SELECTION OF MATERIAL HANDLING EQUIPMENT FOR FLEXIBLE MANUFACTURING SYSTEM USING FAHP

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ABSTRACT

Material handling equipment plays an important role in the design and development of advance manufacturing systems (AMS) like flexible manufacturing systems. Material handling equipments affects the performance and productivity of these advance manufacturing systems. So it becomes very important to select a right kind of equipment while designing the high end manufacturing systems like FMS. In this paper an attempt has been made to select the most appropriate material handling equipment for the design and development of FMS. The proposed model has been build on the basis of material handling attributes and sub attributes which are critical for material handling equipment selection.

KEYWORDS

Analytical hierarchy process, material handling equipments, multi criteria decision making, optimization and flexible manufacturing systems.

1. INTRODUCTION

Material handling technology is becoming the most important criteria to all type of the productive and non productive businesses operating in today’s competitive society. So material handling equipment selection is an important function of a material handling system. Use of proper material handling equipment can enhance the production process, and improves system flexibility (Tuzkaya et al., 2010). Today’s dynamic and global competition in the market due to the rapid growth in technology shortened product life cycle and high quality product expectation by the customers at lowest price makes the concerns more competitive at national and international level (Raj et al. 2008). To overcome these difficulties importance of material handling equipments cannot be ignored. In this modern era of technology, availability of wide range of material handling equipment options, selection of material handling equipment is a complex and tedious task for the decision maker. Therefore, MHE selection problem can be considered as multiple criteria decision making (MCDM) problem.

According to the Sujono and Lashkari (2007) in a typical manufacturing facility material handling accounts for 25% of all employees, 55% of all company space, 87% of the production time and 15-75% of the total cost of the product. Therefore, material handling is considered as a first and active element of the advance manufacturing system. In the current there are many MCDM techniques used for supporting the decision maker views in numerous and conflicting evaluations. Such type of methods can also be used for ranking and conflicting attributes solutions. The most popular MCDM methods are analytic hierarchy process (AHP), analytic network process (ANP), data envelopment analysis (DEA), simple multi attribute ranking (SMART) and TOPSIS etc. (Goodwin and Wright, 2009).
The material handling system (MHS) play a crucial and effective role in flexible manufacturing systems (FMS) environment. Basically FMS is an integrating computer controlled system of automated material handling equipments and numerically controlled (NC) machine tools which can simultaneously process medium sized volumes of a variety of parts. The key characteristics of FMS are to meet the production requirement by producing variety of parts and volume through proper utilization of machines, space, reduced labor cost, flexibility and high quality products with minimization of manufacturing lead time and the parts can also be produced at lower cost by integrating hardware and software of material handling equipments like automated guided vehicle system (AGVS), industrial robotics, automated conveyors, fork lift trucks and cranes etc. A technique is required to evaluate material handling equipments ranking to deal with fuzzy conflicting criteria attributes like automation, cost and load carrying capacity etc for different material handling systems. This paper predicts the material handling equipment to be selected for the purpose of material handling in FMS environment using fuzzy analytical hierarchical process (FAHP).

The main objectives of this research are as follows:

- To identify and rank the attributes which are supportive in the selection of material handling equipment’s.
- To establish relationship between these attributes through FAHP model.
- To identify most significant material handling attributes on the basis of developed FAHP model.
- To suggest directions for future research.

The paper has been organized as follows:

In the remainder of this paper, literature review on material handling equipment in FMS environment is presented in section 2. Fuzzy Analytic Hierarchy Process (FAHP) Method is discussed in section 3. Section 4 discusses the methodology for the selection of material handling equipment. This is followed by an example in section 5. At last, discussion and conclusions are presented in section 6 and 7 respectively.

2. LITERATURE REVIEW

It is evident from the literature that material handling (MH) is an activity which is used to provide the right amount of the right material at the right place, at the right time, in the right sequence, in the right position and at the right cost. Due to the high competition selection of material handling equipment has become a very complex and tedious task for the decision makers. Hence proper selection of appropriate material handling equipment has become a most important parameter for modern manufacturing concerns (Tompkins, 2010). Many studies have been conducted to address the material handling equipment selection problem. In this regard many researchers have applied various models to predict the selection of the various materials handling equipment’s like integer optimization, simulation and modeling, fuzzy genetic support system, holonic, knowledgebase, SAW, TOPSIS, Grey AHP, AHP/M-GRA and dynamic programming. Chan et al. (2001) presented a material handling equipment selection model for the development of an intelligent system called material handling equipment selection advisor (MHESA). Bhattacharya, et al. (2002) discusses the method for material handling equipment selection under multi criteria decision making (MCDM) environment. Chu & Lin. (2003) have developed a fuzzy TOPSIS method for robot selection. Kulak et al. (2004) have selected multi-attribute material handling equipment selection using Information Axiom. Babiceanu et al. (2004) provided a framework for the control of automated material-handling systems using the holonic manufacturing approach. Kulak (2005) developed a decision support system named fuzzy multi-attribute material handling

In this study, FAHP has been used to select the appropriate material handling equipment (MHE).

