A methodology for the selection of Material Handling Equipement in manufacturing systems

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Abstract: Mastering the Material Handling System in manufacturing is a crucial issue. According to (Hellmann et al., 2019), the costs of Material Handling activities range from 15% to 70% of total manufacturing costs depending on the kind of production. This paper discusses the selection of Material Handling Equipment for manufacturing plants. The selection of such equipment and their level of automation plays a significant role in the success of a material handling system definition, which influences the manufacturing performances. Through an analysis of the literature and field studies conducted with industrial companies, a selection methodology and a consistent list of criteria are proposed. A multi-criteria decision technique based on AHP (Analytic Hierarchy Process) is proposed to realize the selection. The proposition is implemented in a demonstrator software tool and illustrated on a simple example.

Keywords: Manufacturing systems, Material Handling Equipment Selection, Criteria Identification and Selection, Multi-criteria decision making, Analytic Hierarchy Process.

1. INTRODUCTION

Material Handling in a manufacturing context is known to be a difficult task for operators. This difficulty can be solved by using appropriate Material Handling Equipment (MHE) e.g. forklifts, Automated Guided Vehicles (AGV), etc. Such equipment can reduce the physical effort and sometimes the cognitive workload needed to perform the operations. Having appropriate MHE in a plant leads to increase the production activities efficiency and the occupational safety.

MHE in the context of this paper is considered as a fraction of a complex structure, which is known as the Material Handling System (MHS). MHS is defined as the interacting and/or independent MHE that form a unified whole (Stephens and Meyers, 2013). In the literature, MHS design problems are highly concentrated on MHE Selection problem (Saputro et al., 2015). This problem consists in selecting the right equipment for the appropriate activity. In this work, we primarily focus on this aspect. The idea is to evaluate different MHE alternatives according to many criteria (financial criteria, production criteria, etc.). Such evaluation allows to choose one solution that satisfies the specific requirements of the company. Works in the literature only focus on some restrained sets of criteria and in most of identified industrial contexts, the relevant criteria are numerous and difficult to merge. Moreover the relevance of these criteria varies from one study to the other. Therefore, a first contribution of this paper consists of identifying and characterizing all these criteria.

To characterize these criteria and their relevancy, five field studies were conducted at different manufacturers plant (a construction machinery manufacturer, a semiconductor manufacturer, a metal wire parts manufacturer, a specific screwing solution manufacturer and a fastening part manufacturer). Interviews were conducted about the most used criteria in selecting Material Handling within each company.

After identifying and characterizing the possible criteria, our second contribution consists of proposing a two levels methodology for the MHE selection problem. The first level is selecting MHE category and the second one is about MHE model selection. For illustration purposes, AHP is used for the evaluation in both selection levels. In each step, the possible criteria that were identified are proposed. Finally, for proof of concept, an implementation of the methodology is proposed on a demonstrator application.

The remaining of this paper is organized as follows, a literature review on MHE Selection Problem is given in the next section. Afterwards, the methodology proposal is discussed and the different steps are explained. Then, the description of the demonstrator is given. Final conclusions are summarized in the last section.

2. MHE Selection Problem

(Saputro et al., 2015) gave an overview of MHE Selection approaches, methods and tools. They reviewed 42 papers and identified three distinct levels of MHE selection:

- High level: MHE selection problem is focused on seeking a suitable MHE among the categories, e.g. conveyor, AGV (Automated Guided Vehicle), forklifts, etc.
- Intermediate level: MHE Selection problem is focused on seeking a suitable type of MHE within a category, e.g. selecting the best alternatives of among conveyors category (chute or wheel or roller).

- Low level: MHE Selection problem is focused on seeking a suitable model of MHE within a type, e.g. selecting the best alternatives among hand pallet truck types in terms of dimension.

Despite the fact that MHE Selection Problem is usually discussed in the literature, some limits related to the way this problem is being addressed can be spotted; the three levels of MHE Selection are mainly treated separately. Although the overall objective of MHE Selection problem is to find the appropriate MHE model for a given Material handling activity/activities.

