimated by purely economic improve product quality [15]. Most of these benefits are for new products development, reduce dues dates, and

Figure 1 illustrates the application of FMS according to the product variety versus production volume ratio.

Figure 1. Relationships between the type of automation, volume, and variety in manufacturing.

Five types of layouts can support FMS [4]: (i) line type, with working centers sequentially positioned and only direct flux of materials, and separate points of load and unload materials to and from the system; (ii) loop type, with working centers positioned in cellular format and circulation of the material, with a single point of load and unload; (iii) ladder type, in which the working centers are positioned pairwise, facing each other, allowing materials to circulate between and around, with a single point of load and unload; and (iv) open field type, in which AGV moves materials freely across all stations, with a single point of load and unload; and (v) robot-centered, in which the working stations are positioned around one or more robots, allowing any movement.

2.1 FMS and multicriteriality

Cost reduction is not the only contribution of FMS’s to the competitiveness of manufacture [7]. FMS also reduce set-up times, increase production flexibility [9], reduce lead times for new products development, reduce dues dates, and improve product quality [15]. Most of these benefits are intangible and cannot be estimated by purely economic methods, such as calculations of return periods and internal rate of return. The decision requires two steps: the sorting, which defines the possible configurations; and the choice, which judges them according to their performance in multiple criteria [16]. Multicriteria decisions arise abundantly in industrial management. The decision-making process is complex and generally with conflicting objectives and multiple alternatives. Such processes requires a group decision and involves high risk. The consequences of the choices are severely subjected to uncertainties [17, 18]. In this study, we present the results of a multi-criteria mathematical model that can help in the process of selection and prioritization of alternatives [19]. The choice and quantity of criteria are fundamental to the quality of the decision. Few criteria can lead to the absence of significant aspects; too much criteria can divert attention from important points. One way to rationalize the number of criteria is to discard those indifferent to the alternatives. Another feature that deserves attention in the multicriteria decision is the independence between criteria. Two criteria are mutually independent when variations in one criterion do not affect the other. In short, if the criteria are objective and independent, multicriteria evaluation is useful in the decision-making process [20]. Multicriteria methods are classified according to the principles of two schools, American and European. The American school considers that the alternatives of a problem must be clear, objective and independent for total comparability. The European school admits that solutions may not be comparable or objectively separable, assuming ambiguous assessments [21]. This study relies only on the American school. Within this school, interests the AHP (Analytic Hierarchy Process). AHP is the most cited and applied method found in the literature [22, 23] and is suitable to deal with modeling of production, logistics, and manufacturing problems [24]. The literature widely describes AHP, and it would become tedious to repeat it. We only point out that the decision-making criteria are pairwise compared, relying on a fundamental scale, regarding the ability in solving the decision problem. The output of this step is a value function. The value function helps to calculate the merit and to rank the alternatives. The decision-maker chooses the option of higher rank. The AHP also calculates a consistency ratio CR, the probability that the choice was based on random, non-rational criteria. If CR > 0.1, this is the case and the decision-maker must redo the judgment [25]. Table 1 shows the fundamental scale [26].

<table>
<thead>
<tr>
<th>Intensity of importance</th>
<th>Definition</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Equal Importance</td>
<td>Two activities contribute equally to the objective</td>
</tr>
<tr>
<td>3</td>
<td>Moderate importance</td>
<td>Experience and judgment slightly favor one activity over another</td>
</tr>
<tr>
<td>5</td>
<td>Strong importance</td>
<td>Experience and judgment strongly favor one activity over another</td>
</tr>
<tr>
<td>7</td>
<td>Very strong importance</td>
<td>An activity is favored very strongly over another; its dominance demonstrated in practice</td>
</tr>
<tr>
<td>9</td>
<td>Extreme importance</td>
<td>The evidence favoring one activity over another is of the highest possible order of affirmation</td>
</tr>
<tr>
<td>2, 4, 6, 8</td>
<td>Intermediate values</td>
<td>Used for graduation in slightly different judgments</td>
</tr>
</tbody>
</table>

Table 1. Fundamental scale [26].

The set of multicriteria used in this study includes the so-called strategic dimensions in manufacturing. Empirical studies showed that the dimensions of cost, quality, flexibility and delivery are the main strategic dimensions in a manufacturing strategy. Other dimensions may eventually have importance in particular cases, but
usually, contain elements present in these four primitive dimensions [27].

