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Administrative Sciences

Provided in Cooperation with:

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Suggested Citation: Dixit, Sandhya; Raj, Tilak (2018) : A hybrid MADM approach for the evaluation of different material handling issues in flexible manufacturing systems, Administrative Sciences, ISSN 2076-3387, MDPI, Basel, Vol. 8, Iss. 4, pp. 1-19,
<https://doi.org/10.3390/admsci8040069>

This Version is available at:

<https://hdl.handle.net/10419/239885>

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Article

A Hybrid MADM Approach for the Evaluation of Different Material Handling Issues in Flexible Manufacturing Systems

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Received: 15 September 2018; Accepted: 12 November 2018; Published: 14 November 2018



Abstract: In today's versatile and dynamic industrial scenario more and more industries are adopting advanced manufacturing technologies and systems like flexible manufacturing system (FMS) which combines the efficiency of a mass production line and the flexibility of a job shop. Material handling equipment form an important component of FMS and using proper material handling equipment can enhance the production process, provide effective utilization of manpower, increase production and improve system flexibility. In this research the main material handling issues in a FMS are identified and further evaluated using ISM and TOPSIS approaches. The purpose of identification of these issues and their analysis is to allow researchers and practicing managers to pay proper attention to these issues which may help them in designing the material handling systems in their organisations in a better way.

Keywords: manufacturing; FMS; material handling equipment; MADM; ISM; TOPSIS

1. Introduction

Material handling (MH) is involved at all stages from the time the raw material enters the factory till the finished product goes out. Depending on the type, a component may be handled even fifty times or more before it changes to finished product. As material handling adds no value but increases the production cycle time, it is desirable to eliminate handling wherever possible. According to [Sule \(1994\)](#); [Sujono and Lashkari \(2007\)](#), material handling accounts for 30–75% of the total cost of a product along the production chain and efficient material handling can be responsible for reducing the manufacturing system operations cost by 15–30%. It, thus, becomes clear that the cost of production of an item can be lowered considerably by making a saving in the material handling cost.

Materials handling management is among many factors that contribute to improve a company's performance ([Vieira et al. 2011](#)). Many researchers have stressed the importance of proper material handling in an organisation. [Tuzkaya et al. \(2010\)](#) point out that the use of proper material handling equipment can enhance the production process and improves system flexibility. Proper selection of appropriate material handling equipment has become a most important parameter for modern manufacturing concerns ([Tompkins 2010](#)). Selecting appropriate material handling equipment can decrease manufacturing lead times, increase the efficiency of material flow, improve facility utilization and increase productivity ([Kulak et al. 2004](#)). An efficient MH system greatly improves the competitiveness of a product through the reduction of handling cost, enhances the production process, increases production and system flexibility, increases efficiency of material flow, improves facility utilization, provides effective utilization of manpower and decreases lead time ([Beamon 1998](#)).

In today's versatile and dynamic industrial scenario the importance of material handling systems is also increasing. Today, more and more industries are adopting advanced manufacturing technologies and systems to cope up with this market pressure. It has been established that the manufacturing flexibility is an important component to respond quickly to changing markets and customer demands without incurring excessive time and cost (Oberoi et al. 2008). So, industries are now opting for low volume, high variety flexible manufacturing system (FMS) instead of the conventional mass production (Dixit and Raj 2016). The mass production line efficiency and the flexibility of a job shop to produce a variety of products on a group of machines are combined in an FMS design (Rao and Parnichkun 2009). For increasing the productivity of modern manufacturing, which involves high product proliferation, FMS is very crucial and is being adopted by both large as well as small scale industries (Dai and Lee 2012).

FMS involve the general purpose manufacturing machines, coupled with material handling systems which have the capability to perform different types of operations within minimum time. In these systems, a central computer system controls the machines and material handling systems (Jahan et al. 2012). Material handling equipment form an important component of FMS and using proper material handling equipment can enhance the production process, provide effective utilization of manpower, increase production and improve system flexibility. Material handling system design is very significant in flexible manufacturing systems because most of the time that material spends on a shop floor is spent either in waiting or in transportation, even though both these activities are non-value added activities. Efficient material handling ensures for less blocking, timely delivery and reduced idle time of machines due to proper availability and gathering of materials at workstations (Ojha et al. 2018).

Groover (2001) highlights that despite its importance, materials handling is a topic that frequently is treated superficially by the companies. So, in this paper an attempt has been made to discuss the different issues related to material handling systems especially in advanced manufacturing systems like FMS. These issues are further modelled based on their importance using ISM (Interpretive Structural Modelling) approach. For the validation of the ISM model, the same issues are evaluated using TOPSIS (Technique for Order Preference by Similarity to the Ideal Solution) technique and the two results are compared and discussed.

The organization of this research paper is as follows: an introduction to different material handling issues is given in Section 2. A literature review of the techniques used in this research is presented in the Section 3. Stepwise methodologies are presented in Section 4. Modelling is done using ISM in Section 5 and TOPSIS in Section 6 respectively. Section 7 discusses the findings and the implications of this research, followed by conclusion in Section 8.

2. Material Handling System and Equipment

The Materials Handling Industry of America [MHIA] defines materials handling management as "Material Handling is the movement, storage, control and protection of material, goods and products throughout the process of manufacturing, distribution, consumption and disposal. The focus is on the methods, mechanical equipment, systems and related controls used to achieve these functions" (mhia.org/learning/glossary).

Material handling involves the movement of materials, manually or mechanically in batches or one item at a time within the plant. The movement may be horizontal, vertical or the combination of the both, it can be on a fixed path or on variable path. There is a need of installing safe and efficient methods and equipment for handling materials. As per MHIA, 35 to 40% of the plant accidents are due to bad methods of material handling.