3. Fuzzy Analytic Hierarchy Process (FAHP) Method

The Fuzzy Analytic Hierarchy Process (FAHP) is an advanced multi-criteria decision-making approach and it was introduced by Saaty (1994 and 2000). Bevilacqua et al., 2004 advocated that AHP is a useful and flexible multi-criteria decision making (MCDM) tool which deals with complex problems of qualitative and quantitative aspects of a problem in to a hierarchy. Nowadays, there are many MCDM methods are in use. The combination of Fuzzy AHP is broadly used for solving complex decision making problems. Decision makers use a fundamental 1-5 scale of absolute numbers to make pair wise comparison in the Saaty’s approach. The advantage of fuzzy AHP method is that it provides to work at certain intervals in judgments rather than certain absolute values. Due to the popularity of this method rather than AHP decision makers use natural linguistic as well as certain numbers to evaluate criteria and alternatives. FAHP method is frequently used due to ability of solving the complex problems in different areas such as supplier selection and evaluation (Sun, 2010; Chamodrakas and Martakos, 2010; Krishnendu et.al., 2012; Kılınççı and Önal, 2011); evaluating performance of national R&D organizations (Jyoti and Deshmukh, 2008); optimal hospital locatin selection; marketing strategy selection (Mohaghar et.al., 2012) and personnel selection problems (Güngör et.al., 2009).

In this method, fuzzy numbers are used for problem solution instead of crisp numbers. Chen and Hwang (1992) have proposed this method. The steps used in this method are as follows:

**Step I:** Conversion of linguistic terms in to fuzzy numbers.

First of all linguistic term will be converted into their corresponding fuzzy numbers. Particularly for this process we consider a five point conversion scales to show the conversion of linguistic terms in to fuzzy numbers. Wenstop et. al. (1976) have also used a conversion scales method for synthesizing and modifying their research works.

**Step II:** Conversion of Fuzzy Numbers in to Crisp Scores.

This step uses a fuzzy scoring approach for conversion in to fuzzy ranking (Chen1985). Conversion process of fuzzy number “M” into crisp score is as follows:

---

27
The value of Max and Min fuzzy numbers can be calculated for the comparison purpose which is as follows:

\[
\mu_{\text{MAX}}(x) = \begin{cases} 
  x, & 0 \leq x \leq 1, \\
  0, & \text{otherwise}
\end{cases}
\]

\[
\mu_{\text{Min}}(x) = \begin{cases} 
  1-x, & 0 \leq x \leq 1, \\
  0, & \text{otherwise}
\end{cases}
\]

Total score of fuzzy number (Mi) is defined as:

\[
\mu_{T}(M) = \frac{\mu_{R}(M) + 1 - \mu_{L}(M)}{2}
\]

**Step III:** Demonstration of the conversion method.

In this process, we have used a 5-point scale for the conversion of fuzzy number into crisp scores by utilizing the linguistic terms like low, below average, average, above average and high as shown in Figure 1.

![Figure 1](image)

Figure 1. Linguistic terms to fuzzy numbers conversion (5-point scale)

<table>
<thead>
<tr>
<th>Linguistic Variables</th>
<th>Fuzzy Numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>M1</td>
</tr>
<tr>
<td>Below average</td>
<td>M2</td>
</tr>
<tr>
<td>Average</td>
<td>M3</td>
</tr>
<tr>
<td>Above average</td>
<td>M4</td>
</tr>
<tr>
<td>High</td>
<td>M5</td>
</tr>
</tbody>
</table>

Then right, left & total score of fuzzy number M are calculates as given below:
\[ \mu_R (M1) = \text{Sup} [\mu max (x) \wedge \mu_{M1} (x)] \]

\[ \mu_L (M1) = \text{Sup} [\mu min (x) \wedge \mu_{M1} (x)] \]

Total score of fuzzy number (Mi) is defined as:

\[ \mu_T (M1) = \frac{\mu_R M1 + 1 - \mu_L M1}{2} \]

