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EXPLORING THE OPERATING CHARACTERISTICS OF INDUSTRIAL TRUCKS FOR VARIOUS TESTS OF MATERIAL HANDLING SYSTEMS

PÉTER TELEK[1]

Abstract: *Modern, automated handling systems today must operate efficiently in a dynamically changing environment and therefore cannot be managed with old design methods. In recent years, new methods have emerged for the efficient design and operation of handling systems, of which optimization methods and simulation software are the most frequently used tools in practice. These are very effective, but they usually serve to properly map processes, and therefore they are less able to take the characteristics of technical devices into account. In order to be able to apply these modern computer methods with sufficient efficiency, it is necessary to analyse the properties of technical devices and to explore those parameters which can influence the operation of the handling system. This article presents the first steps of a research project aimed at the accurate modelling of material handling equipment, primarily for simulation tests of handling systems. In addition to a general description and overview, the most important operating characteristics of industrial trucks are presented on the following pages.*

Key words: *material handling systems, advanced computer methods, machine parameters*

1. INTRODUCTION

At the end of the last century, the design and operation of material handling systems was a deterministic process that fit well into a static consumer and producer environment. Today, this has changed significantly, as today's modern, automated service systems must operate effectively in a dynamically changing environment.

New challenges can no longer be handled with old methods, so new procedures are emerging for the efficient design and operation of handling systems. Of these, optimization methods and simulation software are the most frequently used tools in practice. During optimization, different algorithms are used to find the best solutions, even in a daily changing environment, and simulation is used to model real processes in advance for the most efficient design and operation.

The above-mentioned computer methods are very effective, but they are usually used to properly map processes and therefore are less able to consider the characteristics of technical devices (e.g. material handling machines). In order to be able to apply these modern computer methods with sufficient efficiency in the design and operation of handling devices, the properties of the technical devices must be analysed, and the parameters must be identified.

This article presents the first steps of a research project aimed at the accurate modelling of material handling equipment, primarily for simulation studies of handling systems. In the following pages, in addition to a general description and overview, the most important operating characteristics of industrial trucks are presented.

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

2. TEST METHODS OF MATERIAL HANDLING SYSTEMS

During material handling, different goods are moving among technology or other objects located in given places, to fulfil the requirements of any production, service or consumer systems. The moving process can be realized by human operators or material handling machines [1].

Material handling system involves several handling tasks, processes and handling machines, which can be realized together (Fig. 1). A material handling system combines the specifications of the applied handling machines; however, some handling parameter can be changed because of the integration. Beside it, there are numerous additional tasks related to the operation and design of materials handling systems (harmonization and scheduling of different handling devices at transfer and crossing points, application of different solutions for the waiting phenomenon of handling machines, etc.) [2].

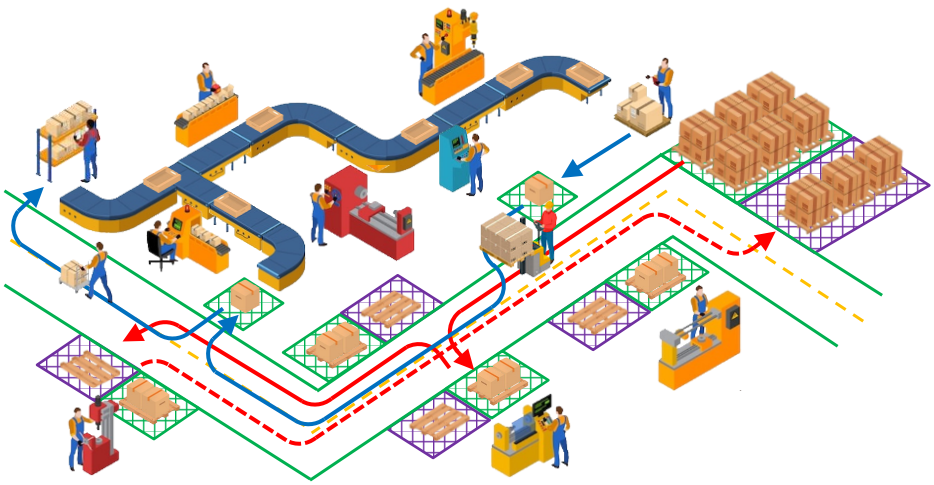

Figure 1. Example for a material handling system. Source: [3]

There are many different material handling system variations in the practice, depending on the requirements and physical structure of the related production or service systems. Differences among the system variations appear in many parts of the handling system solutions. The most important factors which influence the structure and operation of a handling system are [3]

- handling area (internal, external, workplace, etc.),
- transport distances,
- good types (homogeneity, unit loads, etc.),
- handling task types (loading, transport, storing, etc.),
- complexity of the handling activities,
- handling machine types, etc.

Based on Gudehus [4] we can define 3 main groups for material handling systems (handling related areas, handling tasks, machine characterizations), their variations are presented in Fig. 2.

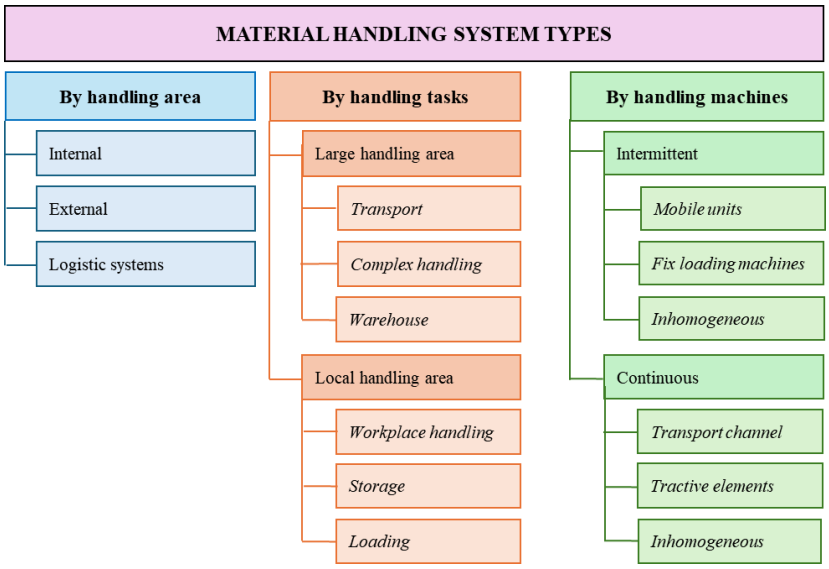

Figure 2. Material handling system variations.

The planning and operation of material handling systems is a complex task (complex system structure or frequently changing tasks), during which various system tests are required to ensure proper efficiency and smooth operation [5]. These tests can be used to determine the optimal system structure and the required values of the operating parameter system. In the case of modern server systems, the following tests are the most often used:

- object layout analysis,
- material handling equipment performance analysis,
- transportation route analysis,
- transportation unit analysis,
- warehouse/storage inventory levels analysis,
- operation time/disruption analysis, etc.

The properties of the system are influenced by many characteristics, but for each study a set of parameters can be defined that is aligned with the objective function used in the analysis.

In the **object layout analysis**, we search for the optimal location of the objects of the handling system, usually by minimizing the material handling work, which most often also means cost minimization. The primary study parameters are the flow quantities and frequencies, the route variants and lengths, and the device capacities and speeds.

In the **performance testing of material handling equipment**, we seek the optimal service equipment, usually by maximizing material handling efficiency. The primary test parameters are object characteristics, flow quantities and frequencies, and route characteristics.

When **examining transportation routes**, we look for optimal routes for the transportation vehicles of the handling system, usually by minimizing the material handling work, which most often also means minimizing costs. The primary examination parameters

are object characteristics, flow characteristics, route characteristics, and the waiting times that occur.

When **examining transport units**, we look for optimal units/unit loads that can be used in the service system, usually by minimizing the number of units, which most often also means minimizing costs. The primary examination parameters are the goods characteristics, the object characteristics, the route characteristics, and the flow characteristics.

