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EFFECTS OF OPERATION PARAMETERS OF MATERIAL HANDLING MACHINES TO THE APPLICABILITY

PÉTER TELEK[1]

Abstract: *In the past period, the structure and technical elements of material handling machines have changed significantly due to changes in service expectations, technical possibilities and environmental conditions. There are devices that are easier to adapt to certain technical changes, while others may be completely out of industrial use. The purpose of this article is to provide an overview of the most important properties affecting the operation of material handling equipment and to present the relationships between these properties and the applicability. By exploring the relationships between these properties and the most typical areas of application, it is possible to select the most suitable tools. An example task is also presented in the article to show how the method works.*

Key words: *material handling parameters, device selection, application areas*

1. INTRODUCTION

Over the past centuries, many types of material handling machines have been created, the applicability of which has now completely changed due to changes in service expectations, technical possibilities and environmental conditions. The extent of the changes largely depends on the features of the given machine. There are devices that are easier to adapt to certain technical changes, while others may be completely out of industrial use.

The purpose of this article is to provide an overview of the most important properties affecting the operation of material handling equipment and to present the relationships between these properties and the applicability.

The expected outcome of this research, primarily to help the selection of material handling machines, and beside this, it is important for outlining trends that may influence technical changes in the near future.

2. OPERATION PARAMETERS OF MATERIAL HANDLING MACHINES

Many types of material handling equipment can be found in the industrial or in economic processes, which at first glance are significantly different from each other. Taking a closer look at these machines, many similarities can be discovered between them, and we can classify them into different types. Based on the structural and operational characteristics, we can distinguish approx. 15-20 main types (e.g. cranes). The reason why there are no clear categories is because different specialists consider certain subtypes as separate types (e.g. traveling cranes and jib cranes).

The main types of material handling machines differ in various parameters, among which there are some features that significantly affect the operation but occur only in a few basic versions.

In terms of the applicability of material handling machines, the following properties play the most important role:

[1] PhD, University of Miskolc, Institute of Logistics, Hungary
peter.telek@uni-miskolc.hu

- the material handling operation performed,
- the method of goods movement used,
- the type of goods handled,
- the operation characteristics of the handling device,
- the track management solution used and
- the control of the operation.

2.1. Material handling operations

Material handling refers to the simple or complex series of activities that are performed during the implementation of a specific service task [1]. Each series of material handling activities is different, or consists of identical operational elements, in a given order and quantity. The most important operational elements:

- movement (horizontal, vertical or a combination of these),
- placement (goods or the specific element of the device),
- fixing (preventing displacement during movement),
- waiting.

Using the action elements, or by combining them, material handling operations can be formed (e.g. the loading operation includes placement, fixing and moving operation elements), which functionally determine the structure and applicability of the material handling equipment. General material handling operations are shown in Figure 1.

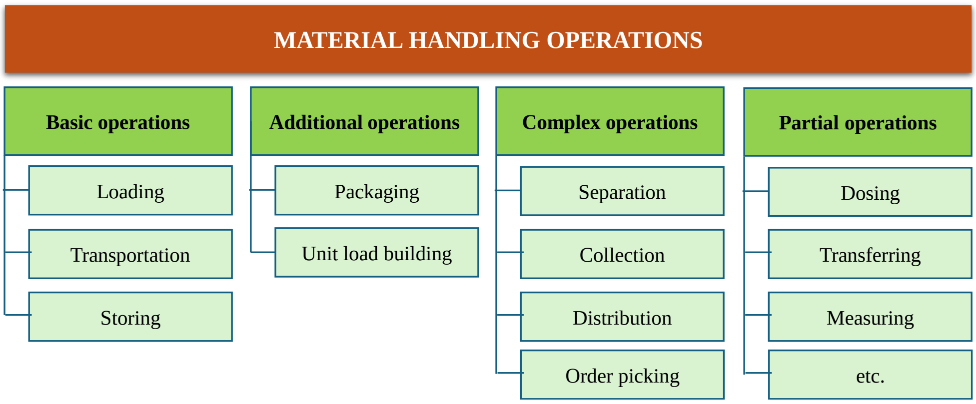


Figure 1. *Types of material handling operations.*

To carry out material handling operations, we usually use material handling machines (e.g. a forklift is a loading machine), the structure and operation of which are adapted to the requirements of the performed operation or operations.