Crisp values can also be calculated from Figure 1 for their fuzzy Numbers M1, M2, M3, M4 and M5 as follows:

\[
\mu M1(x) = \begin{cases} 
1-x = 0 \\
0.3 
\end{cases}, \quad 0.0 \leq x \leq 0.3
\]

\[
\mu M2(x) = \begin{cases} 
(x-0) \\
0.25 
\end{cases}, \quad 0 \leq x \leq 0.3
\]

\[
\mu M3(x) = \begin{cases} 
0 - 0.3 \\
0.2 
\end{cases}, \quad 0.3 \leq x \leq 0.5
\]

\[
\mu M4(x) = \begin{cases} 
(x-0.5) \\
0.25 
\end{cases}, \quad 0.5 \leq x \leq 0.75
\]

\[
\mu M5(x) = \begin{cases} 
(x-0.7) \\
0.3 
\end{cases}, \quad 0.7 \leq x \leq 1.0
\]

The right, left and total score for fuzzy numbers can be calculated by using the following formulas as given below:

\[ \mu_R (M1) = \text{Sup} [\mu max (x) \wedge \mu_{M1} (x)] = 0.23 \]

\[ \mu_L (M1) = \text{Sup} [\mu min (x) \wedge \mu_{M1} (x)] = 0.1 \]

\[ \mu_T (M1) = [\mu_R M1 + 1 - \mu_L M1]/2 = 0.115 \]
Calculated Crisp values of right, left and total Score of fuzzy numbers M1, M2, M3, M4 and M5 are shown below in Table 2:

Table 2. Show right left & total score for M1, M2, M3, M4 and M5.

<table>
<thead>
<tr>
<th>Fuzzy Number</th>
<th>μR</th>
<th>μL</th>
<th>μT</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1</td>
<td>0.23</td>
<td>1.0</td>
<td>0.115</td>
</tr>
<tr>
<td>M2</td>
<td>0.39</td>
<td>0.8</td>
<td>0.295</td>
</tr>
<tr>
<td>M3</td>
<td>0.58</td>
<td>0.59</td>
<td>0.495</td>
</tr>
<tr>
<td>M4</td>
<td>0.79</td>
<td>0.4</td>
<td>0.695</td>
</tr>
<tr>
<td>M5</td>
<td>1.0</td>
<td>0.23</td>
<td>0.895</td>
</tr>
</tbody>
</table>

Table 3. Show linguistic variable along with their fuzzy number and crisp score.

<table>
<thead>
<tr>
<th>Linguistic Variables</th>
<th>Fuzzy Numbers</th>
<th>Crisp score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>M1</td>
<td>0.115</td>
</tr>
<tr>
<td>Below average</td>
<td>M2</td>
<td>0.295</td>
</tr>
<tr>
<td>Average</td>
<td>M3</td>
<td>0.495</td>
</tr>
<tr>
<td>Above average</td>
<td>M4</td>
<td>0.695</td>
</tr>
<tr>
<td>High</td>
<td>M5</td>
<td>0.895</td>
</tr>
</tbody>
</table>

4. METHODOLOGY

Fuzzy Analytic Hierarchy Process (FAHP) is a simple multi-criteria decision-making approach to deal with complex, unstructured and multi-attribute problems. It is a most creative decision making tool used in modeling of complex problem. In this approach, identification of the decision hierarchy is the key aspect of FAHP. This process is essential for the formalization of a complex problem in a hierarchical structure. To solve a decision problem with FAHP, there are some steps which are defined below:

1. Determine objective and evaluation of attributes.
2. Determine attribute importance of different attributes with respective to the objective.
3. Compare the alternatives pair wise with respective to others.
4. Determine overall or composite performance scores for the alternatives.
5. Ranking the alternatives.
6. Choosing the highest ranking from the set of alternative

Step 4.1: Determine the objective and evaluate attributes.

Develop a hierarchical structure with an objective at the top level, the attributes at the middle level and the alternatives at the bottom level.
**Objective**

![Decision Tree Diagram](image)

**Step 4.2:** Determine the relative importance of different attributes with respect to the objective. In this step a decision matrix is developed on the basis of expert opinions and their judgments. An attribute compared with it is always assigned value as 1. So that the main diagonal entries of the pair wise comparison matrix can be entered as 1 for calculation purpose as shown in Table 4.

- Assuming M attributes, the pair-wise comparison of attribute \(i\) with attribute \(j\) yields a square matrix \(B_{M \times M}\) where \(a_{ij}\) denotes the comparative importance of attribute \(i\) with respect to attribute \(j\). In the matrix, \(b_{ij} = 1\) when \(i = j\) and \(b_{ji} = 1/b_{ij}\)

