Field studies analysis for new Material Handling System Design approach

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Abstract

Mastering the Material Handling System (MHS) is still a crucial issue, according to Hellmann et al the costs of Material Handling activities ranges from 15–70% of total manufacturing costs depending on the kind of production [6]. The introduction of industry 4.0 technologies for Material Handling, is renewing the decisions to take in the design of MHS. The practices in MHS design and management are very diversified in industry and no consensus clearly exist on how efficiently designing such system. This paper discusses the need to understand the relation between the different aspects of Material Handling System design, and propose to identify the key challenges to be addressed. Through field studies that were conducted with five distinct companies and an analysis of the literature, five MHS aspects are examined; Material Handling Activities, Material Handling and automation, Material Handling Control System, Material Handling Equipment Selection, and Material Handling System. Based on the results of the analysis, a cross analysis is performed to identify the differences and the common patterns between the literature and the field study. As a result, research directions for new MHS design approach are proposed. It is composed of four main challenges; Material handling specifications, MHE selection, MHE deployment, and MHS analysis. Each challenge is linked to other potential subjects.

1. Introduction

The Material Handling System (MHS) aims at storing, controlling and moving products, they play a key role in the performance of manufacturing systems [2]. An efficient MHS leads to an effective production management, improvement of on-time delivery, and enhancement of production quality [11]. The cost of Material Handling Activities is far from being negligible, it ranges from 15–70% of the total manufacturing cost depending on the production type [6].

In the literature, MHS design is still not defined properly. Main approaches are focused on the definition of design principles (defining lots, optimize flow, ...) without supplying comprehensive methodological approach to form a design process. Many aspects exist on the MHS design. Most of the research works mainly focus on some MHS sub-problems, such as the optimization of material flow [7], the definition of the appropriate Level of Automation (LoA) [3], or the Material Handling Equipment (MHE) Selection Problem [13]. However, the design of the MHS has to be done through solving all these interdependent sub-problems. It is thus lacking a global approach of the MHS design problem.

Furthermore, the technological opportunities brought by industry 4.0 have opened new questions about MHS design. The way to include autonomous robotics systems and IoT (Internet of Things) solutions is to be introduced in the frame of MHS design. Current research addressing these topics is still at its earliest stage. The challenges of transitioning to industry 4.0 are reinforcing the question of selecting the right Level Of Automation (LoA) to conduct the Material Handling Activities. Usually automation is thought to be the effective solution and is regarded as an important principle in classic MHS design approaches. In these approaches the automation of activities is presented of an ever-existing goal without precisely analyzing the context. In [5, 15], automation is presented as the 8th principle of a good

MHS design. This does not match with the LoA analysis literature that supports the idea that LoA must be carefully defined to maintain the effectiveness of the system [4]. The LoA question of MHS is therefore to be carefully integrated in MHS design process.

Moreover, in industries, the observed practices are very dissimilar regarding MHS design. Specific practices are observed depending on the domain (such as semiconductor industry). However, there are also variations of designing MHS within each domain. Therefore, gaps exist between the observed practices and existing literature work. Thus, it is important to understand the reasons and motivations behind these different approaches and practices so to design and manage an MHS.

The objective of this paper is to analyze the practices related to the MHS design in various industries, and to propose research directions that renew MHS design approaches within the context of industry 4.0. This work is based on field studies conducted with industrial companies and literature analysis as well. The study focuses on five main aspects of Material Handling (MH) :

- Material Handling Activities,
- Material Handling Automation,
- Material Handling Equipment Selection,
- Material Handling Control System,
- Material Handling System design in general.

The remaining of this article is organized as follows; It starts with a literature review on MH. Afterward, the field study is presented to identify the progress of MHS and its different practices. A cross analysis of the field studies is then proposed to highlight the relevant practices and challenges. Then, based on the obtained results, MHS design new challenges and research directions are discussed. Final conclusions are summarized in the last section.

2. Literature Review On Material Handling System

Studying MHS is a broad topic. The next sections are clarifying the perimeter of Material handling actions considered in this paper and introduce the various problems related to their development and utilization. First, the purpose and principles of Material Handling Activities are defined. Then, as automation is an important part of MHS selection and deployment, an overview of MH automation concerns is given. The literature is continued by presenting the problem of Material Handling Control System (MHCS) and the topics related to Material Handling Equipment (MHE) Selection. This literature section is concluded by presenting the available techniques for MHS design from a general perspective.

2.1. Material Handling Activities

MH may be summarized as the activity that uses “the right method 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” [5, 15]. In Kim et al. [9] the authors identified five activities of Manual Material Handling that can be performed by the operators; Symmetric lifting and lowering to/from ground/knuckle height, asymmetrical lifting and lowering, carrying, pushing/pulling. In fact, MH includes different functions that supports the production system missions as moving, packaging, and storing of substances in any form [15]. Movement can be of 6 types: transporting, conveying, maneuvering, elevating, positioning, and transferring [5]. Five distinct dimensions related to MH are identified to specify the expected behavior: movement, quantity, time, space, and control [15].

- The movement involves the transfer of materials from one point to another. In this dimension, the efficiency and safety of the move are the major concerns.
- The quantity per move influences the type and nature of MHE and the handling of materials.
- The time dimension defines how fast the material should move through the facility, it affects the amount of the work in process, inventories, and lead times of an order delivery.
- The space dimension is related to the required storage space of MHE and its movement. This dimension is also related to the queuing or staging space for the material.
- The control dimension concerns the material tracking, identification, and inventory management.

It is considered in the remaining of the paper that the MH missions are including: picking, moving and storing material, products or tools; machine or workstation feeding; material packing for inner transportation. The MH activities can be performed by operators, using MHE or by autonomous MHE such as robots.

Some of the MH activities are known to be painful for humans, some articles in the literature try to solve this problem by including assistive devices in the field [16, 27]. Therefore, to be realized, MH activities involve the intervention of various types of MHE (such as forklifts, autonomous guided vehicles, ...). The use of MHE helps to reduce the mechanical efforts, and sometimes the cognitive efforts as well. These aspects are addressed in the next section.

2.2. Material Handling and automation

According to [5, 15], Automation is the 8th principle of MHS design, it is considered as a mean to improve operational efficiency, increase responsiveness, consistency, and predictability. Automation may be measured with several levels that range from a manual level to fully automated level. Finding and implementing the appropriate Level of Automation (LoA) in a controlled way could be a solution to maintain the effectiveness of a system [4].

A field study at five different companies' manufacturing plants driven by Bøgh et al. [19], have shown that more than two thirds of 566 analyzed supportive manufacturing tasks (ex: part feeding, machine tending, transportation…) may benefit from higher LoAs. Moreover, the authors have shown in their study that the transportation activities are by far the most manually performed tasks in the shop floor and are generally assignable to robots from a purely technical point of view [19]. Granlund [33], found in case studies that the LoA of MH activities is low for 7 main reasons: high cost of equipment, need for flexibility, existing concerns on equipment reliability, integration problems, staff acceptance difficulties, lack of top management commitment, need for staff training. Therefore, many opportunities exist for MH activity automation. It becomes an important point to decide if the automation of MH may be profitable for the production system performance. The topic of selecting the appropriate LoA is present in every manufacturing domains and is addressed in a large sense in the literature. Parasuraman et al. [12] explain that automation is technically performed by two approaches: mechanization (for physical task) and computerization (for information processing and decision making). The basic question formulated by Parasuraman et al.: “Which system functions should be automated and to what extent?” is certainly not easy to answer since many aspects should be studied to take a fully enlightened decision.