3 THE RESEARCH

The research object was a manufacture of the automotive industry. The research method is quantitative modeling. The object of study was the starting engine manufacturing cell of a Brazilian company of the automotive industry. The steps were: (i) supported by specialists, propose scenarios for the implantation of FMS in the cell; (ii) a group of experts from the company calculated a value function according to the four criteria; and (iii) the experts judged the scenarios according to the value function.

3.1 Alternatives for the decision

Experts of the company supported by equipment vendors developed three scenarios for the implementation of FMS.

In scenario 1, the layout is ladder type, transport by conveyor and pallets, a single direction of movement, load and unload of machines by pneumatic devices, load and unload (LO/UL) of materials to and from the system in different points. The working stations (WS) are four CNCs with automatic inspection, central tool magazine, temporary storage area (TSA) AS/RS with capacity for four hours of production, sequencing and control by PLC and interconnection by FieldBus. The main advantages are: (i) multiple orders executed simultaneously; (ii) low cost, mainly due to pneumatic devices; and (iii) low set-up time due to the centralized tool magazine. The main disadvantages are: (i) delays, as the transport system has a single direction of movement; (ii) more maintenance, mainly due to pneumatic systems; and (iii) greater variability due to pneumatic systems and the centralized tool magazine.

In scenario 2, the layout is open field, transport by AGV and containers, free movement, load and unload of machines by the AGV, and load and unload of materials at the same point. WS are four CNCs with automatic inspection, individual tool magazines, carousel type temporary storage area with capacity for eight hours, sequencing and control by PLC and wireless interconnection. The main advantages are: (i) more flexibility in processing parts; (ii) more accuracy due to AGVs; and (iii) instant set-up due to individual magazines. The main disadvantages are: (i) excessive dependence on the AGVs, whose autonomy is only two hours; (ii) higher cost; and (iii) possible conflicts in inputting and outputting material by the same point.

In scenario 3, the layout is robot-centered, the transport is by robotic arms (RB) and containers, free movement, load and unload of machines by a circular conveyor and by the robotic arms and input and output of materials at the same point. The WS are four CNCs with automatic inspection, central tool magazine, TSA is AS/RS with capacity for two hours, sequencing and control by PLC and network interconnection by FieldBus. The main advantages are: (i) low cost; (ii) more flexibility and precision due to robots; and (iii) reduced set-up time due to the central tool magazine. The main disadvantages are: (i) small storage capacity; (ii) possible delays for the lack of availability of robots; and (iii) potential conflicts in inputting and outputting material by the same point.

Figure 2 shows the three scenarios.

Table 2 synthesizes the differences among the alternatives.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Layout Type</th>
<th>Transport</th>
<th>Load/Unload</th>
<th>Working Stations</th>
<th>Storage Area</th>
<th>Control</th>
<th>Interconnection</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ladder</td>
<td>Conveyor</td>
<td>LO/UL</td>
<td>4 CNCs</td>
<td>AS/RS</td>
<td>PLC</td>
<td>FieldBus</td>
</tr>
<tr>
<td>2</td>
<td>Open Field</td>
<td>AGV</td>
<td>LO/UL</td>
<td>4 CNCs</td>
<td>AS/RS</td>
<td>PLC</td>
<td>Wireless</td>
</tr>
<tr>
<td>3</td>
<td>Robot-Centric</td>
<td>RB</td>
<td>LO/UL</td>
<td>4 CNCs</td>
<td>AS/RS</td>
<td>PLC</td>
<td>Network</td>
</tr>
</tbody>
</table>

Figure 2. Scenarios 1, 2, and 3 (a, b, c) for the decision.
To calculate the merits of the alternatives, the six experts made pair-wised comparisons among the scenarios according to the competition dimensions of the manufacturing. For the pair-wised comparison, each respondent answered the following question: How do you classify scenario $i$ in comparison with scenario $j$ regarding the ability to influence the competitive dimension? All CRs were below 0.1. Table 4 shows the results.

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Dimensions</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>quality</td>
<td>delivery</td>
<td>cost</td>
<td>flexibility</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>20%</td>
<td>25%</td>
<td>37%</td>
<td>38%</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>41%</td>
<td>31%</td>
<td>35%</td>
<td>18%</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>39%</td>
<td>44%</td>
<td>27%</td>
<td>44%</td>
<td></td>
</tr>
</tbody>
</table>

The percentage merit of each scenario is calculated. To do so, we retrieve the vector of priorities for the four dimensions of competition: quality = 38%; Delivery = 28%; Cost = 23%; and flexibility = 12%. The percentage merit of each alternative is the sum of the products of the capacities of each scenario in influencing a dimension times the priority. Table 5 presents the merits of the alternatives. The sum of the merits reaches 100%, as expected.