**Table 4. Scale of relative importance**

<table>
<thead>
<tr>
<th>Scale of importance</th>
<th>Linguistic variable</th>
<th>Explanation for attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Equal important</td>
<td>Two attributes are equally important</td>
</tr>
<tr>
<td>3</td>
<td>Moderate important</td>
<td>One attribute is moderately influential over the other</td>
</tr>
<tr>
<td>5</td>
<td>Strongly important</td>
<td>One decision attribute is strongly important over the other</td>
</tr>
<tr>
<td>7</td>
<td>Very important</td>
<td>One decision attribute has significantly more influence than the other.</td>
</tr>
<tr>
<td>9</td>
<td>Extremely important</td>
<td>One attribute is absolutely important over the other</td>
</tr>
<tr>
<td>2, 4, 6, 8</td>
<td>Reciprocals</td>
<td>Compromise importance/ intermediate importance between two adjacent judgement 1, 3, 5, 7 and 9</td>
</tr>
</tbody>
</table>

**Table 5. Random Index (RI) values (Saaty 2004)**

<table>
<thead>
<tr>
<th>Attributes (m)</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>RI Values</td>
<td>0.00</td>
<td>0.00</td>
<td>0.58</td>
<td>0.90</td>
<td>1.1</td>
<td>1.2</td>
<td>1.3</td>
<td>1.4</td>
<td>1.4</td>
<td>1.4</td>
</tr>
</tbody>
</table>
• Calculate geometric mean: - It is calculated by multiplying the elements of each row and then dividing by size of matrix. Then, Total geometric mean is calculated by adding geometric mean for each row.

\[
GM_i = \left( \prod_{j=1}^{m} a_{ij} \right)^{\frac{1}{m}}
\]

(1)

\[
w_j = \frac{GM_j}{\sum_{i=1}^{m} GM_i}
\]

(2)

• Calculate normalized weight: - It is calculated for each row by dividing the geometric mean of each row by total geometric mean and then weights obtained are arranged in a matrix denoted by Q2.

• Calculate matrices Q3 and Q4

\[
Q3 = \text{Matrix } Q1_{3X1} \times \text{Matrix } Q2_{3X1}
\]

Where \( Q1 \) = relative importance matrix

\[
Q4 = \text{Matrix } Q3_{3X1} / \text{Matrix } Q2_{3X1}
\]

Where \( Q2 = [w1, w2, \ldots, w_j] \)

• Calculate \( \lambda \text{ max} = \text{Sum of Q4 elements} / \text{No. of Q4 elements} \)

• Calculate consistency Index: CI = (\( \lambda \text{ max} \)-m) / (m-1) \quad \text{Where m = Size of matrix.}

• Calculate consistency ratio: CR = CI / RI

Where RI is random index, which is already specified for specific number of criteria. If value of CR is less than 0.1 then, weights are consistent.

**Step 4.3** This step is used to compare the alternatives pair wise with respect to others and shows the satisfaction level of each attribute.

If there is N number of alternatives, then there will be M number of N x N matrices of judgments since there are M attributes. Develop pair wise comparison matrices by using a scale of relative importance and enter the judgements by using the fundamental scale of the AHP. The remaining procedure is same as shown in step 3.2.

For AHP model, both the relative and absolute modes of comparison can be utilized. The relative mode is used in those cases when decision makers have its prior knowledge of the attributes for different alternatives or when objective data attributes for different alternatives is not available. Similarly the absolute mode is used when data of the attributes for different alternatives are readily available. In case of absolute mode, the value of CI is always equal to 0, since the exact values of consistency are used in comparison matrices.

**Step 4.4** This step is used for finding the overall or composite performance scores for the alternatives by multiplying the relative normalized weight \( (w_j) \) of each attribute with its corresponding normalized weight value for each alternative and summing up over all attributes for each alternative.
Quantitative attributes are generally dealt with some selection problems. If there is any difficulty arises in qualitative attributes or for the qualitative attributes where quantitative attributes values are not available. Generally in such type of problems a ranked value judgment on a fuzzy conversion scale is adopted. A fuzzy set theory is used for deciding the values of its attributes as linguistic terms, its conversion into corresponding fuzzy numbers and than its crisp scores. According to the Chen and Hwang (1992) a numerical approximation method can also be used for conversion of linguistic terms to their corresponding fuzzy numbers. Here a 5-point conversion scale is used as shown in Table 8. In this paper we have considered a 3 point scale for better understanding and representation purpose by using equation 1 as shown in Table 6 and 7. Table 9 has been used to show the 3 different criteria for their fuzzy AHP. This helps the users in assigning the values.

Table 6. Crisp value of fuzzy numbers in 3-point scale

<table>
<thead>
<tr>
<th>Material handling Equipments (Variables)</th>
<th>Material Handling Equipment Selection (Attributes)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Automation</td>
</tr>
<tr>
<td>Auto. Conveyor</td>
<td>0.75</td>
</tr>
<tr>
<td>Robot</td>
<td>0.66</td>
</tr>
<tr>
<td>AGV</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Table 7. Decision making matrix for material handling equipments

<table>
<thead>
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<th>Material handling Equipments (Variables)</th>
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</tr>
</thead>
<tbody>
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</tr>
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<td>0.66</td>
</tr>
<tr>
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</tr>
</tbody>
</table>

Table 8. Linguistic variable along with their fuzzy number & crisp score.

