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Guidelines for technology selection in intralogistics: a scientific approach

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Abstract:

Introduction/purpose: Intralogistics involves the organization, control, realization, and optimization of material and information flows within a technologically integrated system. The selection and application of appropriate material handling equipment (MHE) play a crucial role in shaping intralogistics systems. This paper aims to define guidelines for selecting MHE based on scientific research. The methodology implemented to achieve this goal comprises several fundamental steps.

Methods: The initial step involves analyzing three typical groups of tasks in (intra)logistics systems: transshipment, internal transport, and production activities. The analysis focuses on identifying and describing key task parameters, such as the type of unit load, quantity, flow intensity, and the location and timing of task initiation and completion. Next, there is a step devoted to the analysis of relevant scientific research. The literature is searched according to specific criteria, such as publication year, keywords, and citation count, to form a database of relevant papers. The analysis focuses on identifying and linking the parameters of practical tasks with those described in the literature and on the characteristics of the MHE used to facilitate the selection of appropriate MHE for these tasks.

Results: Following this, in the third step, the observed task is classified according to standard task types found in the literature.

Conclusion: Finally, in the last/fourth step, regression analysis is applied to define the guidelines for MHE selection based on the frequency of use of specific MHE groups for certain task groups as described in the literature.

Key words: intralogistics, MHE selection, transshipment, internal transport, production.

Introduction

The term "intralogistics" was officially adopted at the CeMAT trade fair in 2008 in Hanover. It refers to a set of operations management activities ("*logistics*") within ("*intra*") a technologically integrated unit, such as a storage, a production system, a distribution center, etc. (Fottner et al, 2021). The task of intralogistics is the optimization and planning of material and information flows within the observed system, from the moment the material enters the system until it is packed and delivered further (Tompkins et al, 2010; Fottner et al, 2021). The primary tasks of intralogistics, stemming from the stochastic demands of the market, include efficient inventory management, rapid and accurate order preparation, and adaptability to changes in demand concerning assortment and order quantity. In fulfilling these requirements, the selection and application of appropriate material handling technology (MHE) play a crucial role in shaping intralogistics systems (Tompkins et al, 2010; Zajac & Rozic, 2022).

The task of selecting MHE under specific conditions is highly complex, as it is influenced by a multitude of factors. On the one hand, these include task parameters such as the type of goods, their appearance, quantity, spatial and temporal coordinates, system requirements and constraints, safety and legal regulations, and many other conditions. On the other hand, there is a plethora of potentially applicable MHE, ranging from manual to mechanized and fully automated and robotic technologies, such as carts, forklifts, cranes, conveyor systems, AGVs, AS/RS, and others (Zrnić et al, 2021; Zajac & Rozic, 2022). Material handling stands out due to its share in overall logistics costs, approximately 40% (Tompkins et al, 2010; Zajac & Rozic, 2022). Engaging appropriate MHE can enhance intralogistics systems by efficiently utilizing manpower, increasing flexibility and productivity (Zajac & Rozic, 2022). Generally, the selection of MHE (Material Handling Equipment) in the process of designing intralogistic systems goes through different levels—decision-making phases, characterized by varying degrees of detail, from choosing the type of MHE to specifying the MHE performance, manufacturer, supplier, etc. In the project practice, this complex task has been approached in several ways: relying on equipment manufacturers' recommendations, expert opinions, and stakeholder input; applying ready-made solutions; and utilizing scientific research results to support decision-making. Therefore, the aim of this paper is to establish guidelines for MHE selection based on scientific research. The intention is to frame the selection problem in a practical context and solve it in the manner illustrated in Figure 1.

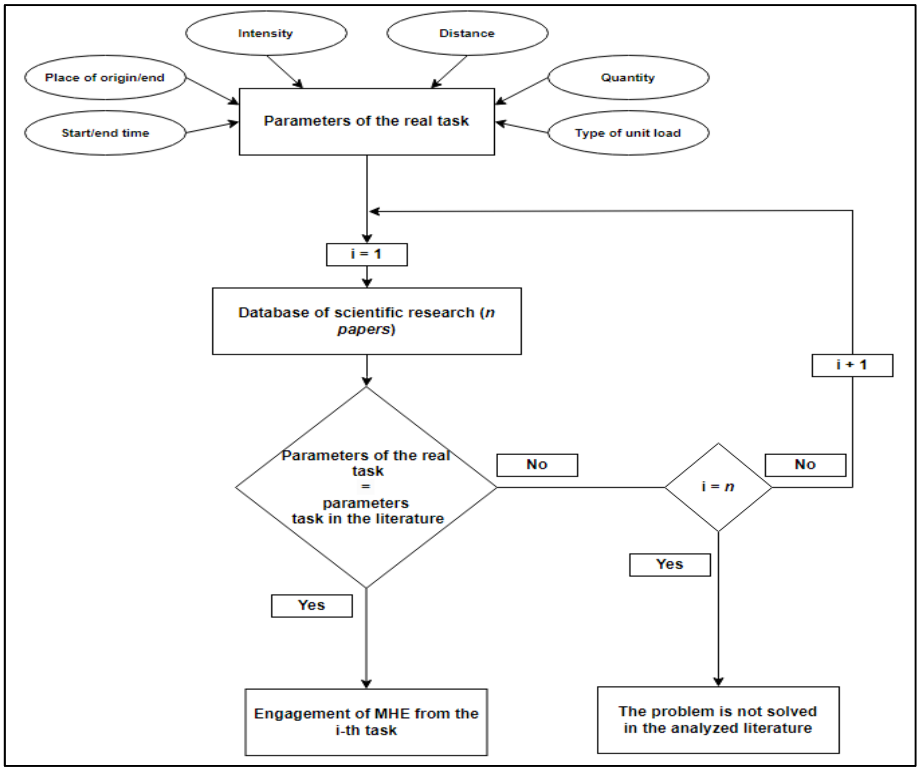

Figure 1 – Methodology for defining guidelines for MHE selection

The methodology for defining guidelines for MHE selection consists of several steps. Initially, it is necessary to identify and describe the key parameters of the analyzed task. These parameters include, but are not limited to (Vukićević, 1995; Sretenović, 1996):

- Task start/end time: outlining when the task starts and ends, important for planning and coordination. It can have stochastic/deterministic, stationary/non-stationary, and continuous/discontinuous features.

- Task origin/end place: the characteristics of the location where tasks begin and end, critical for routing and scheduling. It may have stochastic/deterministic features.

- Distance: the total distance that needs to be covered during the task, affecting travel time and resource allocation. It can have small, medium, or large features.

