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Warehouse Management: Essential Elements for Its Design, A Proposed Model

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ABSTRACT

The operational management of a warehouse is a crucial component in a company's supply chain, directly influencing the efficiency and competitiveness of the entire organization. A well-managed warehouse not only optimizes logistics costs but also improves customer service quality by reducing delivery times and increasing overall satisfaction. The basic components of warehouse operations include receiving and storing goods, inventory management, picking, and order preparation. Each of these phases requires careful planning and effective execution to ensure that operations are carried out efficiently and without errors. Warehouse organization is not only about creating an effective and efficient process—it must also take place within a properly designed environment. In this context, the paper aims to provide both academics and professionals with a set of elements that must be considered and analyzed in order to correctly design warehouse layouts and processes. Starting from a literature review aimed at identifying the key components used in operational design, the main topics addressed by various authors were examined, leading to the presentation of an analytical model. The proposed model identifies the following core elements in warehouse design: the goods and their management, information systems and information management, space, non-removable physical constraints, internal infrastructure, handling and transport equipment, external infrastructure, processes, and personnel. This study aims not only to provide a practical guide for logistics managers and warehouse supervisors—helping them improve the management of storage spaces and achieve efficiency and sustainability goals—but also to offer material for academic study into warehouse operations.

1. Introduction

In recent years, the warehouse is no longer seen merely as a place to store goods but has become a true profit center. The notion that the warehouse is a place capable of creating value for the customer is now well established. Errors in operations, incorrect picking, damaged goods, and

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delays in order preparation are just a few examples of process non-conformities that originate in the warehouse and can jeopardize the trust relationship with customers.

The economic crisis and new international scenarios have pushed companies toward the pursuit of efficiency and flexibility. Lean and agile philosophies have led companies to find, in the proper management of inventory, a way to reduce operational costs. The warehouse has become an entity that must face several trends: on the one hand, customers demand smaller and more punctual deliveries; on the other hand, sourcing from the Far East requires inventory levels that cannot be minimized. The shift of the production center of gravity toward Asian countries has also transformed manufacturing companies into distribution centers. It can be said that the effect of globalization has led many companies to evolve from production hubs to storage and shipping centers. Thus, the role of the warehouse has become fundamental.

Most definitions describe the warehouse as a place where goods are received, stored, handled, and organized for further shipment. After goods are received from a supplier, they may be stored in the warehouse for a certain period while awaiting use (Kocifaj, 2019). A warehouse is also a place where various activities are carried out depending on its function and its position within a company's logistics system or supply chain (Marasová & Šaderová, 2018). It is therefore assumed that one or more processes are performed in this space to ensure the physical flow of materials and products.

According to Gu et al. (2010), warehouse design problems involve five groups of decisions: determining the general structure of the warehouse (conceptual design); sizing; layout calculation; selection of storage equipment; and choice of the operational strategy. Furthermore, a warehouse project must include the definition of policies related to order fulfillment/picking, storage, and inventory rotation (Koster et al., 2007; Chan & Chan, 2011). Gu et al. (2010) argue that there is a gap between published research and actual practice in warehouse design and management. The authors state that to bridge the divide between academia and practice, it is necessary to improve the state of the art in warehouse design methodology. This paper aims to contribute to narrowing that gap between practical application and academic research.

The literature highlights the main activities that make up the warehouse process. The sources report that materials undergo receiving, inspection, storage, picking, and order preparation, along with the final shipment. The flow of items through the warehouse can be divided into several distinct stages or processes (Rouwenhorst et al., 1999):

- The receiving process is the first phase an item goes through upon arrival. Products arrive by truck or internal transport (in the case of a production warehouse). During this phase, products may be inspected or transformed (e.g., repackaged into different storage modules) and may wait for transport to the next stage.
- In the storage process, items are placed in their respective storage areas. In the storage area there is the reserve area, where products are stored in the most cost-effective manner (bulk storage). The picking area, usually in the storage area, is where products are stored in smaller quantities to facilitate retrieval by order pickers. Typically, items in the picking area are placed in easily accessible storage modules. For example, the reserve area may consist of pallet racks, while the picking area may include smaller shelves. The transfer of items from the reserve to the picking area is called replenishment.
- Order picking refers to retrieving items from their storage locations and can be performed manually or semi-automatically. These items may then be moved to the sorting and/or consolidation area. Consolidation refers to collecting and organizing items intended for the same customer.
- In the shipping area, orders are inspected, packed, and finally loaded onto trucks, trains, or other means of transportation.

Warehouse management is an integrated process that encompasses several key functions, all aimed at ensuring the efficient and secure flow of goods from arrival to final distribution. Another essential aspect of warehouse management involves inventory control. This includes implementing strategies to maintain optimal inventory levels, avoiding both shortages and excess stock. Warehouses are increasingly viewed as opportunities to optimize operations and information flows, reduce inventory levels, and make distribution more agile (Vrijhoef & Koskela, 2000). The main objectives of proper warehouse design include cost reduction, achieving economies of scale by transporting large quantities of goods between logistics centers (Rodríguez et al., 2007), managing variability caused by factors such as product seasonality (Gu et al., 2007), maintaining a high level of customer service (Parikh & Meller, 2008), integrating flexibility into the supply chain to ensure greater agility in responding to market changes (Amiri, 2006).

2. Warehouse Design

Designing a warehouse is a complex task that involves a large number of interconnected decisions, including the functional description of the warehouse, technical specifications, selection and layout of equipment, warehouse processes, organization, and other aspects. According to Bartholdi III and Hackman (2008), choosing the best solution for a warehouse is complex because many factors influence the success of warehouse operations, such as the dock area, rack types, rack access, and other elements. In a study by Faber et al. (2001), the authors argue that warehouse organization should be standardized to limit administrative costs. Other relevant aspects to consider in warehouse design include safety, workforce, offices, infrastructure, communications, inventory, and control. One of the goals is to ensure a certain level of flexibility to accommodate potential demand variability. Therefore, warehouse design is the most important factor for its effective operation not only within the company but across the entire supply chain. Lambert and Cooper (2000) state that supply chain management involves the integration of key business processes and, in this context, warehouses are essential hubs within the supply chain in which they operate.

The study by Rouwenhorst et al. (2000) presents a framework and classification of warehouse design and management problems, distinguishing between strategic, tactical, and operational issues. Authors Baker and Canessa (2009) outline the steps in warehouse design by comparing the different phases used by warehouse design companies and the tools employed in each stage. Gu et al. (2010) identify five main decision problems in warehouse design: overall structure, sizing and capacity, department layout, equipment selection, and operational strategy. Karakis et al. propose a hierarchical approach to distribution center design. Hassan emphasizes the importance of layout, which must include the organization of functional areas, the number and position of input/output (I/O) points, the number, size, and orientation of aisles, space estimation, flow models, and picking zone definitions.

The publications by de Koster et al. and Tappia et al. provide an overview of the literature on decision-making issues in manual order picking processes, focusing on internal layout optimization, stock assignment methods, routing strategies, order batching, and zoning. Kapliienko et al. explore the potential for implementing virtual reality in the design of warehouse lighting systems. Several authors have proposed general models for warehouse design and planning. Straka (2013) proposes the PDS (Project for Distribution Stock) model, which consists of a set of variables influencing warehouse design. The core of the model is an equation for designing distribution warehouses, based on a finite number of variables PDS = {T, R, D, M, S, P, I, L}, where:

- T: type of goods to be stored,
- R: warehouse size, area, and volume,
- D: type of transportation vehicles for loading/unloading goods,
- M: degree of mechanization and automation of inventory,
- S: technology used in the warehouse,
- P: handling equipment for storage operations,
- I: use of IT and information systems in the warehouse,
- L: number of workers employed in the warehouse.

The author argues that the PDS model is an efficient tool for rapidly determining a conceptual warehouse design. The technical and organizational conditions for warehouse facility design can be comprehensively described using a mathematical model useful for design purposes. Some authors adapt Straka's approach (Jacina et al., 2015; Wasiak, 2011), proposing a model that can be applied to any warehouse structure with any functional configuration and represented as an ordered sextuple MM = {S, T, Λ, P, O, I}, where:

- S – Functional structure – describes the spatial conditions of the facility.
- T – Internal transport – describes handling technologies, technical resources such as equipment and workforce, their technical parameters, functionality, access limitations, and other aspects.
- Λ – Logistics task – defines volumes and the scope of material flow transformations arising from customer orders and required supplies.
- P – Warehousing process – reflects the sequence of operations performed on material units by the internal transport system within the warehouse's functional areas to fulfill customer orders.
- O – Work organization rules – determine additional aspects necessary for modeling and designing warehouses, such as warehousing operation schedules, assortment allocation rules, human resource task assignments, routing rules, customer order processing principles, and the creation of picking lists.
- I – Information system – defines the scope of information transformation associated with the execution of the warehousing process.

Most scientific publications address specific warehouse problems. Some focus on calculating the operational requirements for handling equipment within a warehouse or logistics centers. Other studies propose models to identify sustainable strategies in material management, optimizing the environmental performance of warehousing activities. Topics covered include layout modeling, warehouse design with cross-aisles for order picking, selection of operational strategies, multi-level pallet SKU storage location assignments, and the issue of aisle flatness for forklifts through geodetic measurements.

Kordos et al. develop a solution based on genetic algorithms to optimize product placement and picking paths within the warehouse. Saderova et al. present a simulation model as a tool for designing bulk material silos. Other authors address aspects such as costs, economic evaluation, and inventory calculation—topics closely related to warehouse management. Finally, Gu et al. (2010) focus on the issue of equipment selection, described as one of the key decisions in warehouse design.

The study by Rouwenhorst et al. (2000) presents a framework and classification of warehouse design and management problems, distinguishing between strategic, tactical, and operational issues. Authors Baker and Canessa (2009) outline the steps in warehouse design in publications from 1973 to 2006, comparing the phases adopted by warehouse design firms and the tools used at each stage. Gu et al. (2010) identify five main decision-making problems in warehouse design: overall structure, sizing and capacity, department layout, equipment selection, and operational strategy. Karakis et al. propose a hierarchical approach to the design of distribution centers. Hassan highlights the importance of layout, including the organization of functional areas, number and location of input/output points, number of aisles, their size and orientation, space estimation, flow model, and picking zone definition. Publications by de Koster et al. and Tappia et al. offer a comprehensive review of the literature on decision-making issues in manual order picking design and management, with a focus on internal layout optimization, stock assignment, routing strategies, order batching, and zoning. Kapliienko et al. explore the potential use of virtual reality for lighting design in warehouses.

We can conclude with a comprehensive definition that describes warehousing as a process whose main function is to store materials, goods, products, and raw materials over time while simultaneously preparing the units for handling in accordance with customer requirements and production and transportation means, in order to ensure continuity of material flow. This process is essential for meeting market demand and optimizing subsequent activities such as loading, unloading, transport, controlled distribution, and shipment documentation preparation (Straka, 2013).Based on this definition, and considering that warehouse design is a complex problem involving a large number of interconnected decisions—including the functional description of the warehouse, technical specifications, selection and layout of equipment, warehouse processes, and organization—the purpose of this paper is to identify all the factors that must be considered to design an effective and efficient warehouse capable of promptly responding to the needs of increasingly volatile and unpredictable markets.

3. Methodology

The objective of this study is to develop an analytical model useful for professionals and researchers. The aim of the work is to list all the elements that must be taken into account when developing a warehouse project at both the operational level and in terms of spatial and resource organization. The professional will find in the proposed model a checklist of elements to consider in order to carry out a complete analysis and efficiency improvement activity. The academic will find a range of topics that can be individually examined for the purpose of proposing research and developing new solutions as well as improving existing processes.

The study was carried out through the following phases:

3.1. Phase 1: Collection and Analysis of Existing Literature

Warehousing is a topic of interest to many researchers. The studies analyzed, published between 1996 and 2022, were identified using the Web of Science and Scopus databases. Additionally, some national articles were searched and reviewed through various databases such as Google Scholar and YOK. The search terms were defined inductively, after reading several articles on topics related to warehouse design and management. In the end, the main keywords used were:

- “warehouse management”
- “design warehouse”
- “design warehouse layout”
- “warehouse location selection”
- “warehouse storage automation”

3.2. Phase 2: Extraction of Research Themes from the Analyzed Papers

This phase enabled the development of a thorough analysis of the elements that predominantly make up warehouse design. The research reviewed approximately 100 articles. The following table (Table 1) compares the elements of the proposed model with those found in two key reference texts—Straka (2013) and Jacyna et al. (2014)—as well as presenting additional bibliographic sources in which the authors highlight fundamental aspects to be considered in warehouse design.

3.3. Phase 3: Development of a Comprehensive Analytical Model

Table 1. The literature review

	The Proposed Model	**Straka (2013)**	**Jacina at al. (2014)**	**Other references**
1	Goods	**T**: type of goods to be stored	Λ – Logistic task	Önüt et al., 2008; Vis & Roodbergen, 2011; Hwang & Cho, 2006; Chan & Chan, 2011; Gu et al., 2010,
2	Information Technologies	**I**: use of information technology and information systems in the warehouse	I – Information system	Ramaa.A, 2012; Javaid et al., 2022; Wan et al., 2020
3	Space	**R**: Warehouse dimensions, volume and surface.	S – Functional structure	Parikh et Meller, 2010; Hwang & Cho, 2006; Vis & Roodbergen, 2011; Carton et. Al., 2000; Roodbergen and Koster, 2001; Bartholdi & Hackman, 2001; Koster et al., 2007; Heragu, 2008; Ghazali et al., 2024; Golari et al., 2017; Heskett at al., 1973; Rafie-Majd et al., 2018; Tavana et al., 2018; Gu et al. 2010,
4	Irremovable Infrastructure Constraints			
5	Internal Infrastructures	**M**: degree of mechanization and automation of the stock **S**: technology used in the warehouse **P**: handling equipment for storage operations		Parikh et Meller, 2008; Muppani et Adil, 2008a; Muppani et Adil, 2008b; Onut et al., 2008; Ventura & Lee, 2001; Lerher et al., 2010; Le-Anh et al., 2006;
6	External Infrastructures			ADB, 2023; Frazelle, 2002; Gu et al., 2010; Richards, 2017; Rouwenhorst et al., 2000; Richards, 2017; Tompkins, 2010; Bartholdi & Hackman, 2016; Gu et al. 2010,
7	Processes		P – Warehousing process	Larson et al., 1997; Canen & Williamson, 1998; van den Berg, 1999; Shouman et al., 2005; Rouwenhorst et al., 1999; Koster, R. et al., 2007; Beamon, 1999; Chen et al., 2011; Gagliardi et al. 2008; Gu et al., 2007; Lai et al., 2002; Malmborg & Al-Tassan, 2000; Muppani & Adil, 2008; Öztürkoğlu et al., 2014; Pan & Shih, 2008; Parikh & Meller, 2008; Pohl et al., 2009; Rouwenhorst et al., 2000; Van den Berg, 1999; Gu et al. 2010,
8	Handling Equipments	**D**: type of transportation vehicles for	T – Internal transportation	Ballou, 1984; Campbell, 1996; Jacya et al., 2015; Meade & Sarkis, 1998; Pyza & Jachimowski, 2015; Rouwenhorst et al., 2000

	The Proposed Model	Straka (2013)	Jacina at al. (2014)	Other references
		loading/unloading goods		
9	People	**L**: number of workers employed in the warehouse	O – Work organization rules	Parikh & Meller, 2010; Onut et al., 2008; Öztürkoğlu et al., 2014; Strack & Pocket, 2010; Mudiyanselage et al., 2021; Lorson e al., 2023

4. Warehouse Design: Essential Elements

Warehouse management is a crucial element of business logistics, focused on the organization and control of operations within warehouses. This process includes receiving, storage, handling, and shipping of goods, with the goal of optimizing operational efficiency and reducing costs. According to Faber et al. (2013), the structure of warehouse management is defined as "the design that specifies how warehouse management processes are organized," including planning, control, and optimization activities. Another fundamental aspect of warehouse management concerns inventory control. This involves implementing strategies to maintain optimal inventory levels, avoiding both shortages and overstocking. Techniques such as ABC analysis are often used to classify items based on their importance and contribution to the total inventory value, allowing for a more precise focus on critical resources. Additionally, warehouse management includes planning storage spaces, organizing workflows, and implementing safety measures to prevent losses or damage to goods. Effective warehouse management significantly contributes to customer satisfaction by ensuring that products are available and delivered on time.

In summary, warehouse management is an integrated process that encompasses several key functions, all aimed at ensuring the efficient and secure flow of goods from arrival to final distribution. It also represents the integration of technologies and a set of operational management practices designed to make warehouses more efficient and "smart." Smart warehouses have evolved into a convergence point for cutting-edge technologies, warehouse processes, and operations management (Zhen & Li, 2022).

Most scientific publications address specific warehouse-related issues. Some focus on calculating operational requirements for handling equipment within a warehouse or logistics center. Other studies propose models to identify sustainable strategies in material management, optimizing the environmental performance of warehouse activities. Topics covered include layout modeling, the design of warehouses with cross-aisles for order picking, the selection of operational strategies, multi-level allocation of storage positions for pallet SKUs, and the issue of aisle flatness for forklifts through geodetic measurements. Other authors deal with aspects such as cost evaluation, economic analysis, and inventory calculation, all of which are closely related to warehouse management. These topics, during the design phase, should not be evaluated individually but should form the core factors that will be proposed in the following sections.

4.1. Goods

This refers to the materials that need to be housed in the warehouse. Articles discussing product characteristics highlight their physical features—visible traits that influence storage and handling (such as fragility or weight) (Önüt et al., 2008). There are also organizational characteristics related to products and their management, such as turnover or mix, which influence the dynamic flows of goods. These aspects have received considerable attention in the literature (Vis & Roodbergen , 2011; Hwang & Cho, 2006; Chan & Chan, 2011). A proper warehouse design assumes the product as one of the core elements around which the organization of spaces and activities is developed. The characteristics of the goods define the need for specific storage activities or infrastructures, such as cold chains, controlled temperature systems, food-grade storage, or hazardous materials handling.

4.2. Information Technology

Information technology forms the foundation of the warehouse, as it provides the data exchange channels and the basic technological support needed to manage products and automation. “Information” in this context refers to all data that can be used to manage the physical flow of goods effectively—such as barcodes or RFID systems—to ensure full traceability and efficient handling. Through item identification systems, it becomes possible to manage product placement, picking, and tracking while complying with inventory rules such as FIFO (First In First Out) or FEFO (First Expired First Out). The warehouse management system (WMS) is also part of this information infrastructure. A Warehouse Management System (WMS) is a database-driven software application designed to improve warehouse efficiency by managing operational flows and maintaining accurate inventory records through real-time tracking of warehouse transactions (Ramaa et al., 2012).

Information technology concerns the high-level design of smart warehouses. It serves as the backbone for both operational and strategic warehouse management. Thanks to technologies derived from the Internet of Things (IoT), cyber-physical systems (CPS), and other emerging innovations, data flows can be shared and processed across multiple logistics nodes, generating added value. Artificial Intelligence (AI) has seen exponential growth in its role in warehouse automation, revolutionizing how warehouses operate and manage their logistics processes. From inventory management to order fulfillment, AI-based warehouse automation systems have become indispensable tools for optimizing operations, increasing efficiency, and enhancing overall productivity (Javaid et al., 2022). AI plays a fundamental role in optimizing warehouse operations by providing real-time analytics, improving resource allocation, and automating repetitive tasks. By analyzing vast amounts of data from sensors, IoT devices, and enterprise systems, AI algorithms can identify patterns, trends, and anomalies—allowing warehouses to make data-driven decisions and proactively address operational challenges (Wan et al., 2020). Recent trends in smart warehousing also include the use of digital twins to simulate and optimize warehouse layouts in real time, as well as blockchain technology for secure and transparent inventory and shipment tracking. These technologies enable not only enhanced control and automation but also higher resilience in the face of supply chain disruptions (Roman et al., 2025).

4.3. Available Space

The primary objective of any warehouse design project is to optimize space to ensure an adequate level of service while minimizing costs. The layout design of the warehouse (Gu et al., 2010) is a key element for further optimization activities and has a significant impact on order picking and travel distances within the facility. Carton et al. (2000) demonstrated that layout design influences over 60% of the total travel distance of warehouse operators. To reduce such inefficiencies, their study presented three different types of basic warehouse layouts. Roodbergen and Koster (2001) introduced parallel yet transverse aisles in the warehouse, highlighting a significant performance improvement. In layouts where rack arrangements are orthogonal, efficiencies are typically calculated based on pallet movements (Bartholdi & Hackman, 2001).

Several factors should be considered when designing the layout, including:

- the number of blocks,
- the length, width, and number of picking aisles,
- the number and shape of cross aisles (if any),
- the number of storage rack levels,
- and the location of the warehouse's entry and exit doors (Koster et al., 2007; Heragu, 2008).

The effective use of warehouse space is essential to ensure a smooth operational flow. Inefficiencies in operational flows, often caused by poor space arrangement and layout configuration, are among the most common problems in warehousing. Each area within the warehouse should be meticulously planned, taking into account the size and location of the warehouse itself, in order to define the best layout solution (Ghazali et al., 2024; Golari et al., 2017; Heskett et al., 1973; Rafie-Majd et al., 2018; Tavana et al., 2018).

4.4. Irremovable Physical Constraints

This factor is introduced in the present study following an in-depth analysis of the needs arising from various projects carried out between 2018 and today. Irremovable physical constraints include all elements within a warehouse that are part of the original infrastructure design and whose presence affects both the layout and the execution of operational activities. Among these constraints are light sources (natural and artificial), safety systems (such as emergency exits and sprinklers), loading and unloading doors, and heating or cooling systems. The proposed model emphasizes that these irremovable constraints must be properly considered in the design phase, as they may compromise the warehouse's operational performance.

The scientific literature often overlooks or does not explicitly mention these factors. Numerous studies presenting different rack layouts (e.g., Pohl et al., 2009; Roodbergen and De Koster, 2001; Gu et al., 2010; Dukic & Tihomir, 2014) typically do not account for the presence of pillars or columns, which can significantly affect the expected outcomes. Huertas et al. (2007) proposed a model based on time and resource studies for each of the core activities involved in warehouse operations. The performance measures considered were operating costs and average picking time. The model was used to evaluate two new layout and operational alternatives for the same warehouse. It was found that the layout option with loading docks on opposite long sides of the warehouse and operations carried out without a dedicated picking zone minimized operating costs (Huertas et al., 2007).

4.5. Internal Storage Infrastructures

Internal storage infrastructures refer to the structures designed to house goods before they are picked. An effective storage layout enables the optimal physical arrangement and management of products within the warehouse. Issues related to storage layout design have been frequently studied. Warehouses and logistics centers dedicated to storage operations often face space utilization challenges. Improving spatial efficiency is crucial for cost optimization. An analysis of operational difficulties in distribution centers shows that 34.8% are related to the lack of adequate storage space (Lee J.W., 2015; Choi et al., 2018).

Automated mobile racking systems have been implemented with the support of the Internet of Things (IoT), improving the use of central storage areas. Other infrastructure solutions include Very Narrow Aisle (VNA) vehicles for use in warehouses with mobile racking systems. The right storage infrastructure can double or even triple capacity by maximizing the use of available space. For example, mobile racking systems can double space efficiency compared to fixed racks. With the rapid advancement of technology, the material handling industry has continued to improve Automated Storage and Retrieval Systems (AS/RS), making them increasingly efficient, intelligent, and cost-effective. Vis and Roodbergen (2011), as well as Gagliardi, Renaud, and Ruiz (2012), conducted investigations covering the development and characteristics of various AS/RS systems. Meanwhile, several optimization methods have been developed to support order picking planning and management for different types of AS/RS (Van Gils et al., 2018). Examples of internal infrastructures include pallet racks, drive-in racks, and cantilever systems, as well as dynamic structures such as AS/RS, miniload systems, and vertical storage units. The warehouse space is divided into functional areas that carry out various phases of the warehousing process and rely on different internal infrastructures. A universal hierarchical functional structure of the warehouse includes the following elements:

- Logistics units (containing specific products): units containing specific items managed within the warehouse.
- Locations (addresses): areas that host defined quantities of logistics units, each characterized by defined dimensions, load capacities, and precise spatial coordinates.
- Racking cells (shelf spaces): zones delimited by structural elements of racking systems (of any type), or by temporary demarcations such as lines drawn on the floor. Cells group locations and define their physical parameters.
- Sub-areas: spaces grouping racking cells based on warehousing process needs. These sub-areas can be dedicated to specific logistics units (products), particular SKUs, selected customers, etc.

Scientific studies analyzing various internal warehouse infrastructures, such as pallet racks and drive-in racks, tend to focus on their operational performance. Although the scientific literature remains limited, technical analyses offer valuable insights. Some articles explicitly compare different internal infrastructures, such as drive-in and pallet racking systems, by evaluating their operational efficiency. The automation of equipment defines the strategic and tactical level of smart warehouses. Automation is the core technical support for smart warehouses. Through the use of automated systems, a high level of automation in warehouse activities can be achieved. Automation improves productivity by reducing the need for manual labor. Furthermore, the operational management of smart warehouses places greater emphasis on equipment characteristics for strategic decisions and on product features for tactical decisions—offering a comprehensive view of technology and enhancing decision-making accuracy.

4.6. External Infrastructures

External infrastructures include all facilities located outside the warehouse that can influence its operational performance. These typically comprise access roads to the warehouse, maneuvering areas for vehