Prioritization of Variables Affecting the Effectiveness of Material Handling System

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Abstract. In today’s competitive technology environment implementation of advanced manufacturing technologies and its systems like flexible manufacturing system (FMS) has become the necessity of manufacturing organizations. Selection of appropriate material handling equipment based on their variables which affect the effectiveness of material handling system has become the necessity requirement of FMS. Keeping this fact in view, the current paper focuses on identification of different variables like speed of delivery, available space, cost and throughput rate etc. which affects the effectiveness of material handling system and prioritization of these variables using TOPSIS approach. The results of present research will aid to select an effective material handling system for enhancing the required productivity of organisations in an effective manner.

Keywords: Manufacturing; FMS; material handling equipment variables; ranking; TOPSIS

1. Introduction

In today’s modern manufacturing industries material handling technology has become very important from the competitive point of view due to the technological advancement throughout the world. As we know that material Handling (MH) is the flow (i.e. movement) of goods and products from raw source to the final stage of modern manufacturing, distribution, storage, customer’s consumption networking and disposal in a right manner safely. Manual and automated mechanical equipment, systems and related controls and protection of material are used to achieve these roles. Now a day’s material transfer techniques have become more intelligent in comparison to the earlier days by the technological modernization and automation existence. In this, knowledge based competitive era customers are insisting the industries for producing variety of goods at the minimal and optimized cost with time (Raj et al. 2008). MH acts as a fundamental quantity of manufacturing expenses and can be recognized as critical decision for the material flow arrangement. Tompkins et al, (1996) stated that MH movements account 50% of operative cost and 20-50% of entire operational expenditures in a manufacturing system. Appropriate arrangement as well as right choice of equipment’s has a significant function for storing, loading and unloading services. Asfahl (1992) stated that MH involves around 87% of overall production time, 55% of an organization space, 15-75% of product cost and 25% time of overall workforces. In recent years various authors (Chu, 2002, Tew et al; 1994) have enumerated that MH involves 35% of entirely workforces, 45% of entire organization space and 80-90% of production time. Modern materials handling equipments like robots, automated guided vehicles (AGVs) and automated pick and place systems are in very hot demand for safe and sound environment. Similarly Ballou, (1993) also suggested that in case of logistics activities as per situations and areas accounts for 12% to 40% of its total costs. Groover (2001) illustrated that
MH involves 20-25% of manufacturing costs according to MHIA. Sule (1994) and Sujono & Lashkari (2007) stated that MH involves 30-75% of total product cost and well-organized MH can reduce the operational cost of a manufacturing system by 15-30%.

The material handling cost (15-75%) has forced the manufacturing managers and their management to analyze their material handling system and associated cost. In view of this, MH equipment’s efficiency has to be analyzed. The number of variables can also affect the MH system effectiveness. These variables need to be peritonised so as to augment the material handling system effectiveness. For this purpose, TOPSIS approach has been used for the prioritization of variables affecting the material handling system effectiveness.

2. Literature review

Literature analysis shows that programmed M.H is a key component of productive and non productive organizations with time. Asef-Vaziri and Laporte (2005) stated that MH creates the production movement possible by offering dynamism to the stagnant components like materials, products, equipments, system layout and human resources. Tompkins et al. (1996) stated that about 80-95% of entire interval is consumed amongst buyer’s order and delivery. In respect to this changing business environment, automatic M.H equipment’s such as conveyors, mobile and stationary robots, AGVs are the prime requirements to compensate the loss between orders and product distributions at a fast pace. Ballou (1993) stated that storing and managing the products are necessary for the logistics operation and its associated cost attributes to 12% to 40% of the total cost. Moreover, MHIA assessed that handling cost results into 20-25% of manufacturing costs. Cost of material handling consists of 35-65% of total product cost. Proficient handling of material handling can reduce the operational cost of a manufacturing system by 20–35%. Chan and Swarankar (2006) stated that high demand of product range and a lesser amount of price for merchandise and service are most important variables for sustaining a market share.

Pramod & Banwet (2010) advocated that proper supply and transport results into cost minimization along with the maximization of speed delivery. MH equipment’s used to accomplish the work should be flexible enough to deal the different shape and size parts. Flexibility in material handling condenses labour cost, lead time and safeguards good quality (Eade, 1989). Enhancement of vehicle capacity reduces the average throughput time along with the production output rate augmentation (Van der Meer, 2000). The prime objective of material movement route is to reduce quantity of vehicles and minimization of overall vehicle travel time (Akturk and Yilmaz, 1996). Automation has become a major need for the material handling system in logistics system. Proper distribution management leads to enhancement of efficiency, profitability and low cost (Barbera et al., 2005). Space requirement has a significant position in the automated M.H equipments selection. Plant layout should be planned with an aim to reduce the material handling cost, time and capitalize production rate flexibility (Malakooti and D'Souza, 1987). Ozden (1988) recommended different approaches in order to reduce the production sequence time and proper arrangement of multiple-load carrier functions. Muller, (1983) stated that overall expenditure of material handling may reduced by implementing right execution of different techniques and strategies such as enhancement in product lifespan, reduction of manufacturing time, working area, equipments utilization and minimization of capital expenditures. Table 1 shows the variables which influence the MH system effectiveness.

| Variables                  | Notation |
|----------------------------|----------|
| Speed of delivery          | V1       |
| Available space            | V2       |
| Flexibility                | V3       |
| Number of machines         | V4       |
| Number of operations       | V5       |
3. TOPSIS Approach

The TOPSIS technique is the most popular multi-criteria decision making approach in the area of decision sciences. The main use of TOPSIS approach is to prioritize the different variables concerned related to a system. It consists of following steps:

- Define main objective and its related attributes.
- Prepare a decision matrix \( (M_{ij}) \). This matrix represents the attribute by row \((i)\) and corresponding attribute by column \((j)\).
- Decision matrix \( (M_{ij}) \) is standardized by using the following equation:

\[
D_{ij} = \frac{M_{ij}}{\sqrt{\sum_{i,j} (M_{ij}^2)}}
\]

(1)

This matrix is known as standard matrix.

- Determine the weights of each attribute in such a way that \( \sum w_k = 1 \). Here, \( w \) is the weight of respective attribute. Normalized weight is computed by using the following equation:

\[
\text{Normalized weight} = \frac{\text{Sum total of individual significance}}{\text{Total significance}}
\]

(2)

- Determine the weighted normalized matrix by multiplying the different elements of \( (D_{ij}) \) with its consequent weight. This can be represented by the following equation:

\[
W_{ij} = w_k D_{ij}
\]

(3)

- Determine the ideal positive attribute. This attribute will have maximum value in weighted normalized matrix. It is shown by \( P \).

- Determine the ideal negative attribute. This attribute will have minimum value in weighted normalized matrix. It is shown by \( N \).

- Compute the distance of weighted matrix from ideal positive attribute and ideal negative attribute.
\[ D_p = \sqrt{\sum_{j=1}^{k}(W_j P)^2} \]  
(4)  
\[ D_n = \sqrt{\sum_{j=1}^{k}(W_j N)^2} \]  
(5)  
- Compute the relative closeness of an attribute to the solution by using the following equation:
\[ Y = \frac{D_n}{D_n + D_p} \]  
(6)  
- Rank the alternatives based on the Y values.

4. Application of TOPSIS on MHE Effectiveness Variables Prioritization

After performing the extensive literature review on the MH system, variables affecting the MH system effectiveness are enlisted in Table 1. Afterwards, a questionnaire was prepared using Likerts scale (1-5 scale). The questionnaire was sent to different northern Indian manufacturing organizations. In the questionnaire, respondents were requested to indicate the importance of MHS implementation variables. 80 filled questionnaire responses were received and three questionnaires were incomplete. So, 77 questionnaires were used for TOPSIS analysis. Afterwards, data is presented in the form of frequency table (Table 2).

| Notation | Rating |
|----------|--------|
|          | 5      | 4      | 3      | 2      | 1      |
|          | Most Important | Very Important | Important | Somewhat important | Least important |
| V1       | 13     | 15     | 30     | 14     | 5      |
| V2       | 12     | 18     | 22     | 20     | 5      |
| V3       | 18     | 22     | 19     | 17     | 1      |
| V4       | 8      | 15     | 17     | 25     | 12     |
| V5       | 15     | 17     | 19     | 18     | 8      |
| V6       | 17     | 20     | 25     | 15     | 0      |
| V7       | 14     | 15     | 25     | 19     | 2      |
| V8       | 17     | 20     | 22     | 18     | 0      |
| V9       | 16     | 19     | 22     | 20     | 0      |
| V10      | 13     | 15     | 25     | 23     | 1      |
| V11      | 11     | 11     | 19     | 30     | 6      |
| V12      | 13     | 18     | 17     | 26     | 3      |
| V13      | 16     | 20     | 20     | 19     | 2      |

Table 2. Collected response survey data
In the next step of TOPSIS methodology, data available in Table 2 is normalized by equation (1). Normalized data is epitomized in Table 3.

Table 3. Normalized survey data

| Variables | Rating | Most Important | Very Important | Important | Somewhat important | Least important |
|-----------|--------|----------------|----------------|----------|--------------------|-----------------|
| V1        | 2.9782 | 3.2985         | 10.5970        | 2.4912   | 1.2876             |
| V2        | 2.5377 | 4.7498         | 5.6989         | 5.0841   | 1.2876             |
| V3        | 5.7097 | 7.0954         | 4.2506         | 3.6733   | 0.0515             |
| V4        | 1.1279 | 3.2985         | 3.4028         | 7.9439   | 7.4164             |
| V5        | 3.9651 | 4.2367         | 4.2506         | 4.1181   | 3.2962             |
| V6        | 5.0930 | 5.8640         | 7.3591         | 2.8598   | 0.0000             |
| V7        | 3.4540 | 3.2985         | 7.3591         | 4.5884   | 0.2060             |
| V8        | 5.0930 | 5.8640         | 5.6989         | 4.1181   | 0.0000             |
| V9        | 4.5114 | 5.2923         | 5.6989         | 5.0841   | 0.0000             |
| V10       | 2.9782 | 3.2985         | 7.3591         | 6.7237   | 0.0515             |
| V11       | 2.1323 | 1.7739         | 4.2506         | 11.4392  | 1.8541             |
| V12       | 2.9782 | 4.7498         | 3.4028         | 8.5921   | 0.4635             |
| V13       | 4.5114 | 5.8640         | 4.7098         | 4.5884   | 0.2060             |
| V14       | 3.9651 | 4.2367         | 5.1925         | 3.2538   | 3.2962             |
| V15       | 5.7097 | 5.2923         | 5.6989         | 4.1181   | 0.0000             |

Afterwards, weights of each attribute are computed by equation (2). Table 4 shows the weight of considered criteria.

Table 4. Rating weight age

| Rating | Most Important | Very Important | Important | Somewhat important | Least important |
|--------|----------------|----------------|----------|--------------------|-----------------|
| Instance of occurrence | 216 | 261 | 325 | 298 | 53   |
| Importance total | 1080 | 1044 | 975 | 596 | 53   |
| Normalized weight for importance | 0.2882 | 0.2785 | 0.2601 | 0.1590 | 0.0141 |
Subsequently, matrix \((D_{ij})\) elements are multiplied with their consequent weights in order to obtain the weighted normalized matrix (Table 5).