According to Karande and Chakraborty (2013), the main functions performed by MH equipment can be classified into four broad categories, that is: (a) transport; (b) positioning; (c) unit formation; and (d) storage. Usually, all the MH functions are one or more combinations of these four primary functions. The transport equipments simply move materials from one point to another and mainly include conveyors, industrial trucks, cranes and so forth. Unlike transport equipment, positioning

equipment are usually employed at workstations to aid machining operations like, robots, index tables, rotary tables and so forth. Unit formation equipment are used for holding or carrying materials in standardized unit load forms for transport and storage and generally includes bins, pallets, skids and containers. Storage equipments are used for holding or buffering materials over a period of time. Typical examples that perform this function are AS/RS, pallet racks and shelves. Today a wide variety of equipments are available for all these functions, each having distinct characteristics and cost. Selection of the proper equipment for a designed manufacturing system is a very complicated task and is often influenced by the ongoing development of new technology, practices and equipment.

As material handling adds no value but increases the production cycle time, so it is desirable to eliminate handling wherever possible. Ideally there should not be any handling at all! So, while designing the MH system, sequence the operations in logical manner so that handling is unidirectional and smooth. Wherever possible, the use of gravity is also desirable. Standardize the handling equipment to the extent possible as it means interchangeable usage, better utilization of handling equipment and lesser spares holding. In selection of handling equipment, criteria of versatility and adaptability must be the governing factor. Weight of unit load must be maximum so that each 'handling trip' is productive. Work study aspects, such as elimination of unnecessary movements and combination of processes should be considered while installing a material handling system. Application of OR techniques such as queuing can be very effective in optimal utilization of materials handling equipment. A very important aspect in the design of a material handling system is the safety aspect. The system designed should be simple and safe to operate.

The main engineering factors to be considered for the design of an efficient MH system are like: the existing plant layout and the handling equipment, the nature of the products to be handled, production processes and equipment, quantities involved. The economic factors to be considered are: The cost of material handling equipment, operating costs, repair and maintenance costs and so forth. A material handling system with the lowest prospective cost is selected. The operating costs are reduced by purchasing flexible material handling systems, increasing the amount of material to be handled at one time, minimizing the idle time for the equipment, increasing speed of handling. A material handling system is said to be economical if the cost of handling per unit weight of the material for a particular movement is minimum.

So, during the design of a materials handling system we are looking for serving equipment for a complex materials handling task and synchronizing their operations (Telek 2013). The MH equipment selection is an important proportion of manufacturing expenses and the most critical material handling decisions in this area are the arrangement and the design of material flow patterns (Asef-Vaziri and Laporte 2005). This idea is shared by Ioannou (2007), which argues that an important aspect of any production system is the design of a material handling system which integrates the production operations.

So, the decision makers have to consider various quantitative (load capacity, energy consumption, reliability, cost, etc.) and qualitative (flexibility, performance, environmental hazard, safety, load shape, load type, etc.) criteria for the design of MH systems. Some of these selection criteria are beneficial (higher values are preferred) and some are non beneficial (lower values are desired). Therefore, MH system design can be viewed as a multicriteria decision-making (MCDM) problem in the presence of many conflicting criteria (Karande and Chakraborty 2013).

Based on the above discussion, 19 issues related to the material handling equipment in FMS were identified. These issues are presented in Table 1.

Table 1. Major issues related to the material handling equipment in FMS.

S. No.	Issue
1.	Initial cost of the MH equipment
2.	Load carrying capacity
3.	Programming flexibility of MH equipment
4.	Operational cost
5.	Throughput rate
6.	Capacity to handle different shapes and volumes
7.	Storage/Retrieval MH equipment
8.	Operational control
9.	Automation
10.	Floor space
11.	AGVs/Robots and other advanced MH equipment already present
12.	Number of AGVs required
13.	Layout of AGV tracks
14.	Vehicle dispatching rules
15.	Traffic management
16.	Positioning of idle vehicles
17.	Failure management
18.	Compatibility of MH equipment with other workstations
19.	Comparison with cheap human labour

3. Literature Review

In this section a review of the literature regarding the methodologies used in this paper is given.

3.1. Review of Literature Regarding ISM

Interpretive Structural Modelling is a method of establishing a relationship between the various attributes of any problem or issue. Warfield (1974) first proposed this technique and later it was used by a number of researchers to develop a visualised structure for the different elements of any complex system. ISM establishes a hierarchical relationship between different directly or indirectly related items which define a problem or an issue (Sage 1977). In this technique, both graphics as well as words are used in a carefully designed pattern to form a systematic model (Singh et al. 2003; Raj et al. 2012). The developed model helps in decision making and hence ISM is a decision making tool (Jharkharia and Shankar 2005). The ISM process transforms unclear, poorly articulated mental models of the systems into visible and well defined models (Dixit and Raj 2016).

In the past, Ravi and Shankar (2005); Faisal (2010); Luthra et al. (2011); Sharma and Bhat (2014) have applied ISM to model the various attributes of the supply chains, Raj et al. (2009) and Dixit and Raj (2016) have used it to structure FMS variables, Govindan et al. (2012) used ISM in the analysis of third party reverse logistics provider. Attri et al. (2012) and Poduval et al. (2015) have modelled the TPM environment using ISM. The drivers of agile manufacturing are modelled by Mishra et al. (2012) and Upadhye et al. (2014) studied the implementation enablers for JIT in Indian packaging industry. Analysis of sustainable manufacturing factors in Indian automotive component sector was done with ISM by Thirupathi and Vinodh (2016). The feasibility analysis of FMS in SMEs in India is done using ISM by Dixit and Raj (2018).

3.2. Review of Literature Regarding TOPSIS

TOPSIS is an acronym for Technique for Order Preference by Similarity to the Ideal Solution. It was developed by Hwang and Yoon (1981) and later used by many researchers like, Lai et al. (1994) and Yoon and Hwang (1995). TOPSIS is a multiple criteria decision making technique which identifies solutions from a given set of attributes based on simultaneous minimization of distance from an ideal point and maximization of distance from a nadir point (Rao 2007). Relative weights of criterion importance can be incorporated in TOPSIS.