Frohm et al. [8] applied this principle to manufacturing activities, they propose a taxonomy of LoA for manufacturing systems which considers cognitive and physical tasks as a decomposition of automation possibilities (see table 1). They define LoA as “the allocation of physical and cognitive tasks between human and technology, described as a continuum ranging from totally manual to totally automatic". According to [8], the physical tasks are the basic core technologies, such as drilling, grinding, etc. In the context of MH, the physical tasks are: packing, picking, storing, transporting, conveying, maneuvering, elevating, positioning, or transferring.

The cognitive tasks deal with controlling and supporting the physical tasks. In MH, the cognitive tasks consist of planning transportation, sensing environment when moving, identifying products, etc. Table 1 details the taxonomy proposed by Frohm et al. illustrated with some examples related to MH.

Table 1

Levels of automation [8] (examples of MH are added)

LoA	Mechanical (Physical tasks)	Cognitive (Cognitive tasks)
1	**Totally manual** - Totally manual work, no tools are used, only the users own muscles power.	**Totally manual** - The operator creates his/her own understanding for the situation, and develops his/her course of action based on his/her earlier experience and knowledge. E.g. The choice of paths and destinations of the handled material is entirely done by the operator.
2	**Static hand tool** - Manual work with support of static tool. E.g. Two-wheel hand trucks	**Decision giving** - The user gets information on what to do, or proposal on how the task can be achieved.
3	**Flexible hand tool** - Manual work with support of flexible tool. E.g. Hand pallet truck	**Teaching** - The user gets instruction on how the task can be achieved. E.g. The operator on a truck lift has to follow signs to reach the destination
4	**Automated hand tool** - Manual work with support of automated tool. E.g. Pneumatic manipulators	**Questioning** - The technology questions the execution, if the execution deviate from what the technology considers being suitable. E.g. if the operator chooses a loaded dwell point, the As/Rs displays an error.
5	**Static machine** - Automatic work by machine that is designed for a specific task. E.g. Automated Guided Vehicles (AGVs)	**Supervision** - The technology call for the user's attention, and direct it to the present task. E.g. AGV displays an error if an obstacle is found.
6	**Flexible machine** - Automatic work by machine that can be reconfigured for different tasks. E.g. Overhead Hoist Transport (OHT)	**Intervene** - The technology takes over and corrects the action, if the executions deviate from what the technology consider being suitable. E.g. if an obstacle is detected, the AIV can find another alternative to reach the destination.
7	**Totally automatic** - Totally automatic work, the machine solves all deviations or problems that occur by itself. E.g. Automated storage and retrieval system (As/Rs)	**Totally automatic** - All information and control are handled by the technology. The user is never involved.

This taxonomy is used in the work of [3] who investigated how the levels of cognitive automation and mechanical automation of the MHS affects manufacturing flexibility. They analyze a real manufacturing system using a method called DYNAMO++ which is used for redesigning a system in terms of LoA, whether it is physical or cognitive automation. Authors concluded through a case study that the automation of cognitive activities can be as significant as the automation of mechanical activities. It improves the operators' performance and decreases their mental workload. As mentioned in [6], MHS can involve many technologies such as hand trucks, carts or lift trucks operated by human, conveyors, until heavily automated solutions such as Automated Guided Vehicle (AGV) or Automated Intelligent Vehicle (AIV). For cognitive automation, connection may be made with plant's Manufacturing Execution System (MES) or by using the technologies of IoT. In this context, the main question that can be addressed is to know when and how to automate a Material Handling activity. Additionally, with the new possibilities brought by industry 4.0 and namely by full connectivity of production actors, it is important to question the applicability of a human-centered approach [30] within the MHS automation context. Automation may be a good strategy to improve MHS performance, but even when needed, the automation process is often hard to implement for companies [33].

2.3. Material Handling Control System (MHCS)

Introducing autonomous MHE in the MHS and synchronizing diverse MH agents (operators & systems) requires an efficient control system of the whole operations. The definition of the Control System for MHS is infrequently addressed in the literature.

Although, some authors tried to propose new communication structures and technologies for the MHCS. In [1], the authors proposed a holonic control system for operating an automated MHS. The holonic control architecture allows the control units to communicate between them and make decisions without consulting any supervising entity. According to the authors, this architecture gives the ability to the control units to choose the schedule with the lowest cost. However, this kind of work is still at a conceptual stage. The communication technologies and devices and the cooperation methodologies and protocols to settle this structure for the MHCS are still to be defined. Wan et al. [17] conducted a study of context-aware cloud robotics (CACR) and its applications. CACR is characterized by two features; context-aware services which is a computing technology that incorporates information about the current location of an equipment to provide more relevant services to the plant, the second feature is about its ability to reach an effective load balancing. Through a case study, simulation results showed that using CACR for Material Handling can improve performance in terms of energy-efficiency and cost-saving compared to traditional methods. In addition to the works mentioned above, Wang et al. [18] propose a model of Cyber Physical System (CPS) for the Material Handling. The model uses algorithms for the optimization of the energy consumption and traveling distances and time, it relies on the prediction of the processing time of works in progress, to increase the readiness of the MHE. Based on the results of the case study, the proposed model showed significant results on the reduction of the traveled distance of trolleys and of their energy consumption. CPS is considered to be one of the latest technologies that was brought with the concept of industry 4.0, it enables companies to keep high traceability and controllability in manufacturing for better quality and improved productivity [18]. From the technologies and structures mentioned above, it is noticeable that tremendous amount of data have to be collected from the shop floor. The technologies related to the CPS (e.g. IoT, Real Time Location System, Cloud computing, etc.) allow various manufacturing resources to be intelligently sensed and automatically managed and controlled [22]. Chen et al. [21] show the ability of Radio Frequency Identification (RFID) to identify, classify, and manage the flow of materials and information wirelessly. They also highlight the potential of RFID to be applied to MHS in order to increase the traceability of deliveries. However, several challenges that are related to these technologies are identified. For instance, the decision to invest in these technologies and for which MHE still remains unclear. In addition, the deployment of these technologies needs an accurate selection of KPIs to allow a proper control.

2.4. Material Handling Equipment Selection

MHE are considered to be key elements for good MHS functioning. The interacting and/or independent MHE including the operators form a unified whole, which is called the MHS. The applicability of LoAs and technologies of the MHCS depends highly on the MHE. For instance, the use of a pallet truck does not allow to reach significant cognitive LoAs and restrains the data exchange between the MHS and the MHCS. In the literature, MHE Selection Problem is one of the most addressed MHS problems. The objective of such decision is to find the appropriate equipment model (e.g. a specific reference of an AGV) for one MH activity or a set of activities. To reach the final objective, a series of selections have to be done; starting from the selection of a specific MHE category (e.g. Cranes, conveyors, or pallet truck), ending up with the MHE model selection. In order to proceed in such decisions, a set of criteria is needed to express the MH activity requirements and restrictions.

In the literature, most of the papers focus on a limited set of criteria and address only one type of MHE Selection [23, 24, 25, 26, 28]. For instance, Onut et al. [23] conducted an MHE Selection based on five criteria (material, move, method, cost, area constraints). Moreover, Karande et al. [26] focused only on economic criteria and characteristics criteria for the selection of a conveyor. Furthermore, Chakraborty et al. [24] displayed a list of criteria that are used for the selection of a specific MHE category amongst four categories (conveying systems, industrial trucks, cranes and hoists, auxiliary equipment). However, a wider list of criteria should be taken into account otherwise the selection decision could be biased.

To address this limit, a methodology for the MHE selection is proposed in [36]. The selection approach is based on two main consecutive steps; MHE category selection (such as selecting whether to use AGVs or ForkLifts) and MHE model selection (such as a specific model of AGV). Each of these two steps is linked with a set of relevant criteria that were selected from the literature and field studies. To narrow the number of criteria and make its integration feasible in a decision tool software, a correlation analysis is conducted. As a result, 61 criteria were classified into 11 different categories. These categories cover most of aspects that are needed for a rational MHE Selection.

It can be seen from these literature reviews, that these problems (MH automation, selection, control) need to be handled as a whole since these problems are highly related. The interaction between all equipment, taking into account these MH problems, form a unified whole called Material Handling System (MHS) [15].

2.5. Material Handling System (MHS)

The design of MHS is studied by many researchers, but no consensus exists. Namely, differences may be found whether the study addresses a system modification or a new system design. MHS design may be of various complexity whether it addresses a single point to point transportation or a whole plant transportation network design. Nevertheless, different descriptions may be found in the literature. For instance, in [5, 15] the authors cite 10 principles that should be taken into consideration during the design of MHS. These principles were developed by "MHI" which is considered as one of the largest Material Handling, logistic and supply chain association (www.mhi.org). The principles to be applied to MHS design are summarized in 10 concepts to consider or define when designing an MHS:

1. Planning: A Material Handling plan is a prescribed course of action that is defined in advance of implementation, specifying the material, moves, and the method of handling.
2. Standardization: It is a way of achieving uniformity in the Material Handling methods, equipment, control, and software without sacrificing needed flexibility, modularity, and throughput.
3. Work: The measure of work is material-handling flow (volume, weight, or count per unit of time) multiplied by the distance moved.
4. Ergonomic: Ergonomics seek to adapt work and working conditions to suit the abilities of the worker.
5. Unit load: A unit load is one that can be stored or moved as a single entity at one time, regardless of the number of individual items that make up the load.
6. Space utilization: Effective and efficient use must be made of all available space.
7. System: A system is a collection of interdependent entities that interact and form a unified whole. Material movement and storage activities should be fully integrated to form a coordinated, operational system which spans receiving, inspection, storage, production, assembly, packaging, unitizing, order selection, shipping, transportation and the handling of returns.
8. Automation: Automation is a technology for operating and controlling production and service activities through electromechanical devices, electronics, and computer-based systems with the result of linking multiple operations and creating a system that can be controlled by programmed instructions.
9. Environmental: The environmental principle in Material Handling refers to conserve natural resources and minimizing the impact of material-handling activities on the environment.
10. Life cycle cost: Life cycle costs include all cash flows that occur between the time the first money unit is spent on the material-handling equipment or method until its disposal or replacement.

In addition to these 10 principles, [5] propose to structure the approach to find the right Material Handling solution with six questions:

1. Why should a Material Handling equipment be selected?
2. What is the material to be moved?
3. Where and when is the move to be made?
4. How the move will be made?
5. Who will make the move?

It might be noticed that these questions, are addressing a single point to point movement, when it can be shown that a global approach of the whole MH system design should be made. Authors in [14] proposed a design approach which is based on the examination of materials and routes, the design approach is composed of four steps:

1. Assemble flow analysis output

1. Routes and intensities
2. Material flow diagrams
3. Layout(s)

2. Class selection for each route and material

a. Container
b. Route structure
c. Equipment

3. Calculation of equipment requirements

4. Evaluation and selection of equipments

In this kind of approaches, it is assumed that the plant layout is constant and known. The workstation placement does not change and cannot be changed. And finally, production volume is assumed constant. It can be noticed that neither the technology nor the communication and control systems are clearly addressed by this proposal. Important aspects has the Internal logistics and automation strategies of the company should also be analyzed [33].

As stated in [14] and [15], it is essential to associate the competitive advantage or the company's strategy to its MHS design. MHS design should fit and supports the firm's manufacturing strategy [14] and should also reflect the strategic objectives and the needs of the organization [15, 33]. All the design approaches found in literature give high level outline of the process but remain vague on its realization. The principles are to be used but the approaches lack of precision and do not explicitly tackle the new challenges of industry 4.0 and the mandatory profound LoA analysis.

Table 2

Cases general information

Case	Field	Size of the company (nb of employees)	Product: size, production volume, complexity	Production strategy	Production organization
Case A	construction machinery manufacturer	102.300	Large, high, complex	Majority make to order, Some make to stock, and engineering to order	Assembly line
Case B	Semiconductor manufacturer	45.500	Small items large batches, very high, complex	Make to order	Flexible job shop
Case C	Stainless steel fixings	40	Small, very high, medium	Make to order	Flexible flow shop
Case D	Fastening and assembly solutions	7.250	Small, very high, medium	Make to stock	Flexible flow shop
Case E	Metal wire parts manufacturer	130	Small & Medium, small to medium, simple	Make to order	Job shop

To improve the understanding of MHS design problems, a field study at various companies is conducted to answer this subject from a field practices perspective. Next section presents the conducted field studies within 5 different industrial companies to share their experience of MHS design, management and usage.

3. Field Studies

Baxter et Al. [20] identified seven types of qualitative case study: explanatory, exploratory, descriptive, multiple-case studies, intrinsic, instrumental, and collective. In this work, multiple field studies are conducted for explanatory and exploratory purposes. Exploratory, in order to explore distinct situations where Material Handling is differently performed, and to understand what are the factors that provoked these differences and the similarities. Explanatory, to seek thorough answers to the main question: What are the mains challenges of the MHS design process ?

3.1. Field studies design

To understand how Material Handling is performed in industries, five interviews are conducted using a grid analysis. Later on, three steps are adopted to exploit the data; data reducing, data display and cross analysis. This procedure is inspired from [29].

Table 2 presents general information about the company typology for each case. The objective of the survey is to define Material Handling parameters, and to understand the approaches used for the design of MHS. Various companies have been chosen to observe different practices. The interviews were semi-directed, with additional questions to deepen interviewee's answers. In most of the cases the interviews were complemented by a plant walk-through.

In order to thoroughly analyze the different cases in terms of LoA, a concept was adopted from the work of Parasuraman et al. [12]. The concept allows to visualize the LoA of different systems through the cognitive and physical aspects. The original concept is used to compare four classes of information functions (information acquisition, information analysis, decision and action selection) and action implementation of different systems. In our case, it is used to visualize the LoA of different cases based on two types of activities; Productive activities and Material Handling activities (see Fig. 1). Figure 1 summarizes the observation made on the visited plant LoA and serves to discuss the observed practices in each case description (Sect. 3.2 to 3.6).

Details about each case study are given in next sections. Each case is described through the following steps:

1. Presentation of the case
2. Presentation of the interviewee
3. Identification of the competitive priorities and objectives of the company
4. Description of the existing Material Handling activities
5. Description of automation (LoA) in productive activities
6. Description of automation in Material Handling activities
7. Description of Material Handling design approach
8. Criteria identification for measuring the performance of Material Handling activities
9. Criteria identification for MHE selection
10. Design experiences or general remarks

3.1.1. Case A

The interviewed company in Case A is a construction machinery manufacturer. It is considered as one of the world's leading manufacturer of construction and mining equipment. The analyzed manufacturing plant is producing bulldozers and mechanical shovels. The productive activities are mainly organized as an assembly line.

The interviewee is a former plant director. He believes that in the context of the production of heavy vehicles, company survival and effectiveness are mainly driven by automation.

The company delivers standard and customized machines to final clients or retailers. Its competitive priorities are :

- Production cost
- On time deliveries (OTD)
- Quality of products
- Design adaptation

The Material Handling activities are of two kinds. The first is to move heavy mechanical parts as truck chassis. The second is to guarantee a good line-side supply.

The productive activities are mainly assembling activities. The mechanical assistance of operators is important for heavy parts lifting but many movements are done manually. For the cognitive side, torque control is applied but many decisions are left to operators. More assistance is given for maintenance activities. The LoA of productive activities in this case study is considered just below the medium grade for both cognitive and physical tasks.

The Material Handling activities are done using the following equipment; Forklifts, trolleys and “water-spider” (a train of wagons guided by an operator which passes across different workstations). Cranes and part lifters are also used. The mechanical effort for lifting parts is fully automated, sometimes the mechanical power needed for transportation is mechanized. However, decisions related to picking and placing items, navigation as well are done by a human. Therefore, the LoA of Material activities is considered below the medium grade as shown in Fig. 1.

The Material Handling System design approach used in this case study, is highly directed by corporate guidelines available for all production sites. Their objective is to optimize transport length and number of parts touches. Their second approach is to benchmark the practices of automotive industry.

To measure the MHS efficiency, some key performance indicators are used: Overall Equipment Effectiveness (OEE), Inventory on location, OTD, number of touches, line balance.

For MHE selection, the important criteria are related to the equipment performance (speed and capacity). Return on investment (ROI) and needed skills of equipment.

Some line-side transportation activities were automated in the past using self-guided vehicles. Then the system was dropped off because its speed movement and reactivity caused a negative impact on the OEE. It has been noticed that replacing the automated guided system by a human was easier to set up and it has been observed that it offers a new communication channel between the workshop and the warehouse.

3.1.2. Case B

This second case is a semiconductor manufacturer, in which two types of silicon wafers are processed. Each type has its own production line. Both lines are organized as a flexible job shop.

The interviewee is an industrial methods manager. He is a proponent of technology and automation, but he considers that nowadays smart robots are still not smart enough when it comes to handling perturbations.

The competitive priorities of the company are based on three main factors:

- Cost
- On Time Delivery (OTD)
- Innovation

The Material Handling activities in the facility are: to transfer the boxes of wafers across different workshops and ensuring a short transportation time.

The productive activities are composed of a set of 600 to 700 steps. All tasks are completely automated, from the production machines to the quality control process. That is why the LoA of productive activities in this case is placed at a high degree for both cognitive and physical tasks.

The Material Handling activities are mainly performed with Automated Guided Vehicles (AGVs) for one workshop and Overhead Hoist Transport system (OHT) for the other. Each equipment is dedicated to handle one product type. The utilization of OHT allows a high layout flexibility for the shopfloor, since the installation of the OHT is done under the ceiling without occupying the floor space. For both of these equipment, human intervention is not needed, except when a breakdown occurs. That is why the physical and cognitive LoA are both placed at a high degree in Fig. 1.

The Material Handling System design approach is based on the definition of the needs and the benchmark of best practices of other industries in the field. After this step, many simulations are done to make sure that the system is able to satisfy the needs. During this phase, lot of factors are considered such as; the capacity of the MHE, the cost of the MHE, the degree of automation, the flow units, the ROI. The performance of the Material Handling system is measured through: number of transports, time of transport, Overall Equipment Effectiveness (OEE), and throughput.

For the MHE selection, the company uses the following criteria: ROI, degree of safety and precision.

The activities done in the facility are measured through a 5 degrees LoA scale that was developed by the interviewee, it considers both of cognitive and physical automation.

Company B tried to introduce new technologies such as Autonomous Intelligent Vehicles (AIVs), but it did not cope with their expectations. The equipment took different paths to reach its destination, which led to increase the transportation time and the risk of collision with operators. The transportation time unpredictability brought by the system was also feared.

3.1.3. Case C

This case addresses the production of drawn wires and stainless-steel fixings. The company is involved on various industrial sectors such as: construction, railway, automotive, food and beverage industry, energy networks and management or solar industry.

The interviewee has been working in the company for almost 9 years and held 2 positions since then; he first started as a Production Manager and now he is a Lean Manager.

The competitive priorities of the company are based on the following factors:

- Quality of products
- On Time Delivery (OTD)
- Design adaptation

The Material Handling activities in the facility have to ensure the movement of the materials across different operations. Wire coils of up to one ton are moved and heavy metal boxes of metal parts as well.

The productive activities are done through the physical tasks are automated, but still need to be configured by the operators. That is why the LoA of physical tasks is higher than the LoA of cognitive tasks. The main activity of shop floor operators is to set and control machines.

The Material Handling activities are mainly done using forklifts, pallet trucks, and one automated equipment which is a conveyor system. The mechanical efforts are automated for some equipment, but the company relies mainly on pallet trucks for their Material Handling activities. For this reason, the LoA of physical tasks in Fig. 1 is placed near the medium degree. All material movements are decided by the operators, except the ones made with the conveyor system. Therefore, the LoA of the cognitive tasks is considered at a very low degree.

This company does not have a Material Handling System design approach, but their main concern is to remove NVA activities and increase the availability of operators so they can focus on their main tasks.

For the MHE selection, the main criterion that is considered is the ROI.

An automated transfer cart on rails was used in the past, but the loading/unloading operations were too difficult to be performed by the operators which increased downtime. The company then removed the automated transfer cart and switched to a completely manual MHE: pallet trucks. The railway remains in the workshop, which causes some traffic restriction.

3.1.4. Case D

Company D is considered as a global leader in fastening and assembly solutions. It is involved on various industrial sectors e.g. automotive, energy networks, construction, and agriculture.

The interviewee has been working in the company for 20 years and held several positions, and now he is a “Factory of the future” coordinator. His role is to manage the transition to a factory which integrates more technologies related to industry 4.0.

This company has the perspective to increase automation in its processes using robots, and cobots by the end of 2030 as stated by the CEO. Its competitive priorities are :

- Innovation
- Design adaptation
- Quality
- On Time Delivery (OTD)
- Cost

The Material Handling activities guarantee the routing of materials across the whole manufacturing process. These activities are whether manual, semi-automated, or fully automated. They consist in moving boxes of very small parts and heavy bulk of raw materials.

The analyzed plant is composed of 2 production workshops; one for the production of metal fastening solutions (D□), and the other for the production of plastic fastening solutions (D□). More investments were done for D□, since the plastic fastening solutions were and still are a highly competitive market according to the interviewee.

The productive activities for both D□ and D□ are done by a fleet of automated production machines. Some machines still need manual configurations and settings, thus the LoA of cognitive tasks is not as high as the LoA of physical tasks.

The Material Handling activities in D□ rely on non-automated equipment such as: forklifts, electric stacker, and pallet trucks. However, the navigation is done by the human, which is, according to the interviewee, time consuming. While in D□, the equipment are completely automated and does not need interventions from the operators.

The Material Handling System design approach is based on making the material flow simple as much as possible. Environmental aspects (carbon footprint) are considered as well.

A value stream mapping is used to follow MHS efficiency with three main KPIs; Intermediate storage time, cost of work-in-progress (WIP), and cycle time.

For the MHE selection, the company relies on 3 main criteria; total cost of ownership (TCO), ROI (ideally less than 2 years), and finally the suppliers' reputation and location.

Autonomous Intelligent Vehicles (AIVs) are used in another plant that belongs to the same company, the interviewee affirmed that the equipment takes short time to transport materials. It is integrated to the information system of the plant, which allows the operator to supervise the movement of the equipment through a screen.

3.1.5. Case E

Case E is a plant of a metal wire special parts manufacturer, in which a variety of custom products are made in small and medium production. The productive activities are organized as a job shop.

The interviewee is the CEO of the company for 34 years. He is a proponent of technology and automation, and constantly tries to integrate new sort of technologies to the plant.

The competitive priorities of the company are based on two main factors:

- Customized product
- Cost

The Material Handling activities in the facility are done through transferring the materials across different operations, the transport time is not an important constraint in company E.

The productive activities done in the workshop are: production of bent curved and shaped wire parts, production of wire grids, productions of hooks and displays, assemblies and sub-assemblies. Most of these activities are automated, but there are still some activities that are manually done. That is why the LoA of physical tasks is placed at a medium grade. The LoA of cognitive tasks is below the medium grade because the machines need to be configured by the operators.

The Material Handling activities are done using the following equipment: forklifts, pallet trucks, electric stacker, and cobots which are used for some pick and place activities. Some of these equipment allow the automation of the mechanical effort but the decisions related to moving the materials are left to the operators. That is why the LoA of physical tasks is placed above the medium grade and the LoA of the cognitive tasks is at a very low degree.

The case E does not have a Material Handling System design approach, but they focus on removing the NVA activities.

For the MHE selection, the company relies on 6 criteria; ROI, ease of implementation, cost of implementation, cost of the equipment, time needed for the implementation and suppliers' location.

Cobots were brought to the workshop to remove the non-value-added activities performed by operators (pick and place activity). This equipment was not accepted by the operators at first. Once the operators started to make use of the cobots, the interviewee noticed that some of the operators appeared to get attached to the cobots. In the company, it is felt that automation is drastically reducing costs.

4. Cross Analysis

In order to sketch a clear vision on the field practices and problems of MHS, this cross analysis is based on four axes; Material Handling Automation, MHCS, MHE Selection, and MHS design. The analysis of each axis starts with a review of practices of the different cases. Then, common and different patterns are highlighted. Besides, when needed, the literature is mentioned to compare between the theoretical and the empirical materials. A summary of the cross analysis is presented at the end of this section opening new research questions.

4.1. Material Handling and Automation

As it is shown in Fig. 1, the gap between the automation of physical tasks and cognitive tasks in Productive activities is not as significant as in Material Handling activities. The automation of Material Handling is more restrained compared to the automation of productive activities. Sometimes this restriction is driven by the corporate culture of the company. On one hand, the small and medium sized companies (such as case C and E) tend to automate the Productive activities more than the Material Handling activities. On the other hand, the large sized companies (such as case B and D) aim to adopt high LoA for both of Productive and Material Handling activities.

Besides, in terms of Material Handling activities, the physical tasks are more automated than the cognitive tasks. In 4 cases (A, C, D, E), decisions related to the cognitive tasks were left to the human, e.g. parts positioning, storing, navigation, and so on.

Although the LoA of cognitive tasks of Material Handling activities is low compared to others, several cases tried to test new technologies that offer higher LoA for cognitive tasks. E.g. both of case B and D tried to deploy AIV in their plants, which offers a high LoA for the cognitive tasks. The use of this equipment was accepted by case D, and rejected by case B due to many factors (behavior unpredictability, collision risks, etc.).

The choice of the appropriate LoA seems to be difficult to make. Automating Material Handling cognitive parts may seem to be linked to the intensity of the product flow (such as in case B and D2 where the flow must be kept at its maximum to satisfy the demand). While the automation of Material Handling physical parts appears to be related to the characteristics of the handled materials (such in case A where the handled materials are heavy and require high physical automation). However, these factors are still restrained to allow a suitable decision of the LoA. Additionally to that, In the literature, methods can be found for redesigning existing systems in terms of LoA. Yet no method is proposed for the selection of LoA for new systems.

4.2. Material Handling Control System

The field studies show that the use of technologies related to the MHCS is still restrained. For some cases, the investment in such technologies is not needed since the used MHE do not have a significant cognitive LoA (e.g. pallet trucks). But for other cases, it is important to deploy this kind of technologies.

In case B, the use of such technologies is mandatory due to the high LoA adopted in the plant. In case D, recent tests were done to include this type of technologies. The MHCS in this case allows the operators to control, program, and supervise the AIVs through a screen. The investments in different cases are mainly driven by two factors; the need to remove Non Value Added (NVA) activities and to have a ROI in a short period of time. In order to present convincing proofs, simulation has to be done to display the possible benefits that can be derived from the use of such technologies. In the literature, several structures and technologies related to the MHCS can be found. While in the field studies, it can be seen that MHCS technologies are slowly emerging for the large sized companies. On the other hand, the MHCS is still not considered by the small and medium sized companies.

Consequently, it can be seen that MHCS is not widely used, and the implementation of such technologies remains unclear in the literature. More research has to be done to develop this subject, and propose methodologies for the deployment of MHCS.

4.3. Material Handling Equipment Selection

Throughout the field studies, it is noticeable that investment for developed MHE is not simply related to the size of the company nor to the complexity and the size of the production. Even small sized companies such as case E, with a small and medium production volume are using equipment such as cobots.

The selection of these equipment is mainly done through benchmark with a restrained list of suppliers, this practice is sometimes successful (e.g. the selection of water-spider in case A). However, it does not always ensure positive results, e.g. in case C, the selection of the automated transfer cart was based on copying the practices of another plant, but appeared to be not suitable. The loading/unloading operations were too difficult to be performed by the operators which negatively impacted the performance of the plant. The criteria used for the MHE selection in the small and medium sized companies are limited and mainly focusing on economics. Furthermore, the large sized companies include diversified criteria during their MHE selection (see table 3).

It may be observed that no clear MHE selection method is shared between cases. The decision is often not formalized and is made with a partial view of the impacts on the production system.

Table 3

Identified criteria for the MHE selection

Categories	Criteria	Cases
Economical	Return on investment (ROI)	A, B, C, D, E
	Total cost of ownership (TCO)	D
	Cost of the implementation	E
	Cost of the equipment	E
Technical	Capacity of the equipment	A
	Speed movement	A
Operational	Safety	B
	Precision	B
	Operating skills	A
	Ease of implementation	E
Supplier	Supplier’s reputation	D, E
	Supplier’s location	D, E

4.4. Material Handling System design

The cases show that companies do not always use a clear method to design their MHS. The large sized companies (case A, B, and D) use approaches based on benchmarks and on copying the best practices. In addition, case A uses corporate guidelines available for all production sites. With the objective of optimizing transport length and number of parts touches. It is noticeable that in these cases, MHS design is associated with the competitive priorities in a way to fit and support the manufacturing strategy followed by the company. This association helps to define the needs and the expected contributions of Material Handling activities. Key Performance Indicators (KPIs) are used to constantly evaluate the system (see table 4). A weak point in these KPIs triggers the modification of some elements of the design e.g. in case A, an MHE was dropped off because its speed movement and reactivity caused to decrease the OEE in the line.

The small and medium sized companies (case C and E) do not use any approach for the design process of MHS. Material Handling is not considered as important as the productive activities, however, the interviewees were aware of the benefits that could be generated by Material Handling. E.g. In case E, the use of cobots for the pick and place activity resulted in removing the NVA activities which were performed by operators.

In case A and D, the MHS is designed as a part of the production, when for case B, C, and E the MHS is designed after the production system design. In this context, the MHS design has been adapted to the workshop configuration. In case A, the organization is an assembly line where moving and gathering parts is an important part of the activity. In case D, flow management was seen as an important priority from the top management. It can be noticed that both companies operate on automotive market and then share comparable approach for flow management. For case B, the management assumes that MHS should adapt to production since growth management and technical constraint already constrained production organization. For case C and E the MHS has not been seen as high priority.

The MHS design process followed in the different cases is mainly composed of MHE Selection. Nevertheless, the literature shows other potential factors that have to be included during the design of MHS.

Table 4

Key performance indicators for the evaluation of MHS

Indicators	Cases
Overall Equipment Effectiveness (OEE)	A, B
Non Value Added (NVA) activities	C, E
Inventory on location	A
On time deliveries	A
Number of touch	A
Line balance	A
Number of transport	B
Duration of transport	B
Throughput	B
Availability of operators	C
Intermediate storage time	D
Cost of work-in-progress (WIP)	D
Cycle time	D

4.5. Summary

The analysis of the field studies allow to identify the similarities and the differences with the literature. First, the results obtained about MH and automation reflect the work of Bøgh et al. [19], which affirms that several MH Activities may benefit from higher LoAs. Different cases try to deploy new MHE that offer high LoAs. However, it does not guarantee a performance improvement .In fact, it might create new problems as seen in case B. This claim shows that the decision of the approriate LoA for MH is a subject that should be addressed thoroughly.

As it is shown through case D, a significant LoA of MH requires supervision. This supervision can be done through an MHCS. The field studies show that the MHCS is still often poorly deployed, while the literature displays various algorithms, structures, and technologies that can be exploited in the MHCS. This limit can be justified by the low LoA adopted in most industrial cases. Especially the small and medium sized companies, where it is impossible to link an MHE (such as pallet trucks) to an MHCS. The observed hinders to higher LoA are often the same as the one pointed by [33] quoted in Sect. 2.2.

The selection of MHE is mostly based on benchmark, and driven with limited criteria. As seen in case C, this practice does not always ensure a good selection. The precise identification of the company competitive priorities, added to the Material Handling Activity requirements appears to give good insight of the important criteria.

The field studies show a lack of a methodological approach for the design of MHS. This issue is even more complicated with the new technological advancements of the fourth industrial revolution. However, all the cases showed an interest in investing in new technologies to cope with the competitive market. The common objective regarding this kind of investments is to remove NVA activities, and to increase operator’s availability for productive activities. MHS design approaches are done through benchmarking which, in most cases, do not guarantee suitable results. It is essential to associate the competitive priorities to the MHS through KPIs. This claim is also addressed in the work of Säfsten et al. [29] and of Granlund [33]. They concluded that the linkage between operational issues and strategic decision is important to support ambitions of improving manufacturing systems. Granlund [33] namely insist on the necessity to define an Internal logistics strategy and an Automation strategy to drive MHS improvment.

In short, it is perceptible from the literature and the field studies that the MHS design should be addressed as a whole and is still not mastered. Based on the previous results, the following section displays the main challenges that are faced during the MHS design.

5. Challenges To Renew Mhs Design Approaches

The theoretical and empirical materials confirm that the design of the MHS is still not appropriately defined. In the literature, MHS problems are addressed as independent problems and are separately solved. While the analysis of the literature, and the results of the field studies show that the MHS aspects are interdependent. An issue in one aspect would naturally affect other aspects.

On one hand, theoretical materials unveil several challenges that can be faced during the MHS design. On the other hand, the empirical materials display various practices and insights about the different MHS design errors that were encountered (e.g. investments on inappropriate MHE, lack of a design approach, etc.). As a result, the relevant topics to be addressed in an MHS design process are proposed in Fig. 2.

Figure 2 presents the different challenges that have to be tackled during the design of MHS. It is composed of four interdependent scopes. Within each one, interdependent subjects are listed.

5.1. Material Handling specifications

The field studies illustrate the magnitude of the decisions related to the MHS, it can be fortunate (e.g. the use of cobots in case E) and it can also be deceiving (e.g. the use of the automated transfer cart in case C). This type of problems can be caused by a lack of problem specification.

The study show that MHS design decisions are multi-facet and influenced by multiple aspects (e.g. Costs, staff skills, production requirements, to cite a few). An efficient MHS design process should carefully assist designers to precisely specify the MHS design problem. New methods are needed to specify the MH activities in a non-technological approach, to specify the expected overall production flow, to specify the companies strategies in term of internal logistics and admissible LoA, to specify the available deployment and support systems.

The challenges in this scope can be defined in four main points: (1) Flow and material analysis, (2) LoA definition, (3) and MH Activity definition. Longo et al. [31] present the results of a project which consists of the flow and material analysis of the system in order to propose lay-out solutions. This work shows the importance of developing methods for the flow and material analysis that could be applied in the context of MHS. Besides, it is important to include constraints associated to the MH and the LoAs needed for a given activity. This additional data would allow the flow and material analysis to focus mainly on the MHS.

5.2. MHE Selection

The selection of the appropriate MHE for given tasks is mandatory for a well-functioning MHS. The challenges for an efficient MHE Selection can be defined in two points: (1) criteria identification and an efficient (2) decision making process. The field studies analysis have shown that the selection process is poorly defined for most of the companies. Only few criteria are used objectively or unconsciously by companies and their selection remain unclear. It is not obvious to understand why certain criteria are retained and other ignored. An analysis of literature on MHE [36] revealed that more than 200 criteria were identified in reviewed MHE selection processes. While in the field studies, 12 distinct criteria were identified and the companies used at most 6 criteria to decide. In [36], a methodology with a list of potential criteria is presented for two analysis levels: MHE category selection and MHE model selection. In order to cope with recent developments, it could be more efficient to propose a preselection of relevant criteria, based on the company characteristics and industrial activity.

5.3. MHE Deployment

The integration of MHE into a plant appears to be challenging due to the high complexity of today's industrial systems. It can be confronted to three main problems: (1) Integration to the information system, (2) MHE activity allocation, and (3) MHE/Operator interaction.

Few works can be found on the integration of MHE to the information system. Wang et al. [18] propose an architecture of Cyber Physical System (CPS) for MH. The paper shows the potential of such technologies to improve the shop-floor production fluency and efficiency. This topic still requires more effort to define other potential technologies that can be used in the context of MH. Numerous interviewed companies expressed their current fear for MHE integration in an MHCS. The deployment of ERP or MES in small and medium sized companies is considered to be a period of intensive work. Therefore, the integration of MHE to a communication network is often feared. Moreover, even if studies such as Choe et al. [3] which show the interest of introducing cognitive automation support in the MHS, it is still difficult to evaluate the benefits of connecting the MHS with regards to the industrial context. However, it seems a relevant research direction for developing evaluation methods of MHCS deployment opportunities.