Identifying the possible criteria for MHE is a necessary step that affects the final choice. However, the criteria used in the literature are sometimes not representative or limited. From seventeen articles, we noticed that the average number of criteria is about 14 criteria. e.g. in (Gaur et al. 2020), the authors relied only on seven criteria (safety, cost, maintenance, standardization, capacity, flexibility, space utilization). Furthermore, it is noticeable that in some articles, the categories of criteria are limited e.g. in (Karande et al. 2013) the authors used a list of six criteria that were affected into two categories: costs and characteristics. Therefore, the first objective of this work is to identify and characterize the criteria used in the literature and in industrial field studies before addressing the selection method.

Saputro et al. also identified three main MHE Selection approaches: Multiple Criteria Decision Making (MCDM) approach, Artificial intelligence approach, and optimization approach. Artificial intelligence approach is applied using knowledge basis and simulates the intelligence of experts (Saputro et al., 2015). Optimization approach aims to achieve optimal solution corresponding to quantitative goals, it is usable when all criteria can be quantified. In their review, authors identified that MCDM approaches were used in 32 articles out of 42. It is known to be effective in tackling alternatives under human's judgment. The methodology proposed in this work consists of combining the three levels (cited above) of MHE Selection. We propose in each level a list of potential criteria and evaluate the expert choice using a MCDM method.

3. Methodology for MHE Selection

The proposed methodology is illustrated on figure 1 as a decision support process. Compared to the literature, the objective is to provide an adapted set of criteria depending on the case and the level of the MHE Selection.

This methodology addresses the decision levels identified in (Saputro et al., 2015) and is composed of two main consecutive steps: MHE category selection and MHE model selection. In MHE category selection two decisions levels were combined (high and intermediate decision level) due to the high resemblance of the criteria used in these levels. Each level of decision (Category selection, model selection) uses the following steps:

- Criteria categories definition and comparison: This sub-step analyses thoroughly the aspects that are needed for the MHE Selection. A list of categories that can be used is proposed in the following section. Once the list is defined, an importance comparison is done between each category.
- Criteria definition and comparison: In this sub-step the decision-maker has to identify a list of criteria for each category. A list of criteria is proposed in the following section as well. Once this list is defined, a pairwise comparison is made between each criterion.
- Alternatives definition and comparison: In this final sub-step, the decision-maker has to define a list of MHE alternatives. Then comes the evaluation of these alternatives according to each criterion. Once this step is done, an overall priority ranking is obtained.

3.1 Criteria identification

The identification of the right criteria is an important step before the evaluation and the selection of the best suited alternatives. The alternative solutions are then compared using a MCDM approach.

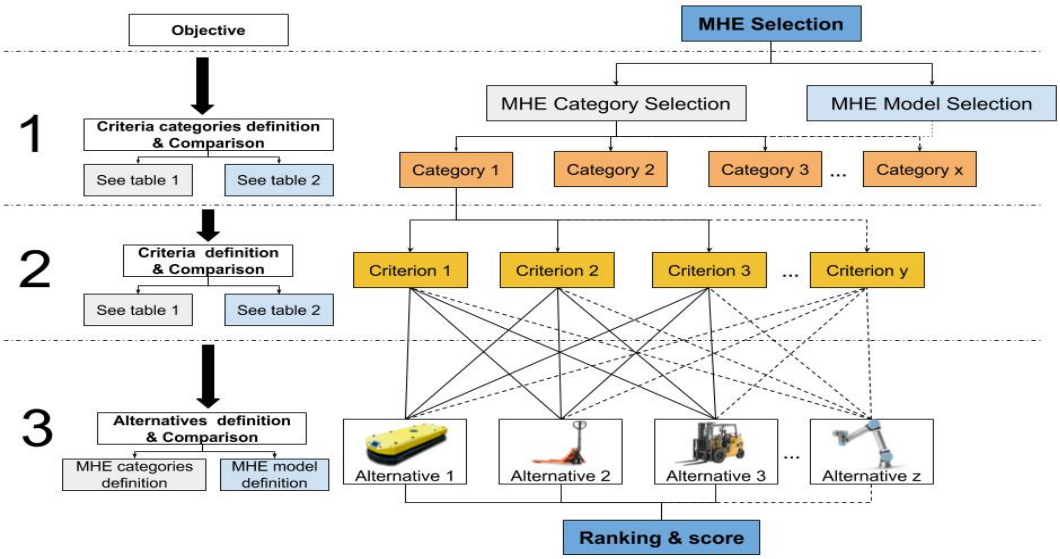

Fig. 1. Methodology to select the appropriate MHE for the design of MHS

278 criteria were identified in our study; 235 criteria from 17 articles that addressed different levels of MHE Selection (for space sparing issue these articles are listed in the "reference used for criteria selection" section) and 43 criteria from five field studies conducted through interviews and plant walk-through within different industries. It can be noticed that the average number of criteria used in each literature paper is about 14 criteria, meanwhile for the field studies, it is about 9 criteria. All these criteria were then classified along their usability into two distinct levels of MHE Selection: Low level, high & intermediate level. Then, a second classification was performed to affect each criterion to a specific category.