Some of the applications in which TOPSIS have been applied in the past are: Agrawal et al. (1992) have used TOPSIS for selection of grippers in FMS, Kim et al. (1997) studied investment opportunities for AMs, Robot selection was done by Parkan and Wu (1999), Deng et al. (2000) have used TOPSIS in

Comparing company performances, Hao and Xie (2006) developed a bidding model for evaluation of manufacturing enterprises. Wang and Chang (2007) used it for the evaluation of initial training aircraft. Kannan et al. (2009) selected reverse logistics provider and Yang and Sun (2010) used it as a new personalized recommendation technique. Personnel selection in multi-type information environment was done by Chen et al. (2011) using TOPSIS while Latpate (2015) solved a supplier selection problem in SCM. Jain and Raj (2015) modelled flexibility in FMs using TOPSIS and Ziaei et al. (2016) improved the performance of water pump manufacturing system.

4. Methodology

4.1. Interpretive Structural Modelling

The methodology for ISM modelling can be described in the following steps (Raj et al. 2008; Dixit and Raj 2018):

- Step 1:** First of all different attributes related to any issue are identified either by a survey or any group problem solving technique.
- Step 2:** Further, these different attributes are related by contextual relationship. For this a Structural self-interaction matrix (SSIM) is developed, which indicates the pair-wise relationship between the different attributes.
- Step 3:** Reachability Matrix (RM) is developed from the SSIM. The transitivity of this matrix is also checked and Final Reachability Matrix containing all the transitive links is developed.
- Step 4:** Different level partitioning is done of RM. The reachability set and antecedent set for each issue are found from the final reachability matrix. Then the intersection set is found and the levels are decided based on all the issues which can reach the issue from bottom.
- Step 5:** Conical matrix is developed with zero elements in the upper diagonal and the unitary elements in the lower half.
- Step 6:** Based on the conical matrix relationships, a directed graph (digraph) without the transitive links is drawn.
- Step 7:** The nodes of the digraph are replaced with statements to convert it into an ISM model.

4.2. TOPSIS

The TOPSIS methodology in a stepwise fashion for the selection of the most desirable attribute from given attributes is described below (Rao 2007):

- Step 1:** Determine the related attributes for the given objective.
- Step 2:** All the information related to the attributes is expressed in matrix form. This information may be collected from a survey or group discussion. Each row of this matrix is allocated to one attribute and each column to one criterion. Raw measurements are standardized by using Equation (1), where, raw measure X_{ij} is standardized into S_{ij} ,

$$S_{ij} = X_{ij} / \left(\left(\sum_{i=1, j=1}^{n, k} (X_{ij}^2) \right)^{1/2} \right) \quad (1)$$

- Step 3:** Importance weights w_k is developed for each of the criteria. The relative importance of these criteria is reflected by these weights. In this work the weightage of rating is calculated by using following criteria:

$$\text{Normalised weight of each importance} = \frac{\text{Total of each importance}}{\text{Grand total of all importances}} \quad (2)$$

5.2. Development of the Reachability Matrix

Binary digits 0 and 1 are used in place of symbols V, A, X, O of SSIM to develop the reachability matrix. The substitution rules are same as [Dixit and Raj \(2018\)](#).

The initial reachability matrix is prepared and is shown in Table 3.

Table 3. Initial Reachability Matrix.

Issue	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
2	1	1	0	1	1	0	0	0	0	0	0	1	1	1	1	0	0	0	1
3	1	0	1	1	1	0	0	1	1	0	0	1	0	0	1	0	0	0	0
4	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
5	0	0	0	0	1	0	0	0	0	0	0	0	0	1	1	0	0	0	0
6	1	1	1	1	0	1	0	0	0	0	0	1	0	1	0	0	0	1	0
7	0	0	0	0	0	1	1	0	1	0	0	0	1	0	0	1	0	1	0
8	0	0	0	1	0	0	0	1	0	0	0	0	0	1	1	0	1	1	0
9	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	1	1	0
10	0	0	0	0	0	0	0	0	0	1	0	1	1	0	1	1	0	0	0
11	0	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	1	0	0
12	1	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0
13	0	0	0	0	1	0	0	0	0	0	0	0	1	1	1	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
18	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	1	0
19	1	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	1

The final reachability matrix is obtained from the initial matrix by incorporating transitivity that is, if an issue *a* influences issue *b* and issue *b* further influences issue *c*, the issue *a* automatically influences issue *c*. The final reachability matrix obtained by incorporating transitivity is shown in Table 4 wherein transitive influences are shown as 1*.

Table 4. Final Reachability Matrix.

Issue	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	1	0	0	0	0	1*	1*	1*	1*	0	0	0	1*	0	0	1*	1*	1*	1
2	1	1	0	1	1	1*	1*	1*	1*	0	0	1	1	1	1	1*	1*	1*	1
3	1	0	1	1	1	0	1*	1	1	0	0	1	1*	1*	1	1*	1*	1*	1*
4	1*	0	0	1	0	1*	1*	1*	1*	0	0	0	1*	0	0	1*	1*	1*	1
5	0	0	0	0	1	0	0	0	0	0	0	0	1*	1	1	1*	0	0	0
6	1	1	1	1	1*	1	0	1*	1*	0	0	1	1*	1	1*	0	1*	1	1*
7	1*	1*	1*	1*	1*	1	1	1*	1	0	0	1*	1	1*	1*	1	1*	1	0
8	1*	0	0	1	1*	0	1*	1	1*	0	0	1*	1*	1	1	1*	1	1	1*
9	1	0	0	1*	1*	0	1*	1	1	0	0	1*	1*	1*	1*	1*	1	1	1*
10	1*	0	0	0	1*	0	0	0	0	1	0	1	1	1*	1	1	0	0	1*
11	1*	1	0	1*	1*	0	1*	0	1*	0	1	1	1	1	1*	1*	1	0	1*
12	1	0	0	0	1*	0	1*	0	1*	0	0	1	1	1	1	1*	0	0	1*
13	0	0	0	0	1	0	0	0	0	0	0	0	1	1	1	1*	0	0	0
14	0	0	0	0	1*	0	0	0	0	0	0	0	1	1	1	1*	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
18	1*	0	0	0	1*	0	0	0	0	0	0	1	1	1	1*	0	0	1	1*
19	1	1*	1*	1*	0	1*	1	1*	1	0	0	1*	1*	1*	1*	1*	1*	1*	1

5.3. Partitioning the Reachability Matrix

The reachability and the antecedent sets for each issue are found by partitioning the final reachability matrix is (Warfield 1974). The process is completed in twelve iterations giving twelve different levels for the ISM model. These levels are shown in Tables 5–16.