**Table 5. Weighted normalized data matrix**

| Variables | Rating          |          |          |          |
|-----------|-----------------|----------|----------|----------|
|           | Most Important  | Very Important | Important | Somewhat important | Least important |
| V1        | 0.8582          | 0.9188   | 2.7567   | 0.3961   | 0.0182   |
| V2        | 0.7312          | 1.3231   | 1.4825   | 0.8085   | 0.0182   |
| V3        | 1.6453          | 1.9764   | 1.1057   | 0.5841   | 0.0007   |
| V4        | 0.3250          | 0.9188   | 0.8852   | 1.2632   | 0.1049   |
| V5        | 1.1426          | 1.1801   | 1.1057   | 0.6549   | 0.0466   |
| V6        | 1.4676          | 1.6334   | 1.9144   | 0.4548   | 0.0000   |
| V7        | 0.9953          | 0.9188   | 1.9144   | 0.7296   | 0.0029   |
| V8        | 1.4676          | 1.6334   | 1.4825   | 0.6549   | 0.0000   |
| V9        | 1.3000          | 1.4741   | 1.4825   | 0.8085   | 0.0000   |
| V10       | 0.8582          | 0.9188   | 1.9144   | 1.0692   | 0.0007   |
| V11       | 0.6144          | 0.4941   | 1.1057   | 1.8190   | 0.0262   |
| V12       | 0.8582          | 1.3231   | 0.8852   | 1.3663   | 0.0066   |
| V13       | 1.3000          | 1.6334   | 1.2252   | 0.7296   | 0.0029   |
| V14       | 1.1426          | 1.1801   | 1.3508   | 0.5174   | 0.0466   |
| V15       | 1.6453          | 1.4741   | 1.4825   | 0.6549   | 0.0000   |

Subsequently, ideal positive solution is chosen. The criterion for choosing the ideal positive solution is that it consists of maximum value in weighted normalized matrix. This value is represented by Q in Table 6.

**Table 6. Table of ideal positive solution**

|               | max Wi1 | max Wi2 | max Wi3 | max Wi4 | max Wi4 |
|---------------|---------|---------|---------|---------|---------|
| Q             | 1.6453  | 1.9764  | 2.7567  | 1.8190  | 0.1049  |

Next, ideal negative solution is chosen. The criterion for choosing the ideal negative solution is that it consists of minimum value in weighted normalized matrix. This value is represented by N in Table 7.

**Table 7. Table of ideal negative solution**

|               | min Wi1 | min Wi2 | min Wi3 | min Wi4 | min Wi5 |
|---------------|---------|---------|---------|---------|---------|
| N             | 0.3250  | 0.4941  | 0.8852  | 0.3961  | 0.0000  |
Afterwards, distance of weighted normalized matrix from the ideal positive and ideal negative solution is computed by using equations (4) and (5). These values are represented by $D^+$ and $D^-$ in Table 8.

Table 8. Distance of ideal positive and ideal negative solution from weighted data

| Variables                  | Notation | $D^+$ | $D^-$ |
|----------------------------|----------|-------|-------|
| Speed of delivery          | V1       | 1.9417| 1.9919|
| Available space            | V2       | 1.9786| 1.1744|
| Flexibility                | V3       | 2.0644| 2.0061|
| Number of machines         | V4       | 2.5832| 0.9712|
| Number of operations       | V5       | 2.2296| 1.1211|
| Safety                     | V6       | 1.6526| 1.9147|
| Material flow path         | V7       | 1.8568| 1.3417|
| Traffic management         | V8       | 1.7718| 1.7399|
| Automation                 | V9       | 1.7399| 1.5614|
| Plant Layout               | V10      | 1.7380| 1.4060|
| Types of material handling systems | V11   | 2.4478| 1.4689|
| Load carrying capacity     | V12      | 2.1826| 1.3830|
| Interface facility with workstation | V13 | 1.9441| 1.5733|
| Cost                       | V14      | 2.1357| 1.1716|
| Throughput rate            | V15      | 1.8006| 1.7684|

In this step of TOPSIS approach, closeness of the attribute to an ideal solution is computed by equation (6). Table 9 shows the relative closeness of variables to ideal solution.