Since, it is not relevant to propose all these criteria to a decision maker, a correlation analysis was conducted to analyse the relation between the criteria of each category. As a result 61 criteria were retained as shown from table 1 and 2. Colors are used to show the origins of the criteria;

- Orange cells show the criteria that were used only in the industrial studies.
- Blue cells show the criteria revealed by the industrial fields studies analysis and never seen in the literature, but that were not formulated as criteria by the interviewees in their MHE selection.
- Green cells show the common criteria used in both the literature and the industrial field studies.
- Non-colored cells represent the criteria that were only used in the literature.

It is thus interesting to observe that both industrial and literature practices may progress with the results of our study. It is important to see that many important aspects in industrial fields (blue and orange cells) were ignored in the literature. And that industrial practices may benefit from literature suggestions. Moreover, it is interesting to observe that criteria were revealed in discussion with the practitioners, but not explicitly used in their processes.

The criteria of MHE category selection, which focus on seeking a suitable MHE among the categories (AGV, forklift, conveyor, ...), seem to be mainly related to the analysis of the Material handling activity. According to (Heragu et al. 2016), this analysis can be done through material, move, and method aspects;

- Material aspect regroups the criteria that determine the characteristics of the material to be moved.
- Move aspect regroups the criteria that define when and where the move is to be made.
- Method aspect defines the way of handling the materials.

Throughout the five field studies and the literature, we concluded that five categories are needed to make decisions related to the MHE category selection: Material, Handling, Control & interaction, Facility constraints, and finally the human factor (see table 1). The decision should then be more precise than with (Heragu et al. 2016) approach.

Table 1. Criteria for MHE category selection

Category	Criteria	Definition
Material	Type	It can be unit load, bulk material, fluid, or gas
	Shape	It can be regular, irregular, or variable
	Volume	The volume of the material
	Nature	It can be fragile, sturdy, or bulky
	Quantity	The quantity of the material to be handled
	Weight	The weight of the material
Handling	Handling type	It can be Loading/unload, feeding, moving, positioning
	Distance	The distance to be travelled from source to destination
	Direction	It can be horizontal, very slight, slight, medium, high, very high and extremely high
	Course	It can be straight, curved and right angle
	Transfer frequency	It can be very low, low, medium, medium–high, high and very high
	Path	It can be fixed or variable
	Level	It can be floor level, over height in horizontal, over height in vertical, or over height in inclined directions
Control & interaction	Mechanical LoA	The required Level of automation for the physical task
	Cognitive LoA	The required Level of automation for the cognitive task
	Control method	It can be automatic, manual, and self
	Ease of implementation	The ease with which the equipment can be implemented
	User-friendliness	The ease with which the equipment can be used
Facility constraints	Facility's equipment height	the height of the facility's equipment (e.g. rack, machines...)
	Doorway height	the height of the doorway
	Clear height of the facility	the clear height of the facility
	Aisle accessibility	The available aisles in the plant and their width
	Traffic	The impact of the equipment on the traffic
	Obstacle	The existence of obstacles that might block the movement of the equipment
Human factor	Acceptance of	The operator's acceptability of

	change	the equipment
	Control skills	Operator skills for the control of the equipment
	Maintenance skills	The maintenance skills needed for the equipment

On the other hand, the criteria of MHE model selection were affected into six groups: Operational, Technical, Economical, Supplier, Ergonomics, and Environmental (see table 2).