When **examining warehouse/storage inventory levels**, we look for the optimal parameters of storage objects (warehouses, workplace, operational and inter-operational storage) in the service system, usually by minimizing the stored quantities and ensuring uninterrupted object supply. The primary examination parameters are the product characteristics, flow characteristics and device characteristics.

When **examining operation times/disruptions**, we seek the optimal scheduling of tasks in the service system, usually by adhering to service time limits and minimizing disruptions or errors. The primary test parameters are flow characteristics, route characteristics, device characteristics, and disturbing factors.

During the tests, the values of certain parameters are considered as predetermined constants (e.g. product characteristics). The parameters required for performing the various tests and their relationships are presented in Fig. 3.

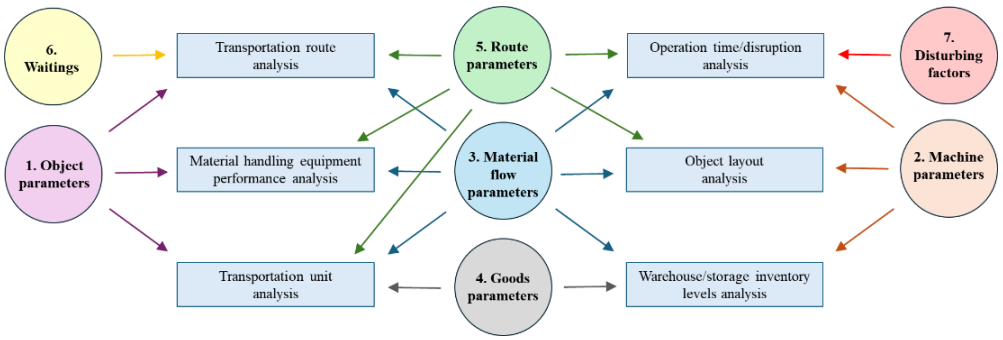

Figure 3. Overview of the tests and the related parameters.

During the tests, various parameters of the handling system are analysed, which can be:

- object characteristics (parameters, locations, connections, etc.),
- handling device characteristics (structural, operational, maintenance, etc.),
- material flow characteristics (relations, quantities, durations, etc.),
- product characteristics (types, physical, handling characteristics, units, etc.),
- route characteristics (length, elevation, complexity, variants, etc.),
- waitings (workplace, during transportation, operational, etc.),
- disruptions (temporary, failure, etc.).

Various methods are available to perform the above investigations:

- analytical methods [6],
- knowledge-based methods [7],
- optimization methods [8],
- simulation software [9],
- CAD design software [10], etc.

Since the nature and testing options of a given handling system are fundamentally determined by the material handling equipment structure used, during the research parameters of each equipment type are examined that can significantly influence the operation of the system. In this article, only the parameters of different versions of industrial trucks are presented.

3. VARIATIONS OF INDUSTRIAL TRUCKS AND THEIR FEATURES

Industrial trucks are intermittently operating mobile moving units used for loading and transporting piece goods or bulk materials, which move the goods placed on them between destinations independently or with the help of a towing device [11].

According to their material handling tasks, transport and loader trucks are fundamentally different (see Fig. 4). Transport trucks only transport goods, they are generally not able to pick them up and put them down, loader trucks always have some kind of equipment for gripping or lifting the goods. There are truck types that can be classified into both groups according to their construction, but the most important difference between the two versions is that the purpose of transport trucks is to transport goods, while loader trucks are basically used for loading.

a) Transport truck. Source: [12]

b) Loader truck. Source: [13]

Figure 4. Example for the main versions of industrial trucks.

The most important operating characteristics of trucks are [14]:

- mobile units,
- intermittent operation,
- perform independent tasks,
- they can also perform transport, loading and/or storage functions,
- they can move any goods, but only with the help of an appropriate transport surface, gripping structure or unit load forming device,
- track-bound or non-track-bound versions, etc.

In the case of both transport and loader trucks, we can distinguish several sub-variants.