Table 5. Iteration 1.

Issue	Reachability Set	Antecedent Set	Intersection Set	Level
1	1,6,7,8,9,13,16,17,18,19	1,2,3,4,6,7,8,9,10,11,12,18,19	1,6,7,8,9,18,19	I
2	1,2,4,5,6,7,8,9,12,13,14,15,16,17,18,19	2,6,7,11,19	2,6,7,19	
3	1,3,4,5,7,8,9,12,13,14,15,16,17,18,19	3,6,7,19	3,7,19	
4	1,4,6,7,8,9,13,16,17,18,19	2,3,4,6,7,8,9,11,19	4,6,7,8,9,19	
5	5, 13,14,15,16	1,2,5,6,7,8,9,10,11,12,13,14,18	5,13,14	
6	1,2,3,4,5,6,8,9,12,13,14,15,17,18,19	1,2,4,6,7,19	1,2,4,6,19	
7	1,2,3,4,5,6,7,8,9,12,13,14,15,16,17,18	1,2,3,4,7,8,9,11,12,19	1,2,3,4,7,8,9,12	
8	1,4,5,7,8,9,12,13,14,15,16,17,18,19	1,2,3,4,6,7,8,9,19	1,4,7,8,9,19	
9	1,4,5,7,8,9,12,13,14,15,16,17,18,19	1,2,3,4,6,7,8,9,11,12,19	1,4,7,8,9,12,19	
10	1,5,10,12,13,14,15,16,19	10	10	
11	1,2,4,5,7,9,11,12,13,14,15,16,17,19	11	11	
12	1,5,7,9,12,13,14,15,16,19	2,3,6,7,8,9,10,11,12,18,19	7,9,12,19	
13	5,13,14,15,16	1,2,3,4,5,6,7,8,9,10,11,12,13,14,18,19	5,13,14	
14	5,13,14,15,16	2,3,5,6,7,8,9,10,11,12,13,14,18,19	5,13,14	
15	15,16	2,3,5,6,7,8,9,10,11,12,13,14,15,18,19	15	
16	16	1,2,3,4,5,7,8,9,10,11,12,13,14,15,16,19	16	
17	17	1,2,3,4,6,7,8,9,11,17,19	17	
18	1,5,12,13,14,15,18,19	1,2,3,4,6,7,8,9,18,19	1,18,19	
19	1,2,3,4,6,7,8,9,12,13,14,15,16,17,18,19	1,2,3,4,6,8,9,10,11,12,18,19	1,2,3,4,6,8,9,12,18,19	

Table 6. Iteration 2.

Issue	Reachability Set	Antecedent Set	Intersection Set	Level
1	1,6,7,8,9,13,18,19	1,2,3,4,6,7,8,9,10,11,12,18,19	1,6,7,8,9,18,19	II
2	1,2,4,5,6,7,8,9,12,13,14,15,18,19	2,6,7,11,19	2,6,7,19	
3	1,3,4,5,7,8,9,12,13,14,15,18,19	3,6,7,19	3,7,19	
4	1,4,6,7,8,9,13,18,19	2,3,4,6,7,8,9,11,19	4,6,7,8,9,19	
5	5, 13,14,15	1,2,5,6,7,8,9,10,11,12,13,14,18	5,13,14	
6	1,2,3,4,5,6,8,9,12,13,14,15,18,19	1,2,4,6,7,19	1,2,4,6,19	
7	1,2,3,4,5,6,7,8,9,12,13,14,15,18	1,2,3,4,7,8,9,11,12,19	1,2,3,4,7,8,9,12	
8	1,4,5,7,8,9,12,13,14,15,18,19	1,2,3,4,6,7,8,9,19	1,4,7,8,9,19	
9	1,4,5,7,8,9,12,13,14,15,18,19	1,2,3,4,6,7,8,9,11,12,19	1,4,7,8,9,12,19	
10	1,5,10,12,13,14,15,19	10	10	
11	1,2,4,5,7,9,11,12,13,14,15,19	11	11	
12	1,5,7,9,12,13,14,15,19	2,3,6,7,8,9,10,11,12,18,19	7,9,12,19	
13	5,13,14,15	1,2,3,4,5,6,7,8,9,10,11,12,13,14,18,19	5,13,14	
14	5,13,14,15	2,3,5,6,7,8,9,10,11,12,13,14,18,19	5,13,14	
15	15	2,3,5,6,7,8,9,10,11,12,13,14,15,18,19	15	
18	1,5,12,13,14,15,18,19	1,2,3,4,6,7,8,9,18,19	1,18,19	
19	1,2,3,4,6,7,8,9,12,13,14,15,18,19	1,2,3,4,6,8,9,10,11,12,18,19	1,2,3,4,6,8,9,12,18,19	

Table 7. Iteration 3.