<table>
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<th>Linguistic Variables</th>
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</thead>
<tbody>
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<td>Low</td>
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<td>0.115</td>
</tr>
<tr>
<td>Below average</td>
<td>M2</td>
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</tr>
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<td>M5</td>
<td>0.895</td>
</tr>
</tbody>
</table>

5. ILLUSTRATIVE EXAMPLE

Now, an example is considered to demonstrate and validate the FAHP method for selection of material handling equipments in an industrial application. The detailed steps involved in the application of the FAHP method for selecting optimal material handling equipment are described below:
For this study we choose material handling equipments attributes as an input parameters a shown in Table 9.

Table 9. Various attributes and alternatives for Fuzzy AHP.

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Automation</td>
</tr>
<tr>
<td>Automated Conveyor</td>
<td>Low</td>
</tr>
<tr>
<td>Robot</td>
<td>High</td>
</tr>
<tr>
<td>AGV</td>
<td>High</td>
</tr>
</tbody>
</table>

**Step 1:** The objective is to select right material handling equipments amongst the number of available material handling equipments. Since for this study we choose only three linguistic variables i.e. Low, Average and High on a three point scale as shown in Table 10 and Table 11.

Table 10. Linguistic variables with fuzzy numbers.

<table>
<thead>
<tr>
<th>Linguistic Variables</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>M1</td>
</tr>
<tr>
<td>Average</td>
<td>M2</td>
</tr>
<tr>
<td>High</td>
<td>M3</td>
</tr>
</tbody>
</table>

These fuzzy numbers are then converted in to crisp score by using Table 2 and Table 3.

Table 11. Crisp scores and fuzzy numbers.

<table>
<thead>
<tr>
<th>Linguistic Variables</th>
<th>Fuzzy Numbers</th>
<th>Crisp Score</th>
</tr>
</thead>
<tbody>
<tr>
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</tr>
<tr>
<td>High</td>
<td>M3</td>
<td>0.895</td>
</tr>
</tbody>
</table>

Based on above crisp score decision making matrix (DMM) has been formed which is as follows

\[
\begin{bmatrix}
0.115 & 0.895 & 0.495 \\
0.895 & 0.495 & 0.895 \\
0.895 & 0.895 & 0.895 \\
\end{bmatrix}
\]

**Step 2:** Calculating the relative importance of different attributes with respect to the objective: These attribute requires higher values as a beneficial factor. To make comparative decisions, the relative importance of all possible pairs of attributes with respect to the overall objective of selecting the right material handling equipments is decided. These are arranged into a matrix form of, \( Q_{13x3} \). The judgments on the attributes are entered in the form of matrix as shown in Table 4.

**Consistency Check**

Construct Relative importance matrix. Each attribute is compared with other attributes and weights are assigned based on expert reasoning, using table 4 Diagonal elements are always 1 because compared with it themselves. It is denoted by Q.
Find out the relative normalized weight \( w_i \) of each attributes by calculating the geometric mean of the \( i^{th} \) row and normalizing the geometric means of rows in the comparison matrix:

- **Geometric mean calculation:**

\[
\begin{align*}
\text{GM1} &= \frac{(1 \times 5 \times 3)}{3} = 2.466 \\
\text{GM2} &= \frac{(1/5 \times 1 \times 1/2)}{3} = 0.464 \\
\text{GM3} &= \frac{(1/3 \times 2 \times 1)}{3} = 0.870 \\
\text{Total GM} &= \frac{\text{GM1}+\text{GM2}+\text{GM3}}{3} = 3.80
\end{align*}
\]

- **Normalized Weight calculation:**

\[
\begin{align*}
W_1 &= \frac{\text{GM1}}{\text{GM}} = \frac{2.466}{3.80} = 0.649 \\
W_2 &= \frac{\text{GM2}}{\text{GM}} = \frac{0.464}{3.80} = 0.1210 \\
W_3 &= \frac{\text{GM3}}{\text{GM}} = \frac{0.870}{3.80} = 0.229
\end{align*}
\]

Matrix \( Q_{23x1} \) is written as:

\[
Q_{23x1}= \begin{bmatrix}
0.649 \\
0.1210 \\
0.229
\end{bmatrix}
\]