- Flow intensity: the amount of material over time, influencing the required capacity and speed of the MHE. It can have small, medium, or large features.
- Quantity: the volume or number of unit loads handled.
- Type of unit load: the nature of the items being transported (e.g., pallets, bags, individual items), which determines the appropriate handling and MHE.

Next, an analysis of relevant scientific research is conducted, focusing on the parameters of the task and the types of the MHE engaged. Following this, the observed task is classified according to standard task types found in the literature. If the parameters of the observed task match those of the resolved task in the literature, the guidelines for MHE selection for the observed task type are derived as a conclusion. This approach allows for systematic analysis and identification of MHE, ensuring that all relevant parameters are considered and that the guidelines are based on established solutions from the literature. The goal of this methodology is to provide concrete, applicable guidelines that will support decision making for MHE selection in future situations.

The paper is organized into seven chapters. Following the introduction, the second chapter discusses the concept and scope of the term intralogistics. The third chapter analyzes typical tasks in intralogistics and the MHE used for their realization. The fourth chapter focuses on the analysis of approaches to MHE selection. The fifth chapter presents and comments on the results of the analysis of relevant studies. The sixth chapter examines the validity of the obtained results through regression analysis and defines the guidelines for MHE selection based on this. In the conclusion, the research is summarized, encompassing the key information obtained from the literature analysis, and potential directions for future research are highlighted.

The role and importance of intralogistics processes

Intralogistics, as a term defining the field of logistics, first emerged in the period immediately following World War II. It referred to material handling activities within a factory, carried out using basic equipment and technologies such as hand carts and overhead cranes. A significant milestone in the development of intralogistics was the advent and implementation of the pallet system. Further development of intralogistics has paralleled the growth of the industry, evolving in step with the third and fourth industrial revolutions. The concept of Industry 4.0 has had a substantial impact on the advancement of intralogistics, introducing the use of smart sensors, information and communication technologies, and cloud-based software support (Zrnić et al, 2021). According to the Intralogistics Forum of VDMA (Verband Deutscher Maschinen und Anlagenbau), intralogistics is defined as the organization, control, realization, and optimization of material and information flow within a technologically integrated unit, as well as the materials handling activities in industry, distribution, and public facilities (Kartnig et al, 2012; Yousefifar et al, 2015). In line with modern business trends, which include circular supply chains, this definition can be expanded to encompass this aspect. Intralogistics represents the complex interaction of various logistics functions aimed at controlling the flow of materials throughout the entire supply chain. It describes the internal flow of materials within different logistics hubs, from material flows in manufacturing, distribution centers, airports, and seaports, along with all accompanying flows (information, financial, and others) (Zrnić et al, 2021).

The connection between the spatial dislocation of production and consumption is achieved through the realization of material flows between them. Transforming these flows (spatially, temporally, quantitatively, and by aligning assortments) generates a large number of intralogistic activities. These activities depend significantly on which (sub)systems are connected, e.g., transshipment-storage, transshipment-production, production-storage, etc. (Overmeyer et al, 2009; Telek, 2016; Jusufbašić, 2023). Within intralogistics processes, activities can be grouped according to different criteria to identify classes of activities with similar characteristics and features. This enables more efficient management and synergy of intralogistics activities. One possible way to categorize them is as follows (Yousefifar et al, 2015; Taş, 2023):

1. <u>Activities related to material flow realization</u>: These involve materials handling and their flow within a technologically integrated unit (e.g., a production facility).
2. <u>Activities related to information and inventory flow management</u>: These activities focus on ensuring and updating inventory information at all levels.
3. <u>Warehouse management operations</u>: This encompasses all logistical operations conducted within a warehouse.

Within (intra)logistics systems, various flows are present, including raw materials, semi-finished products, finished goods, spare parts, maintenance consumables, waste materials, fuels, lubricants, and similar items. The realization of these flows involves fulfilling a multitude of activities and requirements. It is crucial to accurately identify the characteristics and features of tasks to appropriately select suitable MHE for their realization (Overmeyer et al, 2009; Yousefifar et al, 2015; Telek, 2016). The technological requirements' characteristics and features provide detailed information describing the type of units and the quantity of materials; the origin and destination of the requirements; the timing, duration, and completion time of the requirements; tolerance intervals; and limiting factors present during task execution (Sretenović, 1996). Typical tasks encountered in intralogistics systems include transshipment (loading, unloading, storage, retrieval); internal transport (transportation, picking, positioning); production activities (packaging, protection, inspection, sorting); and many others. This research focuses on the previously defined groups of tasks rather than individual activities within them. Additionally, it analyzes the characteristics of the MHE engaged to execute these tasks.

Material handling technologies in intralogistics activities

In the process of technological design for new or enhanced existing (intra)logistics systems, a crucial step is selecting the appropriate MHE that will realize the specified task (Telek, 2016). During the MHE selection process, properly defining the intralogistics task is of great importance. A clear understanding of the task guides decision makers toward the category and type of MHE needed. Conversely, misunderstanding the task can lead to selecting the wrong MHE, resulting in reduced system productivity, increased costs, and similar issues. This chapter is dedicated to analyzing tasks within intralogistics systems and the MHE used to execute them.

Materials handling - task analysis

The analysis of tasks in intralogistics involves identifying and describing technological requirements. Describing technological requirements entails understanding their characteristics and features. This is a crucial step in defining a set of potentially applicable MHE for the realization of specific tasks. Below is a description of the characteristics and features of the previously identified tasks observed in the analyzed papers.

Transshipment represents a part of the intralogistics process where the transfer of goods occurs between transport vehicles and/or storage systems. Transshipment involves activities such as picking up, transporting over short distances, and depositing material at various heights and locations. The transshipment task can be characterized as follows: the unit load type is typically a pallet in the analyzed papers; the intensity is generally high; the origin and destination are stochastic; and the timing of initiation, duration, and completion is discontinuous and stationary over longer periods. **Internal transport** encompasses the movement of materials within storage spaces or manufacturing facilities, emphasizing the transportation function. It involves activities such as picking up, transporting, delaying, and positioning materials at various heights and locations. The characteristics of internal transport tasks include the type of unit load—typically individual pieces, boxes, or pallets in the analyzed papers—moderate intensity; stochastic origin and destination; and the timing of initiation, duration, and completion, which can be continuous, discontinuous, or stationary. **Production tasks** involve assembly, packaging, or other operations that alter the appearance and chemical or physical characteristics of materials. These tasks include activities such as picking up, delaying, packaging, sorting, and similar operations. The characteristics of production tasks include the unit load type, typically individual pieces in analyzed papers, very high intensity, deterministic origin and destination, and the timing of initiation, duration, and completion being continuous and stationary.