2.2. Methods of goods movement

Important question during the material handling process is how the moving of the goods can be realized? The answer is the goods handling method, which principally determines the operation and structure of all handling equipment. There are only four goods handling methods applied in material handling [2]:

- mobile handling units,
- fixed loading arms,
- transport channels,
- moving by towing elements.

The traditional method for the material handling is the using of **mobile handling units**, where the goods are moving on the machines [3]. In this case, the handling characteristics of the goods determined by the machine (speed, acceleration, route, etc.). The uploading and unloading solution of the goods cannot influence the moving. Typical mobile handling units are the lifter trucks, pallet cars, running hoists, travelling cranes, monorails, rack-stackers, etc.

For small distance loading, the simplest solution is the application of **fixed loading arms**. These machines contain an arm system (one or more arm sections), which can be rotated around a fix axle (floor or wall mounted mast or body). The gripping of the goods can be realized by an arm-mounted gripper, or different hoist solutions (fix or mobile). The most important types of this machines are the jib cranes and the handling robots.

The **transport channels** are fixed or moving elements which frame a suitable platform for the transportation of units or bulk solids [2]. The transport line determined by the structure of the device, the uploading and unloading of the goods are realized by other loading machines or self-acting (falling at the end). The best-known types of this handling method are the chutes, the belt conveyors and roller conveyors.

The last goods handling method is the **moving by towing elements**. In this solution, the units or bulk solids are located on/in transport elements (hanger, plate or container) joined to a chain, cable or wheel, which tow them along a given line. The transportation can be realized at floor level or overhead. Tow conveyors, trolley conveyors, elevating conveyors and bucket wheels belong to this group.

2.3. Types of goods

During material handling, we can move living beings (e.g. in a bus) or inanimate objects, but classic material handling machines basically handle various goods and materials. For every type of material (in any physical state), there is equipment that can be used to move it, but material handling only deals with the handling of solid materials, which can be further classified into two main groups according to their handling characteristics, they can be units or bulk materials. When placed in a unit load (e.g. container, bottle, bag), liquids and gases can also be handled as units.

Units are handled individually, their size, shape and weight can be different (parts, finished products, cars, etc.). An important feature of units is the gripping, which can be achieved manually or with gripping equipment. In the various processes, units are handled as individual pieces or placed in a unit load building device (Figure 2). During unit load building the goods are packed into a unit, using a unit load building device (box, pallet, container, etc.). **Unit loads** are also handled as units.

For the handling of units, you can use material handling machines that have the possibility to grip units (e.g. clamping jaws) or a transport-storage surface on which the units can be placed.

Bulk materials are materials [4] containing separate parts (grains, granules) of the same or different sizes and materials, which are moved together in a larger mass (grains, stones, ores, etc.). An important characteristic of such materials is that individual grains cannot be handled individually. Bulk goods can be handled (Figure 2) in the various processes by separating discrete quantities (e.g. grab-bucket) or by ensuring a continuous material flow (continuous transport surface).

For the handling of bulk materials, material handling machines that have a suitable container (e.g. front loader), an active transport surface (e.g. conveyor belt) or a special goods handling solution (e.g. transport screw) are suitable. They can also be handled as units by using various unit-forming devices (e.g. bags, containers), but for this, filling or emptying operations must be carried out, which require additional labour investment, time and expensive packaging device (e.g. flour sacks).