- **Calculate Q3**

Matrix \( Q_{33x1} \) is written as

\[
Q_3 = Q_1 \times Q_2
\]
Matrix Q₄ is written as

\[
Q₄ = \frac{Q₃}{Q₂}
\]

\[
\begin{bmatrix}
1 & 5 & 3 \\
1/5 & 1 & 1/2 \\
1/3 & 2 & 1 \\
\end{bmatrix} \times \begin{bmatrix}
0.649 \\
0.1210 \\
0.229 \\
\end{bmatrix} = \begin{bmatrix}
1.914 \\
0.36 \\
0.678 \\
\end{bmatrix}
\]

- Calculate λₘₐₓ

\[
λₘₐₓ = \frac{\text{Total sum of } Q₄}{\text{Size of } Q₂} = \frac{3.001}{3} = 3.001
\]

- Calculate CI

\[
CI = \frac{λₘₐₓ - m}{m - 1}, \quad m = \text{size of matrix}
\]

\[
= \frac{(3.001 - 3)}{(3 - 1)} = 0.0005
\]

- Calculate CR

\[
CR = \frac{CI}{RI}, \quad \text{for 3 criteria the value of } RI = 0.00096
\]

The RI is obtained from Table 2 for three attributes used in the decision making in the present example and it is 0.58.

The CR is calculated as CR = CI/RI and in the present example this ratio is 0.00096 which is less than the allowed CR of 0.1 and hence the value is acceptable. Thus, there is a good consistency in the judgments and decision matrix is right.
Step 3: Pair-Wise Comparison: Pair wise comparison of alternative to alternative is performed for each criterion as below:

I) Pair wise comparison matrix for criteria Automation

\[
Q1 = \begin{bmatrix}
AutoConveyor & Robot & AGV \\
1 & 0.495 & 0.895 \\
1/0.495 & 1 & 0.895 \\
1/0.895 & 1/0.895 & 1
\end{bmatrix}
\]

• Geometric Mean Calculation:

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>GM1</td>
<td>( (1 \times 0.495 \times 0.895) / 3 )</td>
<td>= 0.7623</td>
</tr>
<tr>
<td>GM2</td>
<td>= ( (1/0.495 \times 1 \times 1/0.895) / 3 )</td>
<td>= 1.2182</td>
</tr>
<tr>
<td>GM3</td>
<td>= ( (1/0.895 \times 1/0.895 \times 1) / 3 )</td>
<td>= 1.0767</td>
</tr>
<tr>
<td>Total GM</td>
<td>= GM1+GM2+GM3</td>
<td>= 3.05</td>
</tr>
</tbody>
</table>

• Normalized Weights Calculation:

\[
W1 = GM1 / GM = 0.7623/3.05 = 0.2530 \\
W2 = GM2 / GM = 1.2182/3.05 = 0.4840 \\
W3 = GM3 / GM = 1.0767/3.05 = 0.3520
\]

Matrix \( Q_{2x1} \) is written as

\[
Q_{2x1} = \begin{bmatrix}
0.2530 \\
0.4848 \\
0.3520
\end{bmatrix}
\]

• Calculate Q3

Matrix \( Q_{3x1} \) is written as \( Q_{3x1} = Q_{1x1} \times Q_{2x1} \)
Calculate $Q_4$

Matrix $Q_{4_{3X1}}$ is written as $Q_{4_{3X1}} = Q_{3_{3X1}} / Q_{2_{3X1}}$

$$
Q_{4_{3X1}} = \begin{bmatrix}
0.7614 & 0.2530 & 3.074 \\
1.2167 & 0.4848 & 3.005 \\
1.0752 & 0.3520 & 3.053
\end{bmatrix}
$$

Calculate $\lambda_{\text{max}}$

$\lambda_{\text{max}} = \text{Total sum of } Q_4 / \text{Size of } Q_4 = 9.132 / 3 = 3.044$

Calculate CI

$CI = \lambda_{\text{max}} - m / m-1$, \hspace{1.5em} m = \text{size of matrix}$

$= (3.044 - 3) / (3-1) = 0.022$

Calculate CR

$CR = CI / RI$

for 3 criteria the value of RI chosen from Table 2 is 0.58.

$CR = 0.022 / 0.58 = 0.0379$

The value of CR is 0.0379 which is less than the allowed value of CR (0.1), therefore the value is acceptable. Hence Weights are consistent.