Understanding the task characteristics plays a significant role in selecting MHE, as it enables the alignment of task requirements with the capabilities of MHE. Further in the paper, the characteristics of the typical MHE engaged in the realization of fundamental types of intralogistics tasks are analyzed.

Characteristics of material handling equipment

In intralogistics, there is a wide range of MHE used for various processes and activities. In recent years, with the development of Industry 4.0, MHE has been continuously evolving and innovating. Each type of MHE has techno-operational characteristics that recommend or limit its engagement for specific tasks to some extent. The primary classification is based on the action of the working organ, distinguishing between equipment with cyclic and continuous actions. Typical representatives of the MHE with cyclic operation include forklifts, tow trucks, AGVs, cranes, and carts, while the MHE with continuous operation includes chutes, belt conveyors, roller conveyors, elevators, and others. Various classifications of MHE are found in the literature based on task type (transport, positioning, unit formation, storage), drive type (motorized, manual, gravitational), degree of automation (semi-automated, automated), and many others, which can be found in the reference literature: (Apple, 1977; Kulweic, 1991; Sretenović, 1996; Vukićević, 1995; Tompkins et al, 2010). This paper highlights and analyzes the MHE applied to typical intralogistics tasks, presented in Table 1.

Table 1 – Typical intralogistics tasks with the corresponding MHE

Task type	MHE
Transshipment	forklifts, cranes, conveyors, AGVs, robotic systems
Internal transport	forklifts, cranes, conveyors, AGVs, robotic systems
Oreder picking	forklifts, conveyors, robotic systems
Storage/retrieval	forklifts, cranes, AGVs, robotic systems
Production activities	cranes, conveyors, robotic systems
Positioning	forklifts, cranes

Forklifts as material handling and manipulation technology in intralogistics processes are represented by various types, most commonly counterbalance, side loader, reach truck, and others. Forklifts are used when overcoming height differences is necessary; they can grasp and deposit units of load (usually pallets), lift and lower them to different positions. They are flexible in terms of path, and are adaptable to various forms and operating modes. Counterbalance forklifts have universal use and can be used at docks, in storage, for positioning tasks, and for similar activities. Side loader forklifts are used for handling longer materials during loading, storage, and unloading tasks. Reach trucks are employed in warehouses for tasks requiring higher lifting heights or narrower aisle operations (Kulweic, 1991; Vukićević, 1995; Sretenović, 1996).

Technology based on conveyors includes belt conveyors, roller conveyors, gravity conveyors, and other types. They are used for loading, transporting, and order picking, as well as in production activities (depending on the configuration of production lines). They are engaged when continuous processes, high demand intensity, and deterministic origins and destinations are required. Belt conveyors, with specific characteristics (such as the type of material the belt is made of, width, and shape), are used for handling small granular and piece goods. They can also be used for horizontal and inclined transport within certain incline limits suitable for the characteristics of the materials and the conveyor. Roller conveyors are used for transporting larger pieces of material, typically at gentle inclines. There are versions of roller conveyors with and without drives. Gravity conveyors are used for both bulk and piece goods when it is necessary to overcome height differences in limited spaces (Kulweic, 1991; Vukićević, 1995; Sretenović, 1996).

The category of cranes includes various types, such as overhead and jib cranes. They are engaged in loading, unloading, internal transport, and production activities. They are involved in labor-intensive processes for handling large quantities of material. Overhead cranes are most commonly used in manufacturing facilities, while jib cranes are designed for handling materials at individual workstations (Kulweic, 1991; Vukićević, 1995; Sretenović, 1996).

AGV technology encompasses MHE such as AGV carts, AGV forklifts, AGV towing vehicles, and similar equipment. They are commonly used for internal transport and loading and unloading in systems requiring a certain level of automation. AGV carts are used for horizontal material transport as they cannot lift materials. AGV forklifts are similar to conventional forklifts but differ in their restricted path of movement compared to AGV vehicles. Robotic systems have wide applications in highly automated systems, from loading and unloading to production activities. Robotic systems include autonomous mobile robots (AMRs) for internal cargo transport, collaborative robots, and robotic arms used in manufacturing environments unsuitable for humans (Kulweic, 1991; Vukićević, 1995; Sretenović, 1996).

Approaches for selecting material handling equipment

The engagement of appropriate MHE can significantly enhance system productivity, activity realization quality, workplace safety, and ergonomic conditions. Therefore, the selection of MHE depends on the specific task that needs to be realized. It is necessary to thoroughly analyze the task parameters to understand their specificity. Additionally, understanding the MHE itself and the context in which it will be engaged is crucial. The selection of MHE in the process of technological design can be realized in the following situations (Saputro et al, 2015):

1. Designing a new system, and
2. Reconstructing an existing system.

The process of selecting MHE involves a series of steps in which the planner makes decisions to select the appropriate MHE that will best meet the specified task (Tompkins et al, 2010; Telek & Cservenák, 2020). The selection of MHE can be done in several ways, depending on the level of detail in the analysis. Depending on the level of decision making, in some situations, it is not enough to simply conclude that the task requires the use of a conveyor; it is also necessary to determine its type and techno-exploitation characteristics. Accordingly, the selection of MHE can be classified at different levels (Saputro et al, 2015):

1. Level I: This level focuses on finding the appropriate category of MHE. It includes the analysis of conveyors, cranes, industrial trucks, positioning equipment, etc.
2. Level II: This level focuses on finding the appropriate type of MHE within the category. The selection is directed towards selecting the best variant from the category of conveyors, such as belt conveyors, roller conveyors, or similar.
3. Level III: This level focuses on finding the appropriate model of MHE within the selected type. For example, selecting the best alternative among types of hand pallet trucks in terms of dimensions and technological and operational characteristics.

There are numerous tools that facilitate the decision-making process in the evaluation and selection of appropriate MHE. One of the pioneers in solving the problem of MHE selection, Apple (1977), in his book "Plant Layout and Material Handling," proposes the Material Handling Equation to aid decision making in selecting MHE. The essence of this equation consists of six main questions related to the following aspects of material handling: WHY (the reason for selecting MHE), WHAT (the materials being handled), WHERE and WHEN (the timing and location of handling), HOW (the method of handling materials), and WHO (the person responsible for handling materials). All six questions are crucial and must be satisfactorily answered. The outcome of the equation, or the solution, should represent a list of the characteristics that the potential MHE must fulfill to be engaged in the given task. Modern research employs analytical methods, multi-criteria decision-making (MCDM) methods, mathematical programming, simulation models, tools based on artificial intelligence, and more. In practice, designers rely most often on the following sources (Fonseca et al, 2004; Sharp et al, 2021):

1. Manufacturer catalogs and MHE manuals;
2. Designers' own experience;
3. Consulting with experts from the same/similar fields;
4. Engaging experts;
5. Including the opinions of workers involved in MHE operations in the decision-making process; and
6. Results from scientific research studies.