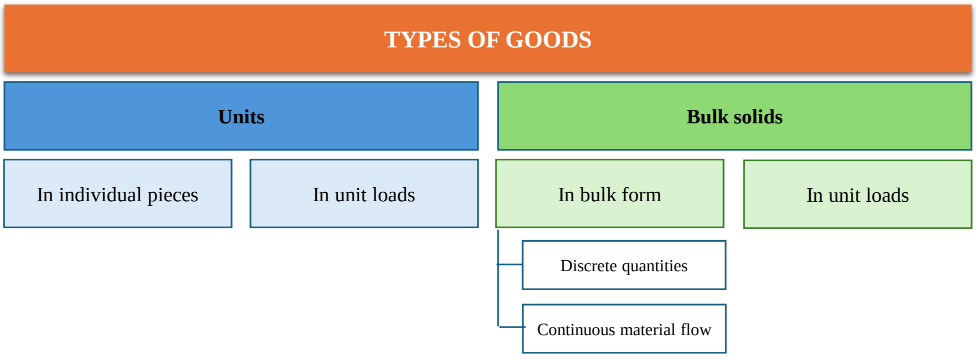


Figure 2. *Handling variations of different goods.*

The type of goods is the defining characteristic of material handling machines, since most of the equipment can basically only handle units (e.g. roller tracks) or only bulk goods (e.g. excavators). Some types of equipment can handle both types of goods, but only with a significant structural change (e.g. crane hook for units or grab-bucket for loading bulk goods).

2.4. Operation characteristics of material handling devices

In industrial processes, two different types of material flow can be defined according to the characteristics of the types of goods: discrete and continuous. In the case of discrete material flow, the tasks only occur at specific times in connection with the handling of specific quantities of goods. This type is basically suit for discrete production, or it is used to describe and characterize the service tasks that occur during the handling of units.

In case of continuous material flow processes the goods can move all times, but the quantity of goods and the speed of movement can also change. This type is suit basically to continuous production or is used to describe and characterize the service tasks that occur during the continuous handling of bulk materials.

Adapting to the management of the above material flow variants, two basic characteristics have also emerged in the operation of material handling machines: intermittent and continuous operation.

Intermittent operation means that the equipment only works until the material handling task is completed, waiting between two tasks (e.g. forklift). The movement of the equipment can be characterized by a work cycle [5], which contains different periods (movement of goods, idling, waiting). The most important advantage of intermittent operation is that the material handling machine only works during the period necessary for the implementation of the given task, so the related performances and costs are minimal, or the waiting times give the opportunity to use the free capacities for other purposes. As a disadvantage, the capacity during waiting times is not used, or the cost (wages) of the related human resource (operator) can also be mentioned while waiting. In case of intermittent operation, the scheduling of the material handling equipment is an important task, because by properly managing the waiting times, the capacity utilization of the equipment can be increased, or service disruptions can be reduced. This mode of operation is primarily suited to discrete production processes.

During **continuous operation**, the equipment works constantly regardless of material handling tasks (e.g. conveyors). In order to carry out the tasks, the goods must be placed on the moving equipment (dispatch) and then removed at the appropriate place (leave). The continuously operating devices move the goods along a given track line, which enables automatic, unattended transport [5]. Another advantage is that there are more dispatches along the track, or a drop-off point can also be set up. As a disadvantage, the significant energy consumption resulting from the continuous operation (it can also move empty), or the complicated structure (long track, several transfer points, etc.) can be mentioned, which means a much more complex operation and maintenance task. In the case of continuous operation, the service tasks must be scheduled, which is a serious challenge, especially in the case of several pick-up and drop-off locations. Such material handling devices were created to serve continuous production technologies, but today their field of application has become much wider.

2.5. Route management solutions

During material handling, goods always move along a specific route. At the beginning of the transportation of goods, natural routes were used (rivers, paths, etc.), and later artificial routes also appeared (highways, railway lines, etc.). In the case of industrial service processes, paved roads or different tracks can be used to implement material handling tasks. According to their movement route, the material handling equipment can be unbound or fixed track devices.

We speak of an **unbound route** if the equipment can follow any route during the movement of the goods (e.g. manual forklift). This means that all objects available in the given area, or station can be visited, usually in an arbitrary order.

The material handling device, or the particularities of the road design may limit the movement (e.g. asphalt road network, road obstacles), but you can choose any route within the possibilities. Unbound handling devices are usually mobile handling machines moving at ground level (e.g. forklifts). As advantages, the option of choosing a route, the possibility of leaving the service area, or the resulting flexibility can be mentioned. Its most important disadvantage is that suitable operation requires effective management (e.g. route plan), which is especially essential in complex systems that use multiple material handling devices.

The movement of **fixed-route** material handling equipment is realized along a given section of a predefined line [6]. The material handling path can be located at ground level or above ground level, at a given height, the direction of movement can be fixed or alternating. Various solutions are available for connecting the material handling device to the line:

– forced tracks (rail),
– physical tracks (induction, optical, magnetic principle),
– virtual tracks.