Table 2. Criteria for MHE model selection

Category	Criteria	Definition
Operational	Safety	Safety of the operators, equipment, and products
	Control skills	The control skills needed for the exploitation of the equipment
	Traffic	The impact of the equipment on the cross traffic
	Capacity flexibility	The potential to handle variation of the production volume
	Maintainability	The ease with which the equipment can be maintained
	Power and space requirements	The power and space mandatory conditions to exploit the equipment
	Supervision easiness	The ease with which the equipment can be supervised (e.g. the ability to track the equipment's localisation)
	Operational flexibility	The ability to do diverse handling operations
	Arrangement flexibility	The ability to change the positioning of the equipment
	Integration to the information system	The ease with which the equipment can be integrated to the information system of a company
	Behaviour predictability	The predictability of the equipment's behaviour in case of new events (e.g. blocked path)
Technical	Capacity	The amount of materials that can be handled by the equipment
	Speed	The speed that can be reached with the equipment
	Equipment width	The width of the equipment
	Equipment weight	The weight of the equipment
	Maintenance	The schedule of maintenance needed to preserve the equipment
Economical	Maintenance cost	The costs incurred to keep the MHE in operation
	Purchasing cost	The cost of the equipment
	Installation cost	The expenses that are incurred due to the installation of the equipment in the plant
	Operating cost	The costs related to the utilization of the equipment
	End-of-use value	The value of the equipment when it's ultimately used
	ROI	Return on investment
Supplier	Guarantee and after sale service	The guarantee and the quality of after sales service offered by the supplier
	Supplier relations	The quality of the relation (e.g. the duration of the contract)
	Supplier reputation	The reputation of the manufacturer
	Supplier's location	The location of the manufacturer
Ergonomics	Vibration	The vibration generated from the use of MHE
	Noise	The noise generated from the use of MHE
	Space for worker	The space left for the movement of the operators
	User-friendliness	The ease with which the equipment can be used
Environmental	Power usage	The power consumption of the equipment
	End-of-use hazardous waste	The waste generated by the ultimate use of the material handling equipment
	In-use hazardous waste	The waste generated during use of the material handling equipment
	Supplier's environmental behavior and image	The image of the manufacturer towards the environment

3.2 Multi-Criteria Decision Method

The MHE selection problem can be seen as a hierarchical problem (as shown in Fig. 1). To answer the selection objective problem cited at the top of the hierarchy, a group of criteria are proposed in the next level. Different alternatives have to be evaluated according to each criterion. This evaluation process can be applied using different techniques such as the analytic hierarchy process (AHP) method. We

focus on AHP as one of he most commonly used MCDM method. It includes both qualitative and quantitative aspects (Hellmann et al., 2019). It converts the problem into a hierarchical structure, where the objective is at the top level, followed by several assessment criteria. These criteria are judged over various alternatives to achieve the best solution (Agarwal & Bharti, 2018). AHP method is based on pairwise comparison matrices which can be used for measuring the importance of criteria (Saputro et al., 2016), and also evaluating alternatives according to each criterion. Applying AHP in our context can be summarized in four steps:

1. First, the problem is modelled as a hierarchy containing the decision goal (MHE category selection or MHE model selection), the alternatives for reaching it (MHE categories or MHE models of one specific category), and the criteria categories and their sub-criteria for evaluating the alternatives.
2. Establish priorities for each level of the obtained hierarchy by making series of pairwise comparisons. Here the preference of the user among criteria is captured.
3. The synthesis of the judgements to obtain a set of global priorities for the hierarchy. The verification of the consistency of judgement.
4. The choice of one alternative based on the results.

For further details about AHP, see (Gaur and Ronge, 2020). Pairwise comparison in this method considers the qualitative and quantitative measures.

In the context of MHE selection, the category given in tables 1 and 2 are used to define the hierarchy of the problem. These categories are selected and compared by the decision-maker. Then, the second level of the hierarchy is described using the criteria given in table 1 and 2 (also inter compared). Once the problem hierarchy is set, each alternatives are evaluated against the selected criteria for quantitative ones and pairwise compared for qualitative ones (the comparison is automatically done for quantitative criteria). A ranking is resulted from this process. The qualitative evaluation can be applied for the MHE category selection where the experts' judgements is highly required. On the other hand, the MHE model selection can be done using both qualitative and quantitative evaluation.