The mentioned approaches have their advantages, but they also carry certain risks. Planers who rely on personal experience tend to select the MHE they are most familiar with, which in some cases may not be suitable for the task at hand. MHE sellers have an interest in selling their equipment, so their recommendations can sometimes be biased. On the other hand, consultants often charge significant fees for their recommendations. Therefore, these options do not always guarantee a cost-effective solution.

The results of scientific research can indeed be utilized as ready-made solutions in specific situations. When research successfully models, analyzes, and solves a particular problem, the findings become valuable references for practical application. Such ready-made solutions have the potential to be adapted and applied to similar or identical problems encountered in practice. The main contribution of this paper lies in facilitating the use of scientific research results as ready-made solutions, thereby simplifying and expediting the decision-making process regarding the selection of MHE in specific scenarios. It is important to note that while research results often serve as ready-made solutions in certain situations, they are not universal and have their limitations. Their applicability requires careful identification of the specific conditions and characteristics of each task. Planers (decision makers) should consider all changes in the environment to ensure that the applied solutions remain relevant and provide long-term efficiency.

This paper aims to establish the guidelines for selecting MHE within the framework of the first level of selection. In this regard, a literature analysis has been conducted focusing on the selection of MHE for specific types of tasks. This approach enables the development of a specific decision-making system (such as algorithms, decision trees, etc.) for selecting MHE. Therefore, the next section of the paper is dedicated to analyzing these research studies.

Analysis of research in the field of MHE selection

In shaping intralogistics systems, a central issue is the selection and engagement of MHE. The task of selecting MHE is widely represented in logistics subsystems, including production, transshipment, storage, and others. The process of selecting MHE involves a series of steps and decisions made by decision makers to select the appropriate MHE that will efficiently meet the specified task requirements (Tompkins et al, 2010; Zubair et al, 2019). This paper focuses on defining the guidelines for selecting MHE based on the findings from scientific research. For the purposes of this paper, the literature base was formed by searching Google Scholar using the keywords such as MHE, MHE selection, and MHE intralogistics. A detailed analysis included 20 relevant studies selected according to the following criteria: published between 2018 and 2023, higher citation levels, and available for online reading. Compared to the existing review papers in this field (Saputro et al, 2015; Telek & Cservenák, 2020), this study connects the task types with the MHE characteristics to provide the guidelines for MHE selection. This approach enables a comprehensive examination of current trends and innovations in the field of MHE selection. By using the criteria such as publication date, citation impact, and accessibility, this analysis ensures that relevant and influential research is included. By linking the task types with the specific MHE characteristics, this study provides practical guidelines that can help optimize intralogistics processes through the selection of appropriate technology. This contributes to improving operational efficiency and effectiveness, reducing costs, and enhancing system performance.

Review of relevant research

In the available literature, there are review articles on the selection of MHE. These papers provide an overview of the current state of the issue for a specific period. Telek and Cservenák (2020) analyzed research dealing with the selection of MHE using the database of the Science Direct publishing house. They considered which MHE is used for certain segments of MHE system planning. Under planning segments, they included MHE engagement in operational tasks and MHE engagement in automation processes. Also, they presented the tools and methods that were used in the analyzed research about the considered MHE. Unlike their research (Telek & Cservenák, 2020), this paper includes research from various publishing houses (Science Direct, MDPI, Springer, and others), and the engagement of MHE is considered for specific types of tasks. Saputro et al. (2015) analyzed 42 studies from the period 1971-2014. They analyzed the research from the aspect of the problem solved, the level of decision-making, and the applied methodology/tools. In relation to the research of Saputro et al. (2015), this paper includes the papers in the period from 2018-2023; in addition, it provides a broader picture of the solved problem and provides an insight into which MHE was considered for which type of task. Based on their paper (Saputro et al, 2015), it can be stated that 20 papers (as many as analyzed in this paper) represent an adequate database for the analysis of this issue. In the analyzed research, a large number of papers are about palletized goods (over 80% of the research). Accordingly, the obtained guidelines for the selection of MHE should be considered as application recommendations for the given task parameters. Table 2 shows the analyzed research from the aspect of the solved task type, the considered MHE, and the applied methods for solving the select problem.

Table 2 – Overview of the analyzed papers

Author	Type of the solved task	Considered MHE	Applied method
Agarwal & Bharti (2022)	internal transport	AGVs	Fuzzy AHP, Fuzzy TOPSIS, Fuzzy DEMETAL
Voćkić et al. (2018)	transshipment, internal transport	forklifts	Rough SWARA, ARAS
Mathew & Sahu (2018)	internal transport	AGVs, conveyors	CODAS, EDAS, MOORA, WASPAS
Zavadskas et al. (2018)	internal transport	AGVs	R-ROV, WASPAS, Rough SAW, Rough MABAC, FUCOM
Průša et al. (2018)	transshipment, internal transport	forklifts	TOPSIS
Zubair et al. (2019)	transshipment, internal transport, production activities	conveyors, AGVs, cranes	AHP
Kučera (2020)	transshipment, internal transport	forklifts, AGVs	AHP, WSA
Goswami et al. (2021)	internal transport, production activities	forklifts, conveyors, robots	TOPSIS, ARAS, COPRAS, CRITIC
Horňáková et al. (2021)	transshipment, internal transport	forklifts, robots	AHP
Soufi et al. (2021)	transshipment, production activities	conveyors	AHP
Chakraborty & Saha (2024)	transshipment, internal transport	forklifts	FUCOM, MOORA

Author	Type of the solved task	Considered MHE	Applied method
Shchemeleva (2022)	transshipment, internal transport	conveyors	Optimization model
Simic et al. (2023)	transshipment, internal transport	AGVs, robots	T2NN-LOPCOW-ARAS
Tadić et al. (2023)	transshipment, internal transport	conveyors, AGVs, robots	Fuzzy AHP, Fuzzy COBRA
Yazid et al. (2023)	transshipment, internal transport, production activities	conveyors, AGVs, robots	CRITIC, TOPSIS
Huskanović et al. (2023)	internal transport	forklifts	SWARA, CRITIC, MARKOS
Chatterjee & Chakraborty (2023)	internal transport, production activities	conveyors, cranes, AGVs	R method
Ulutaş et al. (2023)	transshipment, internal transport	forklifts, cranes	Fuzzy BWM, Fuzzy MCRAT

In the analyzed research, typical factors (criteria) considered during the selection of MHE include productivity, flexibility, automation, safety, material handling capability, spatial constraints, and similar aspects. With increasing the awareness of sustainability and the goal of enhancing it, the following criteria are also included in the MHE selection process: energy consumption, CO_2 emissions, financial indicators (return on investment, profitability, and similar), ecological parameters, and similar factors.