Table 9. Relative closeness to ideal solution

| Variables                  | Notation | $Y$   |
|----------------------------|----------|-------|
| Speed of delivery          | V1       | 0.5064|
| Available space            | V2       | 0.3725|
| Flexibility                | V3       | 0.4928|
| Number of machines         | V4       | 0.2732|
| Number of operations       | V5       | 0.3346|
| Safety                     | V6       | 0.5367|
| Material flow path         | V7       | 0.4195|
| Traffic management         | V8       | 0.4955|
| Automation                 | V9       | 0.4730|
In the last step of TOPSIS approach, data presented in Table 9 are organized in descending order based on the relative closeness of attribute to the ideal solution. Table 10 shows the ranking of variables affecting the M.H system effectiveness.

Table 10. Ranking of variables

| Variables                                | Notation | Y       |
|------------------------------------------|----------|---------|
| Speed of delivery                        | V1       | 0.6329  |
| Available space                          | V2       | 0.6127  |
| Flexibility                              | V3       | 0.5971  |
| Number of machines                       | V6       | 0.5971  |
| Number of operations                     | V5       | 0.5809  |
| Safety                                   | V9       | 0.5465  |
| Material flow path                       | V8       | 0.5408  |
| Traffic management                       | V13      | 0.5268  |
| Automation                               | V14      | 0.5078  |
| Plant Layout                             | V7       | 0.4862  |
| Types of material handling systems       | V4       | 0.4037  |
| Load carrying capacity                   | V12      | 0.3833  |
| Interface facility with workstation      | V15      | 0.3047  |
| Cost                                     | V11      | 0.2547  |
| Throughput rate                          | V10      | 0.2501  |

5. Conclusions
It is quite evident that material handling cost attributes to the total product cost. This has necessitated analyzing the effectiveness of material handling (MH) systems. Keeping this perspective in concern, the current research work is aimed at the identification and prioritization of variables affecting the MH systems. So, in this paper, 15 variables affecting the MH system are being recognized by performing the extensive literature analysis. Afterwards, a more popular multi-criteria decision making approach i.e. TOPSIS approach have been utilized for the prioritization of variables affecting the material handling system effectiveness. The application of TOPSIS method has revealed that speed of delivery is the most significant variable affecting the material handling system effectiveness. It is quite true that speed of delivery reduces the time consumption between manufacturing facilities to the customer end. It is then followed by
available space. Availability of space lays down the foundation for the installation of specific material handling equipment. Flexibility is another third significant variable affecting the MH equipment. Flexibility leads MH system or equipment to perform variety of activities depending upon the requirement such as change in shape and size of product etc. The material handling system selection also depends upon the number of machines. Number of operations is also a significant variable affecting the material handling system effectiveness. This particular variable provides the more flexibility in MH system. Safety is the more critical concern for the manufacturing organizations. Safety aspects in MH system play a significant role in concern to human or operator safety.

Material flow path also decides the selection or utilization of MH system in a particular organization. Traffic management enables the proper management of MH system routing. Automation of MH system leads to reduction of time in travelling from one place to another place and thus condenses the material handling cost or storage cost. Plant Layout basically shows the arrangement of machines. The arrangement of machines decides MH system to be employed in a particular organization. Organization should select the proper MH system on the basis of arrangement and quantity of equipment. Load carrying capacity also affects the choice of MH system to be employed in an organization. Interface facility with workstation is a significant parameter in the material equipment selection. Cost of MH system affects the choice of MH system. Throughput rate gets augmented through usage of automated MH system.

6. Limitations and Scope of Future Research
The current work is not free from limitations. The survey method used in the research work is limited to the northern regions of India. The data has not been collected from the other parts of India. Secondly, variables affecting the material handling system effectiveness have not been analyzed by using graph theoretic approach. So, in future, questionnaire may be circulated in different parts of country. Moreover, the material handling system effectiveness variables can be quantified by using graph theoretic approach.

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