2.1. Transport trucks

The main task of the transport trucks is to move goods between two destinations, without a device for picking up and putting down the goods, which is usually carried out by an external

material handling device (loader). In terms of their structure, they are among the simplest material handling devices, since in order to implement the transport function, in addition to the elements ensuring mobility (running gear, engine, etc.), only a transport surface for placing the goods is required. Certain types of them are capable of simpler goods picking up (e.g. pallet trucks) or placing down (e.g. tilting transport surface), but they cannot perform lifting tasks [15].

The typical application area of transport trucks is movement within the operating area, in the case of bulk materials the operating area can be several square kilometres (e.g. open-pit mines), in which case the transported quantities of goods and the transport distances are much larger.

The most used types of transport trucks (Fig. 5) are hand pallet trucks, trucks with a fixed transport surface, and tractors and freights wagons moved in assemblies. Self-unloading (tilting loading surface) and simple goods handling (special pick-up and drop-off) types can be classified in a separate category.

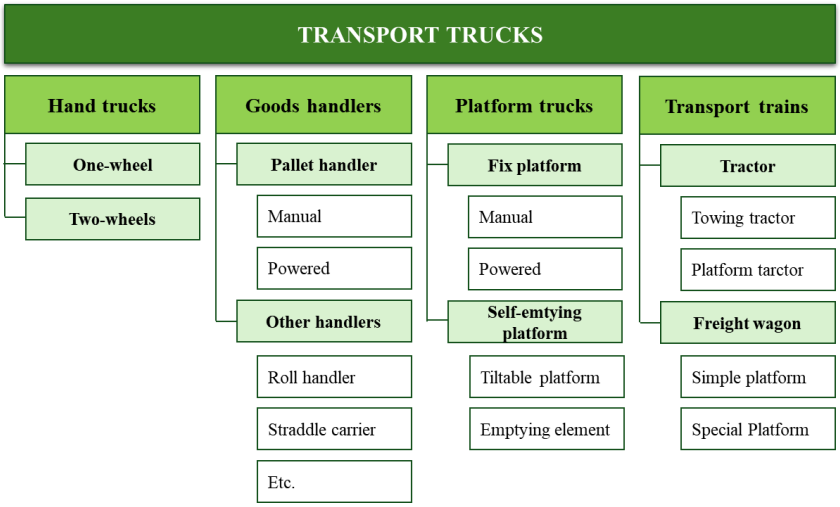

Figure 5. Versions of transport trucks. Source: [16]

2.2. Loader trucks

Loader trucks are used for vertical positioning and placement of goods using a gripping structure, and for short-term horizontal movement [17]. Their primary task is to load piece goods or bulk materials between two objects (material handling, technology, or service), which always requires some kind of equipment for gripping or lifting the goods.

The most used types of loader trucks (Fig. 6) are pallet trucks, forklifts and other lifter trucks with a lifting mast or lifting arm. For loading bulk materials, the types with a compound lifting arm are primarily used.

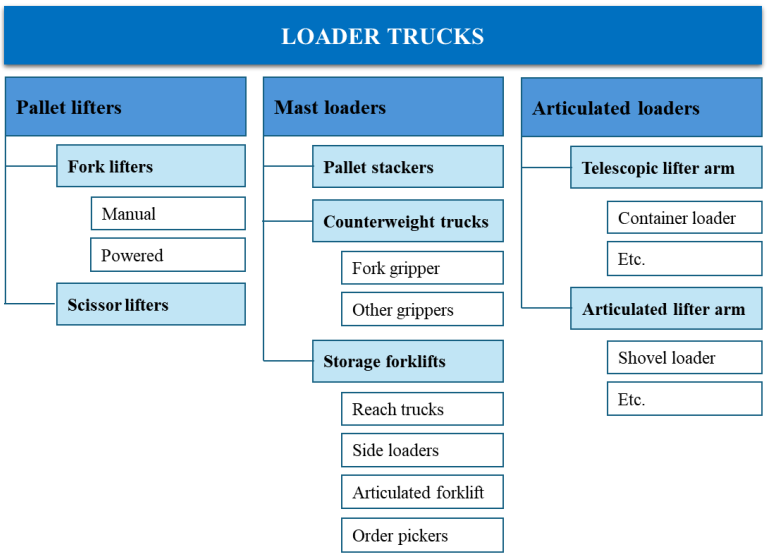

Figure 6. Versions of loader trucks. Source: [16]