In the case of a forced track, the device moves on a rail system with a specific geometry, which cannot be leaved (e.g. conveyor track). Physical track means a special system in which the equipment is held on the track by an electrically operated coercive force (e.g. electromagnet) or positioning device (e.g. camera), the removal of which allows the track to be left (e.g. driverless forklift). We can speak of a virtual path if the material handling machine (e.g. automatic stackers) follows a predefined line determined by the control computer [7].

The characteristics of fixed-route material handling are basically determined by the number and nature of the handling options that can be realized by the equipment, which occurs in 4 main versions (see Figure 3).

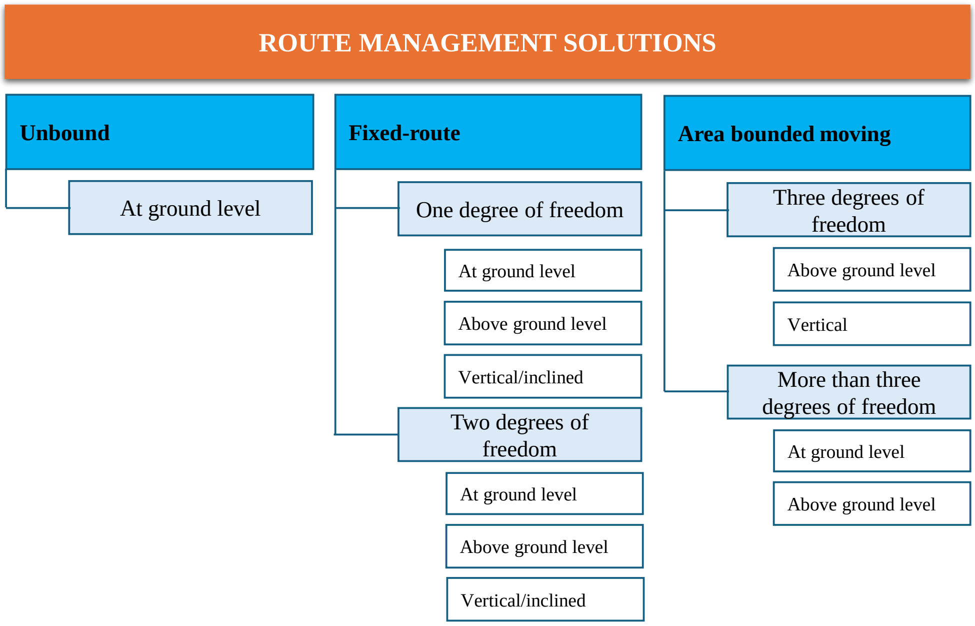


Figure 3. *Bounding variations of handling machines.*

At **one-degree-of-freedom** fixed-route material handling equipment, the movement can only be carried out in one direction – along the route of the track (e.g. conveyor belt), hence it can only be used to service objects located on the track line. Most material handling machines can be classified in this group, including all continuously operating service machines. The movement path can be in any direction (horizontal, vertical, curved, rising, etc.), with appropriate technical solutions, the change of direction is not limited either. In the case of equipment with one degree of freedom, additional loading solutions may be required.

In the case of movement with several degrees of freedom, the movement of the equipment is realized as a result of a series of displacements in different directions. For devices with **two degrees of freedom**, the first degree is the moving between objects, the 2nd is for lifting the goods (e.g. running hoist).

In the case of **three degrees of freedom**, one direction of movement is also linked to lifting the goods, but two directions (usually perpendicular to each other) are used to move between objects. Two-way movement is no longer limited to a track, but covers an area with a given geometry, within the equipment can reach any point (e.g. a bridge crane can move within the rectangle bounded by the track). The area covered by the movement of the equipment can be located not only horizontally, but also vertically (e.g. warehouse stacker).

Movement with **more than three degrees of freedom** can only be realized by some equipment (robots, rotary excavators, etc.), where the actual movement of the goods is created as a result of several linear or rotary movements. In this case, the handling space is usually the full or partial volume of a sphere with a radius reachable by the device.