4. MHE Selection Tool & Illustration

For illustration purposes, we take the example of a company that was interviewed in the field study and wants to invest in a MHE for the transportation of heavy metal boxes full of screws. In this example, the MHE category selection is needed since the problem is to select a type of technology (Conveyor belt, AIV, forklift, ...). In this context, six criteria are selected from table 1: weight and type from Material Criteria, course and transfer frequency from Handling Move Criteria, and aisle accessibility and traffic from Facility Constraints Criteria.

A JAVA interface is developed to deploy the proposed methodology. It processes as follows. The program starts by proposing two choices MHE category selection and MHE model selection. Once the choice is done the user (decision maker) has to select the criteria categories from the proposed list followed by a comparison of these categories. Later on, a list of criteria is proposed for each category, the user has to keep the criteria needed for the MHE Selection and once again, has to compare the criteria. Afterwards, the user gets to choose the alternatives, compare between them according to each criterion (see Fig 2) and finally gets the score and ranking of each alternative.

The program also displays details about the different computations that are done to reach the final results. e.g. in Fig 3 the program shows the matrix of pairwise comparison that was done for alternatives according to Weight criterion and the consistency of the comparison. At the end, the JAVA program displays the score and rank of each alternative (see Fig 4). In this case, the Belt conveyor obtained a score of 37%, while the AGVs got 36%, the decision maker has the ability to pick one of these alternatives based on his judgement.

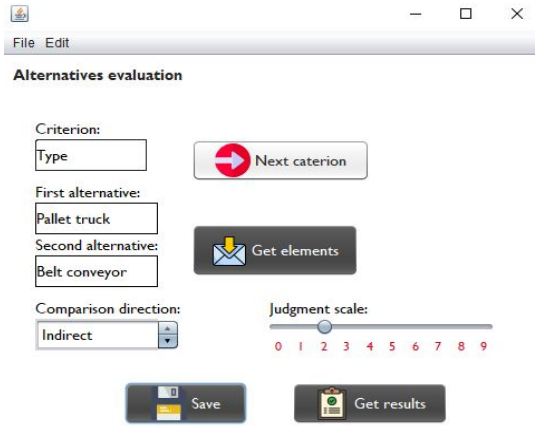

Fig. 2. Alternatives comparison

Pairwise comparison of alternatives according to Weight criterion			
Alternatives	AGV	Pallet truck	Conveyor
AGV	1.0	0.3	0.5
Pallet truck	3.0	1.0	1
Conveyor	2.0	1	1.0
Eigen Value = 3.02			
CI = 0.01			
CR = 0.01			
CR = 0.01 < 0.1			

Fig. 3. Pairwise comparison of alternatives according to one criterion

Categories	Criteria	AGV	Pallet truck	Conveyor
Material	Weight	0.0667	0.1333	0.1333
	Type	0.0283	0.0738	0.0646
Handling	Course	0.0278	0.0278	0.0278
	Transfer frequency	0.0556	0.0556	0.0556
Facility Constraints	Aisle accessibility	0.0417	0.0417	0.0417
	Traffic	0.0417	0.0417	0.0417

Eigen Vector (Global weight of each alternative)		
Alternative	Score	Rank
Pallet truck	26%	3
Belt conveyor	37%	1
AGVs	36%	2

Fig. 4. Results of the decision process

5. CONCLUSIONS

The overall goal of this work is to propose a consistent methodology for the MHE Selection Problem and a list of

criteria that can be used for this problem. The selection can be made at two analysis levels: MHE category selection and MHE model selection. For each kind, a potential list of criteria were identified from 17 articles and industrial case studies. These criteria are classified into different categories. The literature and field analysis have shown that it does not exist a unique list of criteria for any MHE selection problems. It demonstrates that some criteria are lacking in the current literature and that field practices are ignoring some of literature advises. This work considers that criteria selection depends on each case characteristics and provide two carefully constructed sets of criteria. These criteria and related category are used in an AHP to aid the decision of MHE selection.

Such decisions require the intervention of more than one person, for future development, a multi-person MCDM should be included in the methodology. A real case application of the proposed methodology should be conducted for validation purposes. additionally, it could be efficient to propose a preselection of relevant criteria based on the case/company characteristics. Namely, the precise identification of company competitive priorities mixed with Material Handling activity features give good insights about the most important criteria. This statement was also confirmed in a study on analyzing Level of Automation in manufacturing made by (Säfsten et al., 2007) which claims that manufacturing strategies and decisions should support the competitive priorities of the company.

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