4. TYPICAL PARAMETERS OF INDUSTRIAL TRUCKS

Material handling equipment has different properties, which are primarily determined by the structural design and fundamentally influence their applicability [18]. Different approaches can be used to review the characteristics, which are as follows [19]:

- structural properties (structure, elements, dimensions, etc.),
- operational properties (operational nature, track type, etc.),
- handling properties (on-board, remote-operated, automatic, etc.),
- goods handling properties (grabbing, waiting, continuity, etc.),
- system properties (adaptation, link ability, scheduling, etc.),
- operational properties (operating time, maintenance, waiting areas, etc.).

Certain features separate, while others connect the individual device variants. For example, the ability to move bulk materials or piece goods characteristically separates the machine types, but the transport channel as a movement solution enables fundamentally similar handling solutions even in the case of completely different structural designs (e.g. conveyor belt – roller track).

The most important features of industrial trucks (Fig. 6) are the following:

- structural features:
  - mobile units of a given size,
  - structural elements that implement a maximum of 3 different functions,
  - wide size range, etc.
- operating characteristics:
  - independent movement of goods,
  - intermittent operation,
  - generally not track-bound movement (AGV - track-bound), etc.
- handling characteristics:

  - manual or remote-operated, with human supervision,
  - automatic with computer-control, etc.
- goods handling properties:
  - they can move any goods,
  - suitable transport surface/gripping structure/unit load device is required, etc.
- system properties:
  - compatibility with all related system components,
  - connectivity (transfers, loading, etc.),
  - requires precise scheduling, etc.

The most important differences between the characteristics of transport and loader trucks can be defined primarily in the functional structure and the connection to the system components (Table I).

Table I.

Comparison of general characteristics of the main truck types.

Characteristics	Transport trucks	Loader trucks
1. Number of material handling functions	1	3
2. Possible operation types		
transport	√	√
loading		√
storing	√	
3. Structural elements		
moving element	√	√
transport element	√	
gripper		√
lifting element		√
4. Systems characteristics		
self goods handling	external	internal
fitting option		√
relations	simple	complex

The effect of the characteristics of the material handling equipment is primarily reflected in the object layout analysis, the warehouse/storage inventory levels analysis, and the operation times/disruptions analysis (see Fig. 6). In the other analyses, we primarily consider the service equipment as a given, but in the case of the above three analyses, the effect of changing of the equipment characteristics is directly reflected in the values of the system qualifying parameters.

In the case of trucks, the following parameters directly influence the efficiency of the handling system during the relevant tests:

- the transport/loading capacity of the device,
- train formation characteristics (possibility, number of cars, turning limits, etc.),
- the speed of the device (travel, turning, positioning),

- the characteristics of the goods handling (approach, gripping, lifting, etc.),
- track characteristics (width, required height, waiting areas, number of lanes, etc.),
- operation characteristics (useful working time, type and number of malfunctions, etc.),
- maintenance characteristics (duration, frequency, etc.), etc.

When analysing handling systems, different truck types are usually considered with the same parameter values, which can lead to inaccurate test results and does not allow for comparison of subtypes. By customizing the above characteristics, more effective comparisons and evaluations are possible, but further research is needed.

5. CONCLUSIONS

The challenges of the 21st century can no longer be handled with the methods used previously, and new procedures are increasingly emerging for the effective design and operation of service systems. Of these, optimization methods and simulation software are the most frequently used tools, which are very effective, but generally serve to adequately map processes, and are therefore less able to consider the specifications of technical devices. To be able to apply these modern computer methods with sufficient efficiency in the design and operation of service devices, the first steps of a research project aimed at the accurate modelling of material handling equipment, primarily for simulation studies of service systems, have been presented above.

In addition to the general description and overview, this article defines the parameters of different versions of industrial trucks that play the most important role in various system tests.

In the continuation of the research, by examining the revealed characteristics, those parameter values are searched that allow for more effective comparisons and evaluations.

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