II) Pair wise comparison matrix for criteria Robot

$$
Q_1 = \begin{bmatrix}
AutoConveyor & Robot & AGV \\
1 & 0.895 & 0.115 & \text{AutoConveyor} \\
1/0.895 & 1 & 0.115 & \text{Robot} \\
1/0.115 & 1/0.115 & 1 & \text{AGV}
\end{bmatrix}
$$
Geometric Mean Calculation:

Normalized Weights Calculation:

\[ W_1 = \frac{GM_1}{GM} = \frac{0.4686}{5.2012} = 0.090 \]

\[ W_2 = \frac{GM_2}{GM} = \frac{0.5046}{5.2012} = 0.0970 \]

\[ W_3 = \frac{GM_3}{GM} = \frac{4.2280}{5.2012} = 0.8128 \]

Matrix \( Q_{2X1} \) is written as

\[
\begin{bmatrix}
0.090 \\
0.0970 \\
0.8128
\end{bmatrix}
\]

Calculate \( Q_3 \)

Matrix \( Q_{3X1} \) is written as \( Q_{3X1} = Q_{1X1} \times Q_{2X1} \)

\[
Q_{3X1} = \begin{bmatrix}
1 & 0.895 & 0.115 \\
1/0.895 & 1 & 0.115 \\
1/0.115 & 1/0.115 & 1
\end{bmatrix}
\]

\[
\begin{bmatrix}
Automation \\
LoadCarryingcapacity \\
Cost
\end{bmatrix}
\]

\[
\begin{bmatrix}
0.0900 \\
0.0970 \\
0.8128
\end{bmatrix}
\]

\[
\begin{bmatrix}
0.2701 \\
0.2908 \\
2.438
\end{bmatrix}
\]

Calculate \( Q_4 \)

Matrix \( Q_{4X1} \) is written as \( Q_{4X1} = Q_{3X1} / Q_{2X1} \)
Calculate $\lambda_{max}$:

$$\lambda_{max} = \frac{\text{Total sum of Q4}}{\text{Size of Q4}} = \frac{9.00}{3} = 3.00$$

Calculate CI:

$$CI = \frac{\lambda_{max} - m}{m - 1}, \quad m = \text{size of matrix}$$

$$\lambda_{max} - 3 \quad (3.0 - 3) / (3-1) = 0.00$$

Calculate CR

$$CR = \frac{CI}{RI} \quad \text{for 3 criteria the value of RI chosen from Table 2 is 0.58.}$$

$$CR = 0/0.58 \quad CR = 0.0$$

The value of CR is 0.0 which is less than the allowed value of CR (0.1), therefore the value is acceptable. Hence Weights are consistent.

III) Pair wise comparison matrix for criteria Cost

$$Q1 = \begin{bmatrix}
    \text{Automation} & \text{LoadCarryingcapacity} & \text{Cost} \\
    1 & 0.495 & 1 \\
    1 / 0.495 & 1 & 0.895 \\
    1 & 1 / 0.895 & 1
\end{bmatrix}$$

Geometric Mean Calculation

<table>
<thead>
<tr>
<th>GM1</th>
<th>(1 X 0.495 X 1) / 3 = 0.7910</th>
</tr>
</thead>
<tbody>
<tr>
<td>GM2</td>
<td>(1/0.495 X 1 X 1/0.895) / 3 = 0.12182</td>
</tr>
<tr>
<td>GM3</td>
<td>(1 X 1/0.895 X 1) / 3 = 1.0376</td>
</tr>
<tr>
<td>Total GM</td>
<td>GM1+GM2+GM3 = 3.0468</td>
</tr>
</tbody>
</table>

Normalized Weights:

$$W1 = \frac{GM1}{GM} = \frac{0.7910}{3.0468} = 0.2660$$

$$W2 = \frac{GM2}{GM} = \frac{1.2182}{3.0468} = 0.4980$$
W3 = GM3 / GM = 1.0376 / 3.0468 = 0.3406

Matrix Q2_{3x1} is written as

\[
Q2_{3x1} = \begin{bmatrix}
0.2596 \\
0.3998 \\
0.3406
\end{bmatrix}
\]

- Calculate Q3

Matrix Q3_{3x1} is written as

\[
Q3_{3x1} = Q1_{3x1} \times Q2_{3x1}
\]

\[
\begin{bmatrix}
Automation & LoadCarryingcapacity & Cost \\
1 & 0.495 & 1 \\
1/0.495 & 1 & 0.895 \\
1 & 1/0.895 & 1
\end{bmatrix}
\times
\begin{bmatrix}
0.2596 \\
0.3998 \\
0.3406
\end{bmatrix}
= \begin{bmatrix}
0.7981 \\
1.229 \\
1.0469
\end{bmatrix}
\]

- Calculate Q4

Matrix Q4_{3x1} is written as

\[
Q4_{3x1} = Q3_{3x1} / Q2_{3x1}
\]

\[
\begin{bmatrix}
0.7981 \\
1.229 \\
1.0469
\end{bmatrix}
/ \begin{bmatrix}
0.2596 \\
0.3998 \\
0.3406
\end{bmatrix}
= \begin{bmatrix}
3.0743 \\
3.0740 \\
3.0736
\end{bmatrix}
\]

- Calculate \( \lambda_{\text{max}} \):

\[
A_{\text{max}} = \text{Total sum of } Q4 / \text{Size of } Q4 = 9.221 / 3 = 3.073
\]

- Calculate CI

\[
CI = \lambda_{\text{max}} - m / m-1, \quad m = \text{size of matrix}
= (3.073 - 3) / (3 - 1) = 0.036
\]
Calculate CR:

\[ CR = \frac{CI}{RI}, \]
\[ CR = \frac{0.036}{0.58}, \]
\[ CR = 0.062 \]

for 3 criteria the value of RI chosen from Table 2.is 0.58.