Discussion of the analyzed research

This paper aims to analyze the reference research based on Apple's equation. Specifically, the testing of Apple's equation was conducted, which provides a proposed material handling solution for the defined task parameters (type of unit load, quantity, distance, lifting height, etc.). This approach represents a form of Decision Support System (DSS) for selecting MHE. Chan et al. (2001) present an example of the application of Apple's equation. An analysis of the type unit of load and the characteristics of materials may indicate the need to handle pallets.

Further analysis might show that lifting the material to a height of 6 meters is necessary, the transport distance is 50 meters, and certain maneuvering is required during material transport. This suggests that a forklift would be the appropriate MHE in this case. Even further analysis of methods can provide more information about the specific characteristics of the forklift.

In the analyzed papers, it was concluded that forklifts are most commonly used for carrying out transshipment tasks, as shown in Figure 2. The transshipment tasks in the analyzed papers are characterized by the following: the type of unit load– pallet; large quantity of materials (more than 50 pallets) in a unit of time; origin – transshipment dock; destination – storage locations; distance – on average more than 20 meters; occurrence time – stochastic; and lifting height – up to 10 meters required. Accordingly, forklifts are MHE that efficiently handles palletized materials, ensures high process intensity, is flexible regarding movement paths, and provides intermittent operation. Additionally, it is important to highlight the multifunctionality of forklifts, which allows for the realization of multiple types of tasks simultaneously (transshipment and internal transport), a requirement often seen in practice. The least applied technology for the realization of transshipment tasks is cranes, which are considered atypical when it comes to handling palletized materials. Factors such as limited working space, the complexity of grasping loads from the vehicle's cargo area, reduced employee safety (since the load being manipulated is above the working area), and lower productivity compared to forklifts for handling lighter unit loads indicate the incompatibility of cranes for transshipment tasks.

When it comes to internal transport tasks, the conclusion drawn from the analyzed papers addressing this issue is as follows. In the majority of cases (over 50% of the papers), the MHE considered for the realization of internal transport activities are AGVs (Figure 3). Internal transport tasks in the analyzed papers are characterized by the following: the type of unit load – pallets and packages; large quantity in a unit of time; origin and destination – storage locations or workstations; distance – on average more than 50 meters; and occurrence time – stochastic. Based on the task description, AGVs provide the necessary flexibility in handling various types of unit loads, as well as the intermittent operation characteristic that is common in the majority of tasks analyzed. The use of AGVs for internal transport tasks is supported by the automation of intralogistics activities in line with the development of Industry 4.0 solutions. In contrast, cranes are used in the least number of cases due to their limitations in path flexibility and access to storage locations, workstations, and similar areas.

MHE based on conveyors (roller, belt, slide) is most considered in production activities (Figure 4). Production activities require high process intensity, continuity, and determinism, which conveyor technology facilitates. Production is also characterized by: the type of load unit – individual pieces; large quantity in a unit of time; origin and destination – workstations; and occurrence time – deterministic. Additionally, the configuration of production and assembly lines favors the use of conveyors. Forklifts are least used for production activities because the production process is continuous and involves handling individual product units.

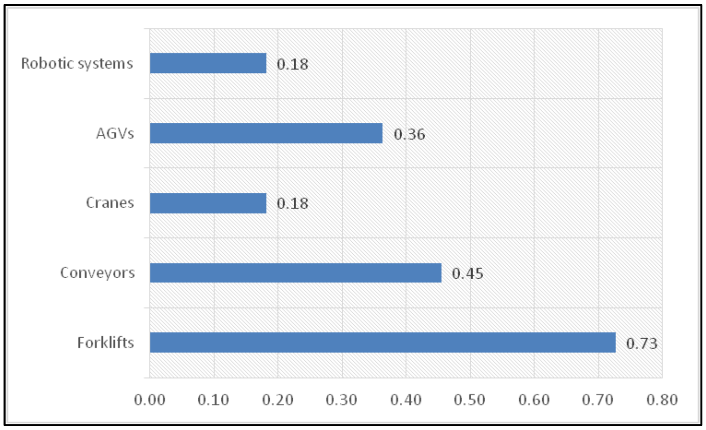

Figure 2 – MHE used for the realization of transshipment tasks

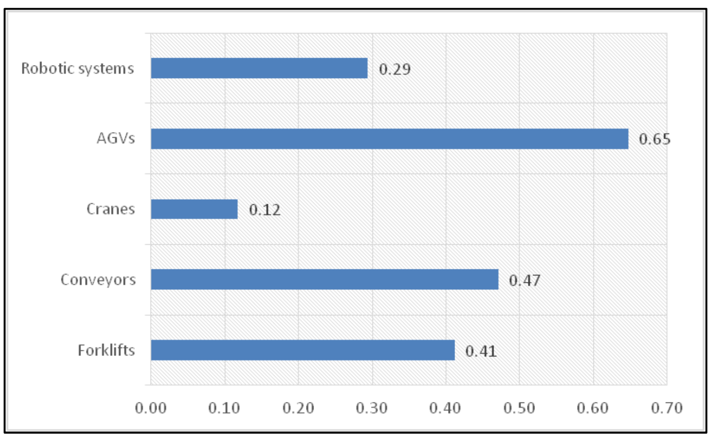

Figure 3 – MHE used for the realization of internal transport tasks

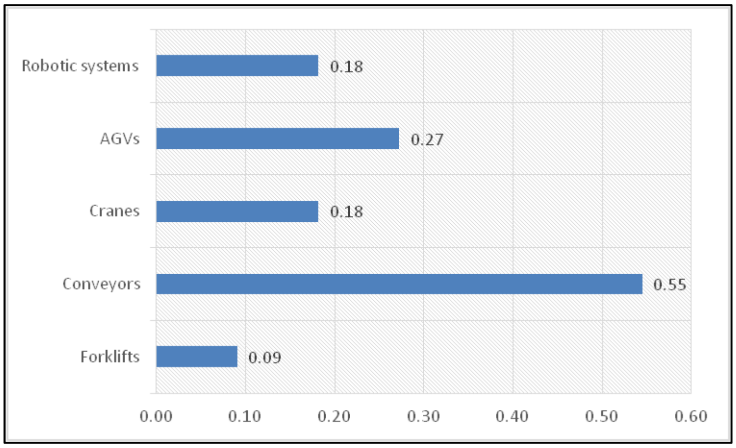

Figure 4 – MHE used in production activities

Analysis of the results and the generation of the guidelines for MHE selection

The results of the analyzed research indicate which MHE is most commonly considered for specific types of tasks. However, the data on the frequency of MHE engagement in the literature is not sufficient to make informed decisions regarding the appropriate selection of MHE. With this in mind, it is necessary to establish the relationship between task parameters on the one hand and the characteristics of the applied MHE on the other. Therefore, this paper applied regression analysis to define this relationship. Based on the obtained relationship, it is possible to establish the guidelines for selecting MHE based on task parameters.

Regression analysis

Regression is a statistical method used to investigate and model relationships between two or more variables. Its primary purpose is to determine how changes in one or more independent variables affect a dependent variable (Uyanık & Güler, 2013). In the context of this paper, regression analysis is employed to define the relationship between the task parameters (independent variables) and the applied MHE (dependent variable), enabling informed decision making for MHE selection. There are several types of regression, with linear regression and logistic regression being the most commonly used. For this paper, linear regression has been used.

The process of applying regression analysis involved several steps. Data were collected from relevant research containing information on task parameters (type of unit load, quantity, intensity, distance, origin/destination time). These task parameters were categorized into two groups based on their physical and temporal characteristics, respectively: Parameter-1 (type of unit load, quantity, distance, origin/destination) and Parameter-2 (intensity and origin/destination time). The values of these parameters were quantified on a scale from 1 to 9. Larger dimensions and types of units of load received higher values, as did larger quantities, intensity, and distance. Origin/destination and time received higher values if they leaned towards determinism and lower values in cases of stochasticity.

Linear regression was chosen as an appropriate model for analyzing the relationship between the task parameters and the MHE characteristics. The equation of the linear regression model is (Uyanık & Güler, 2013):

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_n X_n + \epsilon, \quad (1)$$

where:
Y is the dependent variable (MHE),
X_1, X_2, X_3... are the independent variables (task parameters),
$\beta_0, \beta_1, \ldots, \beta_n$ are the regression coefficients, and
ϵ is the random error.

In Figure 5, the task parameters addressed in the literature are represented by points, with the tasks employing forklifts highlighted in red (Figure 2). The characteristics of forklifts in addressing these tasks are depicted by the regression line. It can be seen that for most of the tasks for which the forklift is considered, it is suitable. Additionally, other tasks that do not deviate significantly from the regression line can also be successfully executed using forklifts. This highlights the flexibility and versatility of forklifts across various task parameters.

In Figure 6,the task parameters for internal transport addressed in the literature are represented by points, with the task engagement AGVs highlighted in red (Figure 3). The characteristics of AGVs in addressing these tasks are depicted by the regression line. It can be seen that for most of the tasks for which AGVs are considered, they are suitable. Additionally, other tasks that do not deviate significantly from the regression line can also be successfully realized using AGVs. This highlights the trend towards automation in intralogistics systems.

In Figure 7, the task parameters for production activities analyzed and addressed in the literature are represented by points, with the tasks employing conveyors highlighted in red (Figure 4). The characteristics of conveyors in addressing these tasks are depicted by the regression line. It can be seen that for most of the tasks for which the conveyor is considered, it is suitable. Additionally, other tasks that do not deviate significantly from the regression line can also be successfully realized using conveyors. This is supported by the configuration of production and assembly lines.

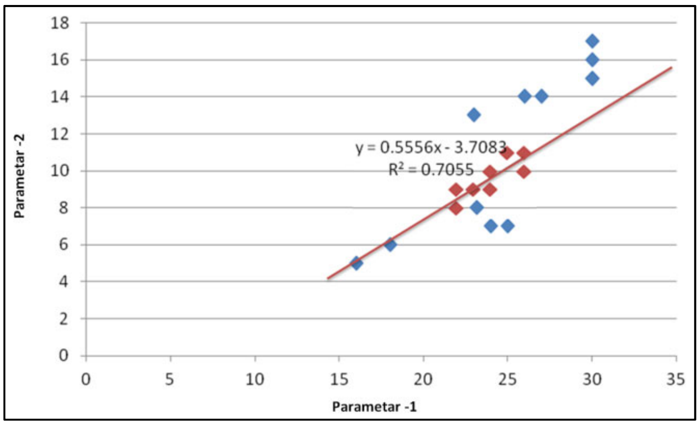

Figure 5 – Regression analysis of the transshipment task

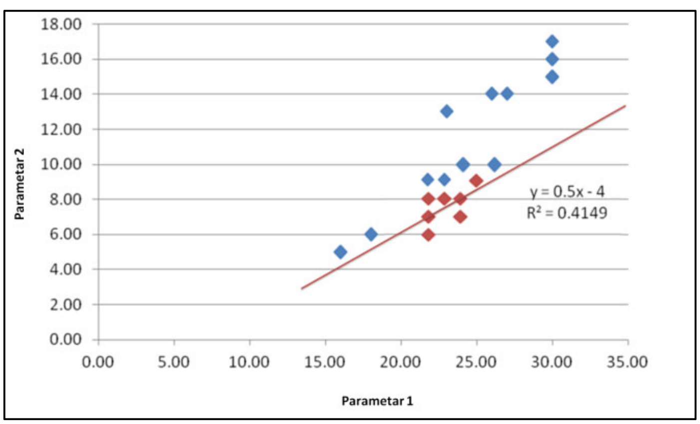

Figure 6 – Regression analysis of the internal transport task

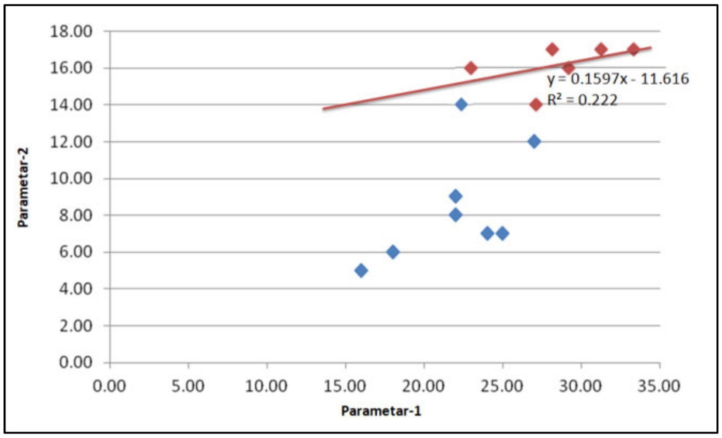

Figure 7 – Regression analysis of production activities

Guidelines for selecting MHE

The conclusion of the research analysis is that different types of MHE are used for various tasks according to task characteristics and technology. Based on the results obtained from the analyzing relevant studies, regression analysis was conducted to validate the applied solutions/MHE. The conclusion of the regression analysis indicates the justification for using MHE most frequently cited in the literature for specific types of tasks. Consequently, the guidelines for selecting MHE derived from this analysis are presented in Figure 8.

In the analyzed studies of intralogistics activities, the tasks were viewed as integrated units. Accordingly, MHE was considered in the context of realizing multiple tasks simultaneously (transshipment and internal transport, internal transport and positioning, transshipment and production activities, etc.). The grouping of MHE according to the types of tasks, i.e., summing up the requirements, contributes to the reduction of costs and the number of required MHE.

It also increases efficiency, optimizes resource utilization, reduces errors in activities, and minimizes damage to goods. In contrast, if the execution of intralogistics activities were considered separately, the outcome would likely be different. Certainly, this area represents a direction for future research.

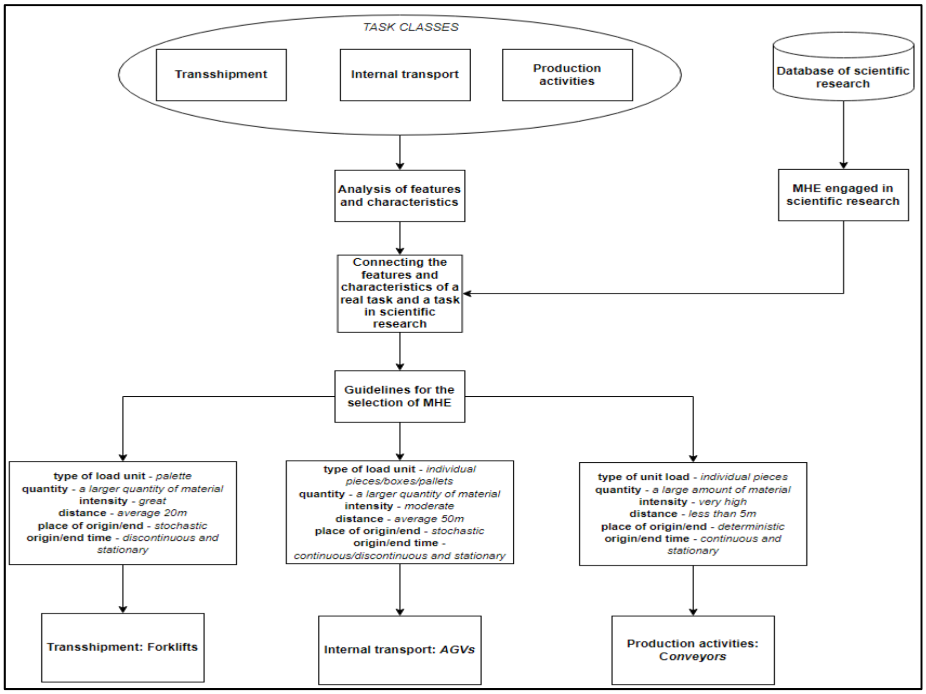

Figure 8 – Guidelines for MHE selection based on scientific research

When deciding the selection of MHE in the analyzed research, MCDM methods dominate. Numerous methods and their combinations are used. Through analysis, it has been determined that the Analytic Hierarchy Process (AHP) method is most commonly used for determining criterion weights, while the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) method is frequently applied for ranking alternatives. The AHP method relies on pairwise comparisons of criterion importance to establish weights, whereas the TOPSIS method calculates the distances of alternatives from ideal and anti-ideal solutions to determine rankings. In the literature, there are attempts to apply artificial intelligence and machine learning to solve MHE selection problems. However, results so far are not as stable and reliable as those from MCDM methods, but progress in this field is expected with advancements in computational algorithms. Another limitation identified in the analyzed research is the inadequate task description for which MHE selection is needed. When tasks are described comprehensively with all relevant characteristics, the process of matching tasks to MHE becomes significantly more straightforward.

Conclusion

When generating intralogistics solutions, the central issue is the selection and engagement of adequate MHE. The process of MHE selection occurs in two scenarios: during the design of new systems and during the reconstruction of the existing ones. Selecting MHE involves aligning task characteristics and requirements with the appropriate type of MHE. Given the existence of a wide range of MHE, which carries with it certain limitations, the task of selection represents a multi-vector quantity. This paper is devoted to the analysis of the reference papers in the field of MHE selection in intralogistics systems. For this research, the Google Academic database was searched for keywords such as MHE, MHE selection, and MHE intralogistics. A more detailed analysis included 20 relevant papers/research studies, which were selected according to the following criteria: period of publication—the period from 2018 to 2023 was taken; number of citations; and online availability. Intralogistics represents a complex interaction of various logistics functions aimed at controlling internal flows of materials, information, money, and others within production, storage, distribution, and other systems. Accordingly, a wide set of intralogistic tasks occurs in these systems. For this research, three types of tasks were analyzed: internal transport, transshipment, and production activities. Numerous MHE types are used for the realization of intralogistics tasks. The paper analyzed the engagement of typical MHE, such as forklifts, cranes, conveyors, AGVs, and robotic systems. Each of these categories includes different types and models (counterbalance forklift, overhead crane, AGV forklift), which are not analyzed in detail in this paper. After the analysis of the research according to the mentioned aspects, the section on data sets on solved types of tasks and the applied MHE was made in the paper. When it comes to transshipment, forklifts are most often engaged. Factors that indicate this are the type of unit load (pallet), the ability to overcome the height difference, adaptability to different intensities, and the ability to realize several different intralogistics tasks. MHE based on AGVs is most often used to realize internal transport tasks, which indicates the trend of automation and improvement of intralogistics systems with the development of Industry 4.0. MHE based on conveyors is the most represented in production activities as a consequence of the configuration of production and assembly lines. In the paper, regression analysis was applied to examine the reliability of these data, that is, the relationship between the task parameters and the applied MHE. Regression analysis showed that in most cases, it is justified to use the proposed MHE from the literature.

By analyzing the papers dedicated to the selection of MHE, certain aspects of the research were identified that were not adequately covered, such as clearly defining the parameters of the task and detailed analysis of MHE according to their characteristics. Also, the existing research often lacks a holistic approach that would include a wider range of criteria. Therefore, the main contribution of this paper is the generation of guidelines for the selection of MHE in intralogistics, taking into account specific parameters of the task such as type of unit, intensity, time of origin/end, and place of origin/end of the task. With this approach, the MHE selection process becomes structured and based on relevant data, which enables consistent and accurate decision making. Future research should be focused on improving the following segments:

Additional types of unit load and materials: It is necessary to pay attention to different types of materials, such as rods, bulk, irregular, and others encountered in practice.

Industrial specifics: The problem of MHE selection should be viewed in the context of different industries, which have specific types of tasks with stricter restrictions on their implementation.

Atypical MHE: Consideration of certain atypical MHE (monorail cranes, air cushion vehicles) in the realization of intralogistics tasks.

New MCDM methods: Implementation of new MCDM methods and their combinations, application of fuzzy logic, efficiency assessment model (DEA), and operational research model.

Artificial intelligence and machine learning: Direct research towards the development of MHE selection algorithms based on machine learning is in accordance with the development of artificial intelligence and computer technology.

These directions of research would contribute to the further improvement of the MHE selection process, enabling even more efficient, economical, and sustainable intralogistics systems.

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Directrices para la selección de tecnología en intralogística: un enfoque científico

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CAMPO: ingeniería mecánica, logística
TIPO DE ARTÍCULO: artículo científico original

Resumen:

Introducción/objetivo: La intralogística implica la organización, control, realización y optimización de flujos de materiales e información dentro de un sistema tecnológicamente integrado. La selección y aplicación de equipos de manipulación de materiales (MHE) adecuados desempeñan un papel crucial en la configuración de los sistemas intralogísticos. Este artículo tiene como objetivo definir pautas para la selección de MHE con base en investigaciones científicas. La metodología implementada para lograr este objetivo comprende varios pasos fundamentales.

Métodos: El paso inicial implica analizar tres grupos típicos de tareas en los sistemas (intra)logísticos: transbordo, transporte interno y actividades de producción. El análisis se centra en identificar y describir parámetros clave de la tarea, como el tipo de carga unitaria, la cantidad, la intensidad del flujo y la ubicación y el momento de inicio y finalización de la tarea. A continuación, hay un paso dedicado al análisis de investigaciones científicas relevantes. Se busca en la bibliografia según criterios específicos, como año de publicación, palabras clave y recuento de citas, para formar una base de datos de artículos relevantes. El análisis se centra en identificar y vincular los parámetros de las tareas prácticas con los descritos en la bibliografia y en las características del MHE utilizado para facilitar la selección del MHE apropiado para estas tareas.

Resultados: Continuando, en el tercer paso, la tarea observada se clasifica según los tipos de tareas estándar que se encuentran en la bibliografia.

Conclusión: Finalmente, en el último/cuarto paso, se aplica el análisis de regresión para definir las pautas para la selección de MHE en función de la frecuencia de uso de grupos MHE específicos para ciertos grupos de tareas como se describe en la bibliografia.

Palabras claves: intralogística, selección de MHE, transbordo, transporte interno, producción.

Рекомендации по выбору технологии в интралогистике, основанные на научных исследованиях

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РУБРИКА ГРНТИ: 81.88.00 Материально-техническое снабжение. Логистика
ВИД СТАТЬИ: оригинальная научная статья

Резюме:

Введение/цель: Интралогистика включает в себя организацию, контроль, реализацию и оптимизацию материальных и информационных потоков в рамках технологически интегрированной системы. Выбор и применение соответствующего погрузочно-разгрузочного оборудования (MHE) играют решающую роль в формировании интралогистических систем. Цель данной статьи − определить главные принципы отбора, основанные на научных исследованиях. Метод, применяемый для достижения этой цели, включает в себя несколько основных этапов.

Методы: Начальный этап включал в себя анализ трех типичных групп задач в (внутри) логистических системах: перевалка, внутренние перевозки и производственная деятельность. Анализ сосредоточен на выявлении и описании ключевых параметров задачи, таких как: способ погрузки товара, количество, интенсивность товарного потока, а также местоположение и время начала и завершения задачи. Далее следует этап, посвященный анализу соответствующих научных исследований. Для формирования базы данных соответствующих статей исследование литературы осуществлялось в соответствии с определенными критериями, такими как: год публикации, ключевые слова и количество цитирований.

Результаты: Анализ сосредоточен на выявлении и увязке параметров практических задач с параметрами, описанными в литературе, а также на характеристиках MHE, используемых для облегчения выбора подходящего MHE для этих задач.

Вывод: После этого, на третьем этапе, наблюдаемая задача была классифицирована в соответствии со стандартными типами задач, описанными в литературе.

Ключевые слова: интралогистика, выбор MHE, перевалка, внутренний транспорт, производство.

Смернице за избор технологије у интралогистици, засноване на научним истраживањима

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КАТЕГОРИЈА (ТИП) ЧЛАНКА: оригинални научни рад

Сажетак:

Увод/циљ: Интралогистика обухвата организацију, контролу, реализацију и оптимизацију токова материјала и информација унутар технолошке заокружене целине. Кључну улогу у обликовању интралогистичких система има избор и примена одговарајуће технологије руковања материјалима (МХЕ). Циљ овог рада јесте дефинисање смерница за избор МХЕ, ослањањем на научна истраживања. За његову реализацију примењена је методологија која се састоји од неколико основних корака.

Методе: Почетни корак обухвата анализу три типичне групе задатака у (интра)логистичким системима: претовару, унутрашњем транспорту и активностима у производњи. Анализа је посвећена идентификацији и опису кључних параметара задатка, као што су: појавни облик робе, количина, интензитет робног тока, место и време настанка и завршетак задатка. Затим, следи корак посвећен анализи релевантних научних истраживања. Литература је претраживана према одређеним критеријумима, као што су године објављивања, кључне речи и број цитата, на основу којих је формирана база релевантних радова.

Резултати: Фокус анализе био је на идентификацији и повезивању параметара практичних задатака са задацима описаним у литератури, као и на карактеристикама коришћених МХЕ, како би се омогућио избор одговарајућих МХЕ за те задатке.

Закључак: У трећем кораку посматрани задатак се класификује према стандардним типовима задатака из литературе.

Кључне речи: интралогистика, избор МХЕ, претовар, унутрашњи транспорт, производња.

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