The most important advantage of material handling with a fixed-route is the simplicity of control, which is mainly valid for one or two degrees of freedom. In this case, the control task only occurs at the pick-up and drop-off points, the movement on the track does not require intervention (in case of no problems). The advantage of multi-degree-of-freedom handling machines is the arbitrary path, which is realized as a simple combination of several movements. As a disadvantage, the location of the trackside object is forced, or the lack of alternative movement options can be mentioned, which does not exist at devices with multiple degrees of freedom.

2.6. Operation control methods

For a long time, humans played the most important role in material handling processes. In the beginning, as a controlling and executing element (manual material handling), then with the appearance of different material handling devices, control became its main task. During manual material handling, human effort is used to perform material handling, which does not require external energy consumption. This solution is also indispensable in modern service systems, as it is the most efficient and flexible way of moving of small and heavy goods over short distances, especially in the case of complex goods structure and random service needs.

With the appearance of material-handling machines, the role of man has fundamentally changed, various driving forces and technical solutions have been incorporated for satisfy the force requirement, in addition to the use of properly trained operating personnel. This solution was sufficient for industrial tasks until the end of the 20th century, but the operational safety and due to efficiency advantages, automatic material handling devices are appearing in more and more places, which can be more easily regulated and checked. Material handling equipment used today can be divided into three groups according to operation, they can be manually operated, semi-automatic and automatic machines (Figure 4).

During **manual operation**, the equipment is controlled by operating personnel. Due to the human factor, various uncertainties may appear when performing material handling tasks, but human flexibility or problem-solving ability can compensate for this disadvantage. It is generally more economical to use manual operation in service processes with lower performance requirements.

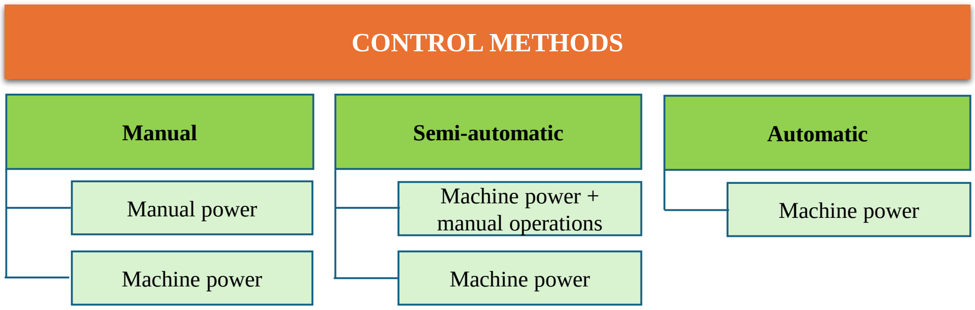


Figure 4. *Control methods of handling machines.*

During **automatic material handling**, the equipment is operated and controlled without operator personnel, according to a given control program [8]. The basic purpose of automation is generally to ensure safety (protection of people and goods), operational safety (functionality), controllability of processes and productivity, as well as to reduce human resources. During automation, the various detection, control and control tasks must be solved individually, in many cases using a separate device, which in many cases requires a complicated device and connection system. At the same time, today's performance and efficiency-centric expectations demand the use of automated equipment in more and more places. There are process elements that are difficult or impossible to automate (due to technical or cost constraints), in which case **semi-automatic** equipment is used [9]. During semi-automatic operation, one or more of the equipment's functions (gripping, moving, positioning, etc.) are performed with the involvement of some type of operator (e.g. semi-automatic order picker).

We can only talk about automation in the classical sense of equipment with intermittent operation. At continuous material handling devices, the goods are moved without human intervention, so only the service and additional operations require automation.

3. Relation among the operation parameters and the applicability

It is easy to find connections between material handling devices and areas of application, but with the help of the operating parameters described in the previous chapter, the selection process of the equipment best suited to the given task can be significantly facilitated. Since the operational parameters usually contain few and easily distinguishable versions, the examination of the relationship between the parameters and the application characteristics is an important opportunity to reduce the number of the suitable device versions.

3.1. Operation parameters of the handling machines

The material handling characteristics detailed in Chapter 2 for each type of material handling machine are summarized in Figure 5. In the present research phase, we only deal with the main device types, the differences between the individual versions will be covered in a later publication.

Figure 5 shows which characteristics determine the operation of each machine version [10] (e.g. continuous operation) or limit its applicability (e.g. handling of units or bulk materials).