Issue	Reachability Set	Antecedent Set	Intersection Set	Level
1	1,6,7,8,9,13,18,19	1,2,3,4,6,7,8,9,10,11,12,18,19	1,6,7,8,9,18,19	III
2	1,2,4,5,6,7,8,9,12,13,14,18,19	2,6,7,11,19	2,6,7,19	
3	1,3,4,5,7,8,9,12,13,14,18,19	3,6,7,19	3,7,19	
4	1,4,6,7,8,9,13,18,19	2,3,4,6,7,8,9,11,19	4,6,7,8,9,19	
5	5, 13,14	1,2,5,6,7,8,9,10,11,12,13,14,18	5,13,14	
6	1,2,3,4,5,6,8,9,12,13,14,18,19	1,2,4,6,7,19	1,2,4,6,19	
7	1,2,3,4,5,6,7,8,9,12,13,14,18	1,2,3,4,7,8,9,11,12,19	1,2,3,4,7,8,9,12	
8	1,4,5,7,8,9,12,13,14,18,19	1,2,3,4,6,7,8,9,19	1,4,7,8,9,19	
9	1,4,5,7,8,9,12,13,14,18,19	1,2,3,4,6,7,8,9,11,12,19	1,4,7,8,9,12,19	
10	1,5,10,12,13,14,19	10	10	
11	1,2,4,5,7,9,11,12,13,14,19	11	11	
12	1,5,7,9,12,13,14,19	2,3,6,7,8,9,10,11,12,18,19	7,9,12,19	
13	5,13,14	1,2,3,4,5,6,7,8,9,10,11,12,13,14,18,19	5,13,14	
14	5,13,14	2,3,5,6,7,8,9,10,11,12,13,14,18,19	5,13,14	
18	1,5,12,13,14,18,19	1,2,3,4,6,7,8,9,18,19	1,18,19	
19	1,2,3,4,6,7,8,9,12,13,14,18,19	1,2,3,4,6,8,9,10,11,12,18,19	1,2,3,4,6,8,9,12,18,19	

Table 8. Iteration 4.

Issue	Reachability Set	Antecedent Set	Intersection Set	Level
1	1,6,7,8,9,18,19	1,2,3,4,6,7,8,9,10,11,12,18,19	1,6,7,8,9,18,19	IV
2	1,2,4,6,7,8,9,12,18,19	2,6,7,11,19	2,6,7,19	
3	1,3,4,7,8,9,12,18,19	3,6,7,19	3,7,19	
4	1,4,6,7,8,9,18,19	2,3,4,6,7,8,9,11,19	4,6,7,8,9,19	
6	1,2,3,4,6,8,9,12,18,19	1,2,4,6,7,19	1,2,4,6,19	
7	1,2,3,4,6,7,8,9,12,18	1,2,3,4,7,8,9,11,12,19	1,2,3,4,7,8,9,12	
8	1,4,7,8,9,12,18,19	1,2,3,4,6,7,8,9,19	1,4,7,8,9,19	
9	1,4,7,8,9,12,18,19	1,2,3,4,6,7,8,9,11,12,19	1,4,7,8,9,12,19	
10	1,10,12,19	10	10	
11	1,2,4,7,9,11,12,19	11	11	
12	1,7,9,12,19	2,3,6,7,8,9,10,11,12,18,19	7,9,12,19	
18	1,12,18,19	1,2,3,4,6,7,8,9,18,19	1,18,19	
19	1,2,3,4,6,7,8,9,12,18,19	1,2,3,4,6,8,9,10,11,12,18,19	1,2,3,4,6,8,9,12,18,19	

Table 9. Iteration 5.

Issue	Reachability Set	Antecedent Set	Intersection Set	Level
2	2,4,6,7,8,9,12,18,19	2,6,7,11,19	2,6,7,19	V
3	3,4,7,8,9,12,18,19	3,6,7,19	3,7,19	
4	4,6,7,8,9,18,19	2,3,4,6,7,8,9,11,19	4,6,7,8,9,19	
6	2,3,4,6,8,9,12,18,19	2,4,6,7,19	2,4,6,19	
7	2,3,4,6,7,8,9,12,18	2,3,4,7,8,9,11,12,19	2,3,4,7,8,9,12	
8	4,7,8,9,12,18,19	2,3,4,6,7,8,9,19	4,7,8,9,19	
9	4,7,8,9,12,18,19	2,3,4,6,7,8,9,11,12,19	4,7,8,9,12,19	
10	10,12,19	10	10	
11	2,4,7,9,11,12,19	11	11	
12	7,9,12,19	2,3,6,7,8,9,10,11,12,18,19	7,9,12,19	
18	12,18,19	2,3,4,6,7,8,9,18,19	18,19	
19	2,3,4,6,7,8,9,12,18,19	2,3,4,6,8,9,10,11,12,18,19	2,3,4,6,8,9,12,18,19	

Table 10. Iteration 6.

Issue	Reachability Set	Antecedent Set	Intersection Set	Level
2	2,4,6,7,8,9,18,19	2,6,7,11,19	2,6,7,19	VI
3	3,4,7,8,9,18,19	3,6,7,19	3,7,19	
4	4,6,7,8,9,18,19	2,3,4,6,7,8,9,11,19	4,6,7,8,9,19	
6	2,3,4,6,8,9,18,19	2,4,6,7,19	2,4,6,19	
7	2,3,4,6,7,8,9,18	2,3,4,7,8,9,11,19	2,3,4,7,8,9	
8	4,7,8,9,18,19	2,3,4,6,7,8,9,19	4,7,8,9,19	
9	4,7,8,9,18,19	2,3,4,6,7,8,9,11,19	4,7,8,9,19	
10	10,19	10	10	
11	2,4,7,9,11,19	11	11	
18	18,19	2,3,4,6,7,8,9,18,19	18,19	
19	2,3,4,6,7,8,9,18,19	2,3,4,6,8,9,10,11,18,19	2,3,4,6,8,9,18,19	

Table 11. Iteration 7.

Issue	Reachability Set	Antecedent Set	Intersection Set	Level
2	2,4,6,7,8,9,19	2,6,7,11,19	2,6,7,19	VII
3	3,4,7,8,9,19	3,6,7,19	3,7,19	
4	4,6,7,8,9,19	2,3,4,6,7,8,9,11,19	4,6,7,8,9,19	
6	2,3,4,6,8,9,19	2,4,6,7,19	2,4,6,19	
7	2,3,4,6,7,8,9	2,3,4,7,8,9,11,19	2,3,4,7,8,9	
8	4,7,8,9,19	2,3,4,6,7,8,9,19	4,7,8,9,19	
9	4,7,8,9,19	2,3,4,6,7,8,9,11,19	4,7,8,9,19	
10	10,19	10	10	
11	2,4,7,9,11,19	11	11	
19	2,3,4,6,7,8,9,19	2,3,4,6,8,9,10,11,19	2,3,4,6,8,9,19	

Table 12. Iteration 8.