Furthermore, as MHS becomes more complex, the MHE activity problem arises. Many factors should be considered for the activities allocation. Some factors can be identified from the work of Klausnitzer et al. [32] such as traveling distance, facilities arrangement, I/O location, path design, and aisle design. However, more work is to be done to fully address this issue taking into account the connected systems capabilities

Finally, interaction between MHE and the operators should be carefully considered for a successful deployment. As encountered in case E, the company staff may be reluctant to share the workspace with automated systems. In this context, new questions and opportunities about human-machine cooperation arise. The extent of the interventions that should be made by the operators is to be analyzed. Human-Machine Cooperation principles in a manufacturing system context are proposed in Pacaux-Lemoine et al. [30]. These principales can be adapted to the context of MHS.

5.4. MHS analysis

From the above literature and the field studies, it can be noticed that the MHS is a complex system. Namely, it involves many stakeholders, many interactions between subsystems and changing missions. The analysis of these systems is facing new challenges for their analysis due to their complexity that follows industry 4.0 trends. This give rise to the need to better conduct MHS analysis on various domains: (1) Company strategies elicitation, (2) current and new MHS analysis, (3) scenarios definition.

Prior to any design process or modification, it is important to model and analyze the current system (if it exists) and the expected new system. The modeling and analysis could help to take rational decisions. According to McGinnis [35], formal systems modeling languages enable the creation of high fidelity representations of large complex systems. In the work of McGinnis [35], the author highlights the feasibility of a Model Driven Architecture (MDA) approach in the context of MHS.

Additionally, the generation of different scenarios seems to be a crucial part of the MHS analysis. Case B and D show how the exploitation of the same MHE could lead to two different results. Therefore, the simulation of different scenarios considering the facility constraints and other factors could help to avoid heavy financial losses.

As a global guideline, it can be suggested that MHS design problem are to be addressed following Systems Engineering practices. MHS design is a complex system design and therefore deserves well established design process to be carried. IEC 15288 [34] proposes efficient guidelines to address such systems development. An MHS design process should take inspiration of such design approaches. It will encourage high quality specification, stakeholders integration and rationalized design and selection choices. Complementary to a structured technical design process comes the company strategies definition. Granlund and Säfsten et al. [29, 33] insist on the mandatory analysis of companies strategies on automation and internal logistics for MHS automation systems. In their work, only automation is highlighted but the authors give relevant advices on these strategies decomposition. Similar approaches could be used in the context of MHS design, as most of the field studies show a weak connection between the companies strategies and the MHS design.

6. Conclusion

The objective of this paper is to address MHS design and identify gaps between the literature work and the industrial practices. It is also to propose research directions to extend MHS design approaches. The literature review shows that fractions of MHS design problems are solved separately. Meanwhile in the field studies, it has been shown that there is a lack of formal MHS design approaches. However, some existing practices are used and highlighted in this work, as comparison and benchmarking. These practices do not have constant outcomes. It has been shown that sometimes, these practices led to a significant financial loss. The comparisons and analysis stressed the need of having a properly detailed methodology for MHS design that tackles diverse sub problems as MHS specification, MHS Analysis, MHE selection and MHE deployment. Such global approach should enhance the use and efficiency of MHS and therefore the manufacturing system’s performances. Moreover, the need to enhance MHS design methodology is increasing with the arrival of industry 4.0 demands and technologies. It has been shown that the deployment of communicating and automatized MHE is difficult for many companies.To address this issue, both theoretical and empirical materials were analyzed based on five MH aspects; MH activities, MH and Automation, MHCS, MHE selection, and MHS. As a result, MHS design directions are proposed. It appears that four main challenges need to be tackled during MHS specification; MHS Analysis, MHE Selection, MHE deployment, and MHS analysis.

For future development, a thorough analysis of each aspect of the MHS design approach is to be done. For this purpose, techniques for data collection and specification have to be whether identified from the literature or developed. MDA approach could be adapted to propose a generic framework to regroup complementing views on MHS. Such framework should rely on a MHS domain metamodel that could enhance data viewing, comparison and translation to adapted analysis models such as discrete event simulation that could enhance deep MHS analysis.

Declarations

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The authors have no conflicts of interest to declare that are relevant to the content of this article.

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Not applicable

Code availability

Not applicable

Ethics approval

Not applicable

Consent to participate

Not applicable

Consent for publication

The authors have obtained the valid consent from all participants of the interviews that appear in this work and confirm that it can be shared for research purposes.

References

1. Babiceanu, R. F., Chen, F. F., & Sturges, R. H. (2004). Framework for the control of automated Material Handling systems using the holonic manufacturing approach. International Journal of Production

Research, 42(17), 3551–3564.

2. Esmaeilian, B., Behdad, S., & Wang, B. (2016). The evolution and future of manufacturing: A review. Journal of Manufacturing Systems, 39, 79–100
3. Choe, P., Tew, J. D., & Tong, S. (2015). Effect of cognitive automation in a Material Handling system on manufacturing flexibility. International Journal of Production Economics, 170, 891–899.
4. Granell, V., Frohm, J., & Winroth, M. (2006). Controlling levels of automation - A model for identifying manufacturing parameters. IFAC Proceedings Volumes (IFAC-PapersOnline), 9(PART 1), 65–70.
5. Heragu, S. S. (2016). Material Handling. In Facility design fourth edition (Vol. 16, Issue 5). CRC Press.
6. Hellmann, W., Marino, D., Megahed, M., Suggs, M., Borowski, J., & Negahban, A. (2019). Human , AGV or AIV? An integrated framework for Material Handling system selection with real-world application in an injection molding facility. The International Journal of Advanced Manufacturing Technology, 101(1-4), 815-824.
7. MacGregor Smith. Queeing Network Models of Material Handling and Transportation System. Handbook of stochastic models and analysis of manufacturing system operations. Springer.2013
8. Frohm, J., Lindström, V., Stahre, J., & Winroth, M. (2008). Levels of automation in manufacturing. Ergonomia-an International journal of ergonomics and human factors, 30(3).
9. Kim, S., & Nussbaum, M. A. (2013). Performance evaluation of a wearable inertial motion capture system for capturing physical exposures during manual Material Handling tasks. Ergonomics, 56(2), 314–326.
10. Telek, P. (2016). Material flow relations in the design process of materials handling. Advanced Logistic Systems, 10(1), 53-64.
11. Montoya-Torres, J. R. (2006). A literature survey on the design approaches and operational issues of automated wafer-transport systems for wafer fabs. Production Planning and Control, 17(7), 648–663.
12. Parasuraman, R., Sheridan, T. B., & Wickens, C. D. (2000). A model for types and levels of human interaction with automation. IEEE Transactions on Systems, Man, and Cybernetics Part A:Systems and Humans., 30(3), 286–297.
13. Saputro, T. E., Masudin, I., & Rouyendegh, B. D. (2015). A literature review on MHE selection problem: Levels, contexts, and approaches. International Journal of Production Research, 53(17), 5139–5152.
14. Shell, R., Hall, E., Wrennall, W., & Tuttle, H. (2000). Material Handling and Storage Systems. Handbook Of Industrial Automation.
15. Stephens, M. P., & Meyers, F. E. (2013). Material Handling. In Manufacturing facilities design and Material Handling. Purdue University Press.
16. Verbeek, J., Martimo, K. P., Karppinen, J., Kuijer, P. P., Takala, E. P., & Viikari-Juntura, E. (2012). Manual Material Handling advice and assistive devices for preventing and treating back pain in workers: A Cochrane Systematic Review. Occupational and Environmental Medicine, 69(1), 79–80.