	Machine type	Handling operation	Goods handling method	Type of goods	Operation characteristics	Track management	Control method
1.	Loading trucks	LO/TR	MU	PIE/BUL	DC	NL/L1D	MAN/AUT/SEA
2.	Pallet trucks	TR/ST	MU	ANY	DC	NL/L1D	MAN/AUT
3.	Travelling cranes	LO/TR	MU	PIE/BUL	DC	L2D/3D	MAN/AUT
4.	Rotary cranes	LO	LA	PIE/BUL	DC	L2D/3D	MAN/AUT
5.	Monorails	TR	MU	PIE	DC	L1D	MAN/AUT
6.	Robots	LO	LA	PIE	DC	L3D+	AUT
7.	Stacker machines	LO	MU	PIE	DC	L3D	MAN/AUT
8.	Elevators	TR	MU	PIE/HUM	DC	L1D	MAN
9.	Rotary excavators	LO	LA	BUL	DC	L3D+	MAN
10.	Car dumpers	LO	LA	BUL	DC	L1D	MAN/AUT
11.	Chutes	TR	TC	PIE/BUL	CO	L1D	AGM
12.	Rotary tables	TR	TC	PIE	CO	L1D/2D	AGM
13.	Belt conveyors	TR	TC	ANY	CO	L1D	AGM
14.	Roller conveyors	TR	TC	PIE	CO	L1D	AGM
15.	Vibrating conveyors	TR	TC	BUL	CO	L1D	AGM
16.	Pneumatic conveyors	TR/LO	TC	BUL	CO	L1D	AGM
17.	Screw conveyors	TR	TC	BUL	CO	L 1D	AGM
18.	Tow and trolley conveyors	TR	TE	PIE	CO	L1D	AGM
19.	Cable conveyors	TR	TE	BUL/HUM	CO	L1D	AGM
20.	Bucket elevators	TR/LO	TE	BUL	CO	L1D	AGM
21.	Continuous excavators	LO	TE	BUL	CO	L2D/3D	MAN/AUT

TR - Transport
LO - Loading
ST - Storing

MU – Mobile handling unit
LA – Fixed loading arm
TC – Transport channel
TE – Towing element

PIE – Piece goods
BUL – Bulk solids
HUM - Human

DC - Intermittent
CO - Continuous

NL – Unbound line
L1D – Fixed track, 1D
L2D – Fixed track, 2D
L3D – Area bounded, 3D
L3D+ - Area bounded, 3D+

AGM – Automatic goods movement
MAN – Manual control
AUT – Automatic control
SEA – Semi-automatic control

Figure 5. *Operation parameters of material handling machine types.*

3.2. Application areas

Regarding the areas of application of material handling machines, we can start from the versions of material handling systems [11]. Material handling systems can be classified into the following groups according to their service characteristics:

- material handling outside the company
  - among remote objects (e. g. transportation),
  - connected to the object (e. g. mine),
  - within the object (e. g. terminal),
- material handling within the company:
  - between plants, warehouses,
  - in-house:
    - between objects,
    - object-related,
  - within the object:
    - workplace,
    - storage space.

In line with the above, the material handling properties required by each field of application can be seen in Figure 6.