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Calculation</th>
<th>Merit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$(0.20 \times 0.38) + (0.25 \times 0.28)$ + $(0.37 \times 0.23) + (0.38 \times 0.12)$</td>
<td>0.275</td>
</tr>
<tr>
<td>2</td>
<td>$(0.41 \times 0.38) + (0.31 \times 0.28)$ + $(0.35 \times 0.23) + (0.18 \times 0.12)$</td>
<td>0.340</td>
</tr>
<tr>
<td>3</td>
<td>$(0.39 \times 0.38) + (0.44 \times 0.28)$ + $(0.27 \times 0.23) + (0.44 \times 0.12)$</td>
<td>0.385</td>
</tr>
</tbody>
</table>

The second method of calculating the merits of the scenarios makes use of qualitative evaluations of the respondents about the effectiveness of each scenario in each dimension of competition. For all scenarios and dimensions, given scenario $i$ and dimension $j$, each respondent answered the following question: in your opinion, how much the scenario $i$, if applied to the cell under study, would contribute to create competitive advantage related to dimension $j$? The responses were quantified according to a scale: $1 = \text{very high contribution}$; $0.75 = \text{high contribution}$; $0.5 = \text{fair contribution}$; $0.25 = \text{low contribution}$; and $0 = \text{very low contribution}$.
Table 7 shows the percentage merits of the scenarios.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Merit</th>
<th>Percentage merit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.757</td>
<td>30.8%</td>
</tr>
<tr>
<td>2</td>
<td>0.822</td>
<td>33.4%</td>
</tr>
<tr>
<td>3</td>
<td>0.878</td>
<td>35.7%</td>
</tr>
</tbody>
</table>

With the averages of the evaluations of the three scenarios, referring to the four strategic dimensions, the merit of each alternative was calculated. The merit of a scenario is given by the sum of products [mean of the assessment in dimension x importance of dimension], resulting in a linear combination.

Equations 2, 3, and 4 calculate the merits of the scenarios.

Merit of scenario 1 = (0.71 x 0.23) + (0.79 x 0.38) + (0.67 x 0.28) + (0.88 x 0.12) = 0.756

Merit of scenario 2 = (0.63 x 0.23) + (0.88 x 0.38) + (0.83 x 0.28) + (0.92 x 0.12) = 0.822

Merit of scenario 3 = (0.58 x 0.23) + (0.92 x 0.38) + (1.00 x 0.28) + (0.96 x 0.12) = 0.878

Table 8 shows results.

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Priority</th>
<th>Scenario 3</th>
<th>Current situation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quality</td>
<td>38%</td>
<td>0.92</td>
<td>0.54</td>
</tr>
<tr>
<td>Delivery</td>
<td>28%</td>
<td>1</td>
<td>0.37</td>
</tr>
<tr>
<td>Cost</td>
<td>23%</td>
<td>0.58</td>
<td>0.71</td>
</tr>
<tr>
<td>Flexibility</td>
<td>12%</td>
<td>0.96</td>
<td>0.54</td>
</tr>
<tr>
<td>Merit</td>
<td>87.8%</td>
<td>0.878</td>
<td>0.54</td>
</tr>
</tbody>
</table>

The study concludes that the better alternative of choice, scenario 3, is also better than do nothing.

5 FINAL REMARKS

The purpose of this study was to develop and test a decision support method for choosing Flexible Manufacturing Systems (FMS) technology. The developed method uses the main dimensions of manufacturing competition and relies on the judgment of three technological alternatives built by FMS specialists. The method pointed to the third alternative as the best. As none of the alternatives is better in all dimensions of judgment, it was necessary to develop a value function and to check which alternative maximizes this function. The purpose of this function is to inform how much each alternative of decision can add to the capacity of competing that the manufacture provides to the company to face the competition in the industry.
As a suggestion of new research, we point the use of other multicriteria methods and other competitive dimensions. It would also be important that executives from technology vendors to take part in new research, so vendors became aware of the competitive capacity that their equipment can add to the industry. Finally, we suggest the replications of this study in other industries that also use FMS. We suggest two types of new applications. The first is according to the same criteria. The second is according to new criteria, retrieved from further empirical cases of the literature. The objective of further research is to create a list of possible viable criteria for supporting the decision of implementing FMS in the manufacture.

6 ACKNOWLEDGMENTS
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7 REFERENCES