17. Wan, J., Tang, S., Hua, Q., Li, D., Liu, C., & Lloret, J. (2018). Context-aware cloud robotics for Material Handling in cognitive industrial Internet of Things. IEEE Internet of Things Journal, 5(4), 2272–2281.
18. Wang, W., Zhang, Y., & Zhong, R. Y. (2020). A proactive Material Handling method for CPS enabled shop-floor. Robotics and Computer-Integrated Manufacturing, 61(December 2018), 101849.
19. Bøgh, S., Hvilshøj, M., Kristiansen, M., & Madsen, O. (2012). Identifying and evaluating suitable tasks for autonomous industrial mobile manipulators (AIMM). The International Journal of Advanced Manufacturing Technology, 61(5-8), 713-726.
20. Baxter, P., & Jack, S. (2008). Qualitative case study methodology: Study design and implementation for novice researchers. The qualitative report, 13(4), 544-559.
21. Chen, J. C., Cheng, C. H., Huang, P. B., Wang, K. J., Huang, C. J., & Ting, T. C. (2013). Warehouse management with lean and RFID application: A case study. International Journal of Advanced Manufacturing Technology, 69(1–4), 531–542.
22. Huang, B., Li, C., Yin, C., & Zhao, X. (2013). Cloud manufacturing service platform for small- and medium-sized enterprises. International Journal of Advanced Manufacturing Technology, 65(9–12), 1261–1272.
23. Onut, S., Kara, S. S., & Mert, S. (2009). Selecting the suitable material handling equipment in the presence of vagueness. International Journal of Advanced Manufacturing Technology, 44(7–8), 818–828.
24. Chakraborty, S., & Banik, D. (2006). Design of a material handling equipment selection model using analytic hierarchy process. International Journal of Advanced Manufacturing Technology, 28(11–12), 1237–1245.
25. Gaur, A. V., & Ronge, B. P. (2020). Ranking Material Handling Equipment Selection Criteria by AHP. Techno-Societal 2018, 175–182.
26. Karande, P., & Chakraborty, S. (2013). Material Handling Equipment Selection Using Weighted Utility Additive Theory. Journal of Industrial Engineering, 2013, 1–9.
27. Angerer, S., Strassmair, C., Staehr, M., Roettenbacher, M., & Robertson, N. M. (2012, April). Give me a hand—The potential of mobile assistive robots in automotive logistics and assembly applications. In 2012 IEEE International Conference on Technologies for Practical Robot Applications (TePRA).
28. Agarwal, D., & Bharti, P. S. (2018). A case study on AGV's alternatives selection problem. International Journal of Information Technology, 1-13.
29. Säfsten, K., Winroth, M., & Stahre, J. (2007). The content and process of automation strategies. International Journal of Production Economics, 110(1-2), 25-38.
30. Pacaux-Lemoine, M. P., Trentesaux, D., Rey, G. Z., & Millot, P. (2017). Designing intelligent manufacturing systems through Human-Machine Cooperation principles: A human-centered approach. Computers & Industrial Engineering, 111, 581-595.
31. Longo, F., Mirabelli, G., & Papoff, E. (2005, September). Material flow analysis and plant lay-out optimization of a manufacturing system. In 2005 IEEE Intelligent Data Acquisition and Advanced Computing Systems: Technology and Applications (pp. 727-731).

32. Klausnitzer, A., & Lasch, R. (2019). Optimal facility layout and material handling network design. Computers & Operations Research, 103, 237-251.
33. Granlund, A. (2014). Facilitating automation development in internal logistics systems (Doctoral dissertation, Mälardalen University).
34. International Organization for Standardization. (2015). ISO/IEC/IEEE 15288: 2015–Systems and software engineering–System life cycle processes.
35. McGinnis, L. F. (2010). The Future of Modeling in Material Handling Systems.
36. Soufi, Z., David, P., & Yahouni, Z. (2021). A methodology for the selection of Material Handling Equipement in manufacturing systems. 17th IFAC Symposium on Information Control Problems in Manufacturing.

Figures

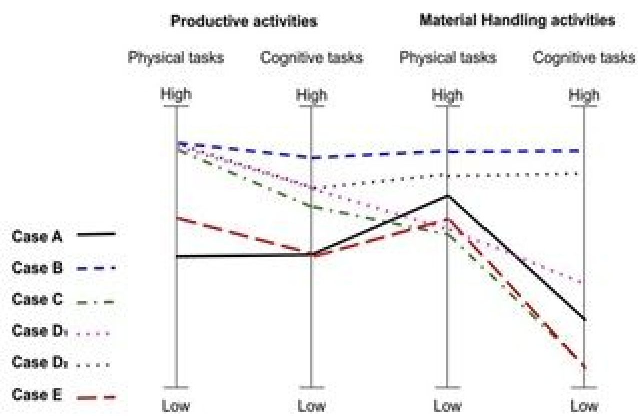

Figure 1

Advancement in terms of Automation

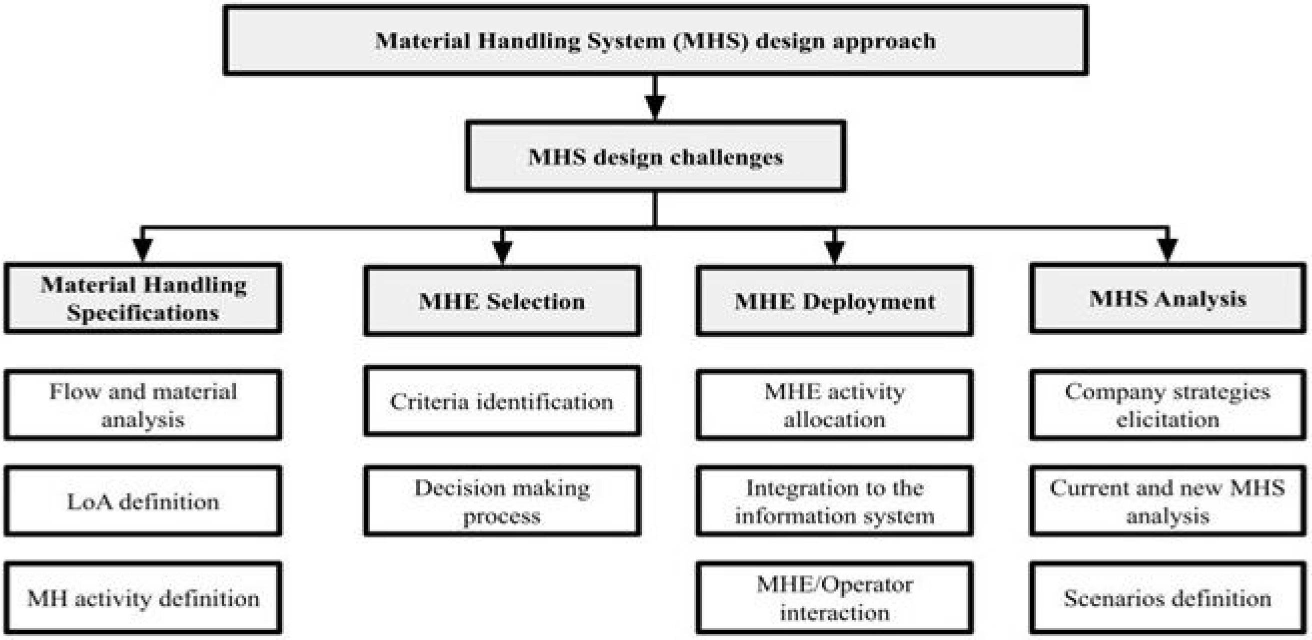

Figure 2

MHS design challenges