The value of CR is 0.062 which is less than the allowed value of CR (0.1), therefore the value is acceptable. Hence Weights are consistent.

**Step: 4**

Matrix is formed for pair wise comparison based on results i.e. weights received from step 4 for different criteria

\[
Q1 = \begin{bmatrix}
0.2530 & 0.090 & 0.2660 \\
0.4840 & 0.0970 & 0.4980 \\
0.3521 & 0.8128 & 0.3406
\end{bmatrix} = \begin{bmatrix}
0.2319 \\
0.3617 \\
0.4047
\end{bmatrix}
\]

Decision of material handling equipments is based on the Higher Ranking

<table>
<thead>
<tr>
<th>Material handling Equipments</th>
<th>Results</th>
<th>Ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>0.2319</td>
<td>R3</td>
</tr>
<tr>
<td>A2</td>
<td>0.3617</td>
<td>R2</td>
</tr>
<tr>
<td>A3</td>
<td>0.4047</td>
<td>R1</td>
</tr>
</tbody>
</table>

Based on their final ranking received through pair wise comparison between alternatives of each attribute A3 (AGV) is a best material handling equipment.

**6. DISCUSSION**

The main aim of this research is to develop a frame work for the selection of appropriate material handling equipment amongst the number of available material handling equipment’s under the given conditions. For this purpose, a model has been prepared to analyze the interaction between various attributes of material handling equipments. This frame work will be useful in understanding the hierarchy of actions to be taken for the selection of different material handling equipment’s on the basis of these attributes. The management and production managers of the manufacturing field can take the idea from these attributes in understanding their relative importance. This model has been developed by using FAHP approach. FAHP is an effective problem solving multi criteria decision making technique. The decision problem may contain various attributes that need to be evaluated by linguistic variables. Fuzzy numbers numerical
values of linguistic variables are used for evaluation. Hence Fuzzy AHP (FAHP) is a well suited technique to deal with such situations very well. The importance of material handling equipments variables is as under:

- Attributes, automation, cost and load carrying capacities are the main attributes of the material handling equipments which has more influence on alternatives.
- The relationship between the attributes and alternatives of material handling equipment’s can be understood by visualization of Figure 2.
- The automated conveyors can only be used for material handling for specific path and application whenever the AGVs can move freely to carry the material within the layout.
- The automated conveyors cannot be easily interfaced with all equipments and machinery used for manufacturing facility whenever AGV can be easily interface with manufacturing facilities.
- Movement of the robots is limited between one work station to the other for material handling. They generally move about their own axis whenever AGVs can easily move between the required work stations.
- Robots have small and limited load carrying capacity whenever the AGVs can carry the heavy load easily.

7. CONCLUSION

In this paper Fuzzy AHP approach has been used for the evaluation of different material handling equipment’s for the FMS environment under the given conditions. The example cited in the paper consists of 3 attributes along with 3 alternatives. This simple example has been presented for the demonstration of proposed methodology.

In this paper, a pair wise comparison was carried out between the various alternatives for each considered attribute and finally weights were obtained. These weights are then utilized for deciding the ranking of material handling equipments as A1 (Automatic Conveyor), A2 (Robot) and A3 (AGV). In the considered example, it is found that the material handling equipment A3 (AGV) is the best alternative among the considered alternatives.

The major limitations of FAHP are as follows:

- Pair wise comparisons are based on the expert opinions and this may lead to biasness.
- Application of Fuzzy AHP is inappropriate in general decision making.
- FAHP fails to capture the uncertainty in the operational environment.
- Decision is based on the comparison ratios. Moreover, uncertainties are used by the decision maker.
- Absolute values are not sufficient to make real life decisions.

So, in future, following work may be carried out:

- More numbers of attributes can be identified for developing FAHP model.
- A comparison can also be executed with other fuzzy MCDM techniques like fuzzy TOPSIS approach which will be beneficial in enhancing the production and flexibility of the organization.
- Sensitivity analysis can be carried out to know the effect of different criterion on the material handling equipment selection.
REFERENCES


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