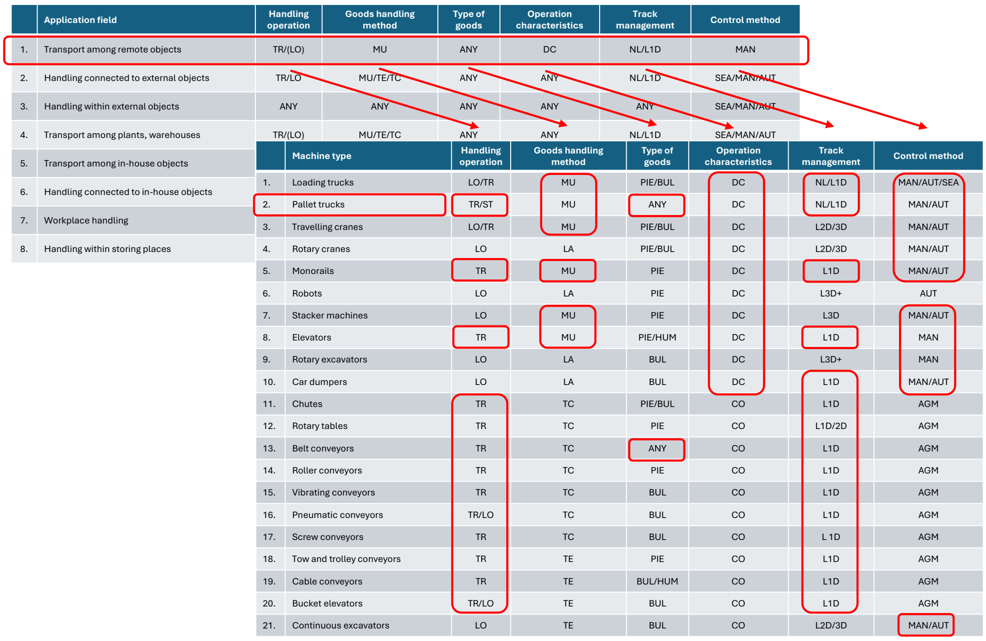
	Application field	Handling operation	Goods handling method	Type of goods	Operation characteristics	Track management	Control method
1.	Transport among remote objects	TR/(LO)	MU	ANY	DC	NL/L1D	MAN
2.	Handling connected to external objects	TR/LO	MU/TE/TC	ANY	ANY	NL/L1D	SEA/MAN/AUT
3.	Handling within external objects	ANY	ANY	ANY	ANY	ANY	SEA/MAN/AUT
4.	Transport among plants, warehouses	TR/(LO)	MU/TE/TC	ANY	ANY	NL/L1D	SEA/MAN/AUT
5.	Transport among in-house objects	TR/LO	MU/TE/TC	PIE/BUL	ANY	NL/L1D/2D/3D	SEA/MAN/AUT
6.	Handling connected to in-house objects	ANY	ANY	PIE/BUL	ANY	ANY	SEA/MAN/AUT
7.	Workplace handling	ANY	ANY	PIE/BUL	ANY	ANY	SEA/MAN/AUT
8.	Handling within storing places	ANY	ANY	PIE/BUL	ANY	ANY	ANY

Figure 6. *Requirements of application fields.*

In the case of different fields of application, the most important option is to exclude certain machine variants (e.g. track management), since the duration of the selection process can be reduced even without in-depth tests.

3.3. Relation between the application fields and the machine types

If the parameters of the machines and the application areas are known, then by comparing the two, we can find an intersection point that can help in delimiting the types of handling devices that can be used. Figure 7 shows an example of the comparison of the two tables.



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3.	Handling within external objects	ANY	ANY	ANY	ANY	ANY	SEA/MAN/AUT
4.	Transport among plants, warehouses	TR/(LO)	MU/TE/TC	ANY	ANY	NL/L1D	SEA/MAN/AUT
5.	Transport among in-house objects						
6.	Handling connected to in-house objects						
7.	Workplace handling						
8.	Handling within storing places						

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21.	Continuous excavators	LO	TE	BUL	CO	L2D/3D	MAN/AUT

Figure 7. *Using of the parameter tables.*

In the case of the selected field of application (Transportation between remote objects), the required values of the 6 general operating parameters only match for a few devices, and in the present example only one device matches all parameters (forklift and its variants).

Of course, this is only a simplified example task, but it clearly shows how the method works. In real cases, it is necessary to further narrow the area of application (e.g. storage [12]) and use more specified parameters (e.g. transport distance) [13] that can make the result more precise. In such cases, the method can also be used to select certain subtypes.

4. SUMMARY

In the past period, the structure and technical elements of material handling machines have changed significantly due to changes in service expectations, technical possibilities and environmental conditions.

In this article, I gave an overview of the most important properties affecting the operation of material handling equipment. By exploring the relationships between these properties and the most typical areas of application, it is possible to select the most suitable tools.

The example task presented in the article clearly shows how the method works, but in real cases, the areas of application need to be further narrowed and apply more specified parameters. With this changes, the method can also be made suitable for selecting certain subtypes.

The next part of the research will be the examination of the parameters of certain narrower areas of application (e.g. storage systems), the expected results of which can significantly help the selection, design and optimization (see [14]) of devices used in material handling systems, as well as the examination of material flow processes (see [15]).

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