Issue	Reachability Set	Antecedent Set	Intersection Set	Level
2	2,6,7,19	2,6,7,11,19	2,6,7,19	VIII
3	3,7,19	3,6,7,19	3,7,19	
6	2,3,6,19	2,6,7,19	2,6,19	
7	2,3,6,7	2,3,7,11,19	2,3,7	
10	10,19	10	10	
11	2,7,11,19	11	11	
19	2,3,6,7,19	2,3,6,10,11,19	2,3,6,19	

Table 13. Iteration 9.

Issue	Reachability Set	Antecedent Set	Intersection Set	Level
6	6,19	6,7,19	6,19	IX
7	6,7	7,11,19	7	
10	10,19	10	10	
11	7,11,19	11	11	
19	6,7,19	6,10,11,19	6,19	

Table 14. Iteration 10.

Issue	Reachability Set	Antecedent Set	Intersection Set	Level
7	7	7,11,19	7	X
10	10,19	10	10	
11	7,11,19	11	11	
19	7,19	10,11,19	19	

Table 15. Iteration 11.

Issue	Reachability Set	Antecedent Set	Intersection Set	Level
10	10,19	10	10	XI
11	11,19	11	11	
19	19	10,11,19	19	

Table 16. Iteration 12.

Issue	Reachability Set	Antecedent Set	Intersection Set	Level
10	10	10	10	XII
11	11	11	11	XII

5.4. Development of the Conical Matrix

In the next step, the issues in the same level are clubbed together to form a conical matrix. As shown in Table 17. The summing up of the number of ones in rows gives the drive power of an issue and the summing up of the ones across columns gives the dependence power of the issue. Next, drive power and dependence power ranks are calculated by giving highest ranks to the issues that have the maximum number of ones in the rows and columns respectively (Raj et al. 2008; Attri et al. 2013).

5.5. Development of the Digraph and the ISM Model

From the conical matrix the digraph (Figure 1) of nodes and lines is obtained by placing the top level issues at the top of the digraph and second level issues at second position and so on, until the bottom level is placed at the lowest position in the digraph (Raj et al. 2008; Attri et al. 2013).

Table 17. Conical Matrix.

Issue	16	17	15	5	13	14	1	12	18	4	8	9	2	3	6	7	19	10	11	Driving Power
16	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
17	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
15	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
5	1	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	5
13	1	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	5
14	1	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	5
1	1	1	0	0	1	0	1	0	1	0	1	1	0	0	1	1	1	0	0	10
12	1	0	1	1	1	1	1	1	0	0	0	1	0	0	0	1	1	0	0	10
18	0	0	1	1	1	1	1	1	1	0	0	0	0	0	0	0	1	0	0	8
4	1	1	0	0	1	0	1	0	1	1	1	1	0	0	1	1	1	0	0	11
8	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	0	0	14
9	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	0	0	14
2	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	0	0	16
3	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	1	1	0	0	15
6	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	0	15
7	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	16
19	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	16
10	1	0	1	1	1	1	1	1	0	0	0	0	0	0	0	0	1	1	0	9
11	1	1	1	1	1	1	1	1	0	1	0	1	1	0	0	1	1	0	1	14
Dependence Power	16	11	15	13	16	14	13	11	10	9	9	11	5	4	6	10	12	1	1	

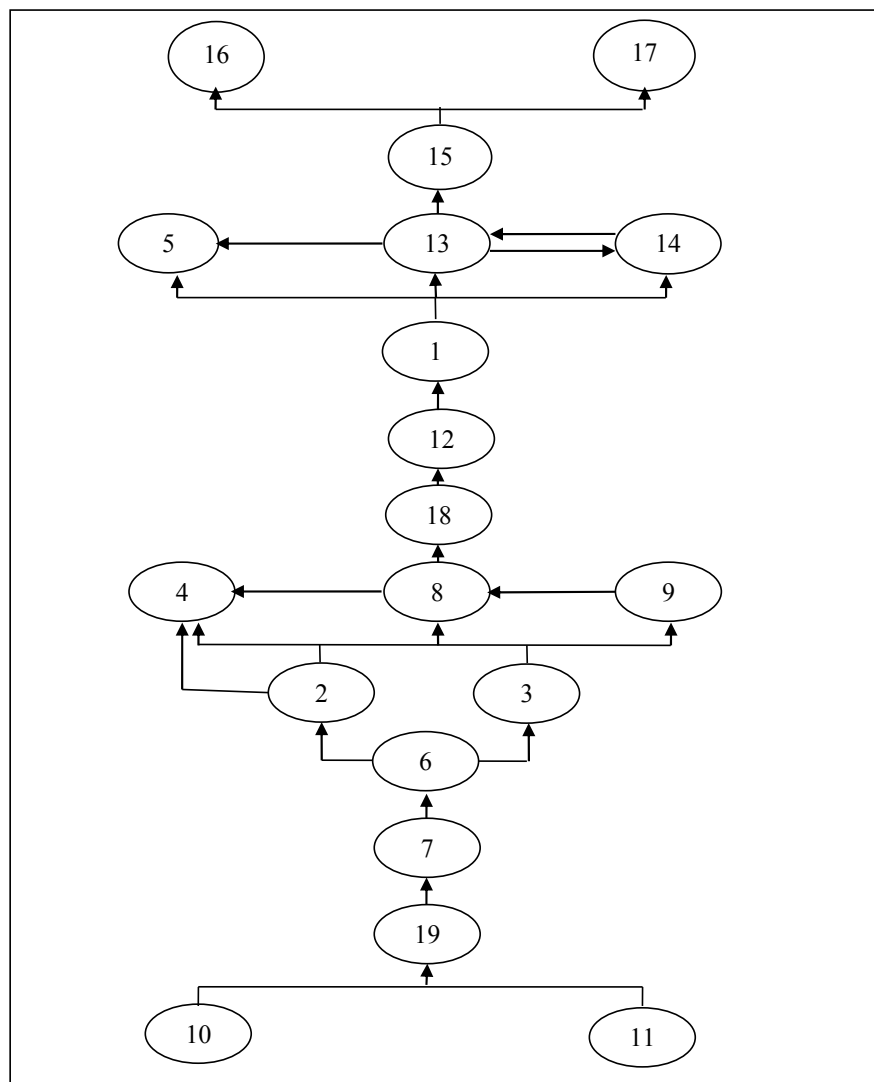


Figure 1. A digraph showing the relationship between different material handling issues in FMS.

Step 1: Objective is to find the significance hierarchy of different material handling issues. For this 19 issues were identified as given in Table 1.

Step 2: The next step is to represent all the information available for the issues in the form of a decision matrix. For this step, the data is collected from a survey and 19 issues of material handling in FMS were rated on a scale of 5 in which responses from 63 respondents were collected. Thus, number of attributes is, $n = 19$ and criteria, $k = 5$. This raw data in the form of frequency table is shown in Table 18.

Table 18. Data collected through Survey.

Rating	5	4	3	2	1
Issue	Most Important	Above Average	Average	Below Average	Least Important
1	2	5	24	28	4
2	1	10	33	15	4
3	0	10	34	16	3
4	0	23	28	12	0
5	5	4	29	20	5
6	12	9	34	8	0
7	6	18	34	2	3
8	2	28	15	18	0
9	0	21	30	12	0
10	4	9	50	0	0
11	5	34	22	2	0
12	0	11	30	22	0
13	6	8	22	27	0
14	7	14	30	12	0
15	17	17	18	10	1
16	2	18	13	24	6
17	4	2	18	28	11
18	11	25	25	2	0
19	3	4	50	6	0

Now the standardized matrix is obtained by normalizing the data of Table 18 using the Equation (1). The same is shown in Table 19.

Table 19. Data in Normalised Form.

Rating	5	4	3	2	1
Issue	Most Important	Above Average	Average	Below Average	Least Important
1	0.1433	0.3442	4.4057	10.8659	1.0482
2	0.0358	1.3767	8.3295	3.1184	1.0482
3	0.0000	1.3767	8.8420	3.5480	0.5896
4	0.0000	7.2829	5.9966	1.9958	0.0000
5	0.8957	0.2203	6.4326	5.5438	1.6378
6	5.1593	1.1151	8.8420	0.8870	0.0000
7	1.2898	4.4606	8.8420	0.0554	0.5896
8	0.1433	10.7935	1.7210	4.4905	0.0000
9	0.0000	6.0714	6.8839	1.9958	0.0000
10	0.5733	1.1151	19.1219	0.0000	0.0000
11	0.8957	15.9150	3.7020	0.0554	0.0000
12	0.0000	1.6658	6.8839	6.7080	0.0000
13	1.2898	0.8811	3.7020	10.1036	0.0000
14	1.7556	2.6984	6.8839	1.9958	0.0000
15	10.3545	3.9787	2.4782	1.3860	0.0655
16	0.1433	4.4606	1.2926	7.9831	2.3584
17	0.5733	0.0551	2.4782	10.8659	7.9270
18	4.3353	8.6045	4.7805	0.0554	0.0000
19	0.3225	0.2203	19.1219	0.4989	0.0000

Step 3: Table 20 shows these criteria weights developed for each criteria using Equation (2).

Table 20. Weightage of Rating.

Rating	Most Important	Above Average	Average	Below Average	Least Important
Instance of each importance	87	270	539	264	37
Total of each importance	435	1080	1617	528	37
Normalized weight of each importance	0.1177	0.2921	0.4374	0.1428	0.0100

Step 4: Now the weighted matrix is developed by multiplying each value of a rating column by its respective weight. The same is shown in Table 21.

Table 21. Weighted Matrix of Normalized Data.

Rating	5	4	3	2	1
Issue	Most Important	Above Average	Average	Below Average	Least Important
1	0.0252	0.1360	1.3506	1.1561	0.0160
2	0.0063	0.5441	2.5576	0.3318	0.0160
3	0.0000	0.5441	2.7152	0.3775	0.0090
4	0.0000	2.8782	1.8400	0.2123	0.0000
5	0.1572	0.0871	1.9741	0.5899	0.0251
6	0.9055	0.4407	2.7152	0.0944	0.0000
7	0.2264	1.7628	2.7152	0.0059	0.0090
8	0.0252	4.2656	0.5248	0.4778	0.0000
9	0.0000	2.3994	2.1129	0.2123	0.0000
10	0.1006	0.4407	5.8773	0.0000	0.0000
11	0.1572	6.2896	1.1341	0.0059	0.0000
12	0.0000	0.6583	2.1129	0.7137	0.0000
13	0.2264	0.3482	1.1341	1.0750	0.0000
14	0.3081	1.0664	2.1129	0.2123	0.0000
15	1.8172	1.5724	0.7577	0.1475	0.0010
16	0.0252	1.7628	0.3930	0.8494	0.0361
17	0.1006	0.0218	0.7577	1.1561	0.1213
18	0.7608	3.4005	1.4659	0.0059	0.0000
19	0.0566	0.0871	5.8773	0.0531	0.0000

Step 5: Table 22 displays the ideal alternative chosen from Table 18.

Table 22. Table of ideal issue.

	max W_{i1}	max W_{i2}	max W_{i3}	max W_{i4}	max W_{i5}
S+	1.8172	6.2896	5.8819	1.1561	0.1213

Step 6: Table 23 displays the nadir alternative chosen from Table 18.

Table 23. Table of nadir issue.

	min W_{i1}	min W_{i2}	min W_{i3}	min W_{i4}	min W_{i5}
S−	0.0000	0.0218	0.3976	0.0000	0.0000

Step 7: By using the Equations (4) and (5), a distance measure over each criterion to both ideal (D^+) and nadir (D^-) is developed. The same is shown in Table 24.

Table 24. Distance of ideal and nadir issue from weighted data.

Issue	D_i^+	D_i^-
Initial cost of the MH equipment	10.9437	1.7833
Load carrying capacity	10.4622	2.6358
Programming flexibility of MH equipment	10.3733	2.7948
Operational cost	9.5797	3.4227
Throughput rate	10.8597	2.0683
Capacity to handle different shapes and volumes	10.3192	2.8975
Storage/Retrieval MH equipment	9.7465	3.2452
Operational control	9.7077	4.3243
Automation	9.6648	3.2041
Floor space	9.6956	5.8947
AGVs/Robots and other advanced MH equipment already present	9.0706	6.3930
Number of AGVs required	10.4161	2.3253
Layout of AGV tracks	10.8966	1.6169
Vehicle dispatching rules	10.3076	2.3961
Traffic management	10.4425	2.5240
Positioning of idle vehicles	10.6712	1.9964
Failure management	11.3093	1.3914
Compatibility of MH equipment with other workstations	9.4341	3.7804
Comparison with cheap human labour	9.9357	5.8785

Step 8: A ratio R is determined for each issue which is equal to the distance to the nadir divided by the sum of the distance to the nadir and the distance to the ideal, as shown in Equation (6) and calculated in Table 25.

Step 9: Rank the issues by maximizing the ratio in Step 8 as shown in Table 26.

Table 25. Ratio of distance to nadir from total.

Issue	R_i
Initial cost of the MH equipment	0.1401
Load carrying capacity	0.2012
Programming flexibility of MH equipment	0.2122
Operational cost	0.2632
Throughput rate	0.1600
Capacity to handle different shapes and volumes	0.2192
Storage/Retrieval MH equipment	0.2498
Operational control	0.3082
Automation	0.2490
Floor space	0.3781
AGVs/Robots and other advanced MH equipment already present	0.4134
Number of AGVs required	0.1825
Layout of AGV tracks	0.1292
Vehicle dispatching rules	0.1886
Traffic management	0.1947
Positioning of idle vehicles	0.1576
Failure management	0.1096
Compatibility of MH equipment with other workstations	0.2861
Comparison with cheap human labour	0.3717

Table 26. Ranking the issues from largest to smallest value.

Issue	R_i
AGVs/Robots and other advanced MH equipment already present	0.4134
Floor space	0.3781
Comparison with cheap human labour	0.3717
Operational control	0.3082
Compatibility of MH equipment with other workstations	0.2861
Operational cost	0.2632
Storage/Retrieval MH equipment	0.2498
Automation	0.2490
Capacity to handle different shapes and volumes	0.2192
Programming flexibility of MH equipment	0.2122
Load carrying capacity	0.2012
Traffic management	0.1947
Vehicle dispatching rules	0.1886
Number of AGVs required	0.1825
Throughput rate	0.1600
Positioning of idle vehicles	0.1576
Initial cost of the MH equipment	0.1401
Layout of AGV tracks	0.1292
Failure management	0.1096

7. Discussion

The aim of this research paper is to identify the different material handling issues in an advanced manufacturing system like FMS. For this 19 issues have been identified which influence the MH system of FMS. Further these are modelled using two distinct, well established modelling approaches, ISM and TOPSIS. In ISM based model a hierarchy of different issues based on their relative importance is established. The practising managers of these industries can get an insight of these issues and understand their relative importance and interdependencies. The drive power- dependence power (Table 19) gives some valuable insights about the relative importance and interdependence among these issues. Research indicates that positioning of idle vehicles, failure management, traffic management, throughput rate, layout of AGV tracks and vehicle dispatching rules and so forth are the top level issues. They have less influence and more dependence on the other MH issues. Initial cost, number of AGVs, compatibility of different MH equipment with other processing workstations and AS/RS devices, operational cost, operational control, automation, load carrying capacity and the programming flexibility form the middle level attributes. They have both the driving as well as dependence power. So they influence as well as are influenced by the other MH issues. The capacity to handle different shapes and volumes, storage and retrieval MH equipment, comparison with cheap human labour, floor space and MH equipment already present form the lowest level issues. The ISM model suggests the lowest level issues have a very high driving power and as such influence all other issues.

This implies for the proper design of a MH system in FMS the main criteria/issue is the floor space and the existing MH system. Further, comparison with cheap human labour is also important. Especially in countries, where cheap labour is available, it may not be economically viable option to select and use the sophisticated MH equipment. So, some of the researchers have also come up with the concept of a humanised FMS where the material handling tasks in the FMS environment can be carried out by human labour (Nagar and Raj 2012). The other middle level and top level issues although very important for the success of MH system design in FMS can be achieved with the availability of lower level issues.

The ISM model is validated using TOPSIS methodology on the same issues. The hierarchy model given by TOPSIS is similar to that of ISM to a large extent. The TOPSIS also evaluated that the existing MH equipment and the floor space are the most necessary issues to be considered for the design of the MH system, followed by the comparison with cheap labour, operational control and compatibility of

MH equipment with other workstations. So these issues can be treated as the key issues for designing and selecting the MH system for FMS.

8. Conclusions

The present work identifies and models the main material handling issues in FMS. The purpose of identification of these issues and their analysis is to allow researchers and practicing managers to pay proper attention to these issues which may help them in designing the material handling systems in their organisations in a better way. The main limitation is this work is that, it is based on the opinions of the experts and industrial personnel which may be biased and based on their individual, personal experiences. This work can be further extended by using some MCDM techniques like AHP to precisely select the equipment required for the MH system.

Author Contributions: S.D. has done the planning, design, survey, modelling and writing of the present research. T.R. has the supervision during the research.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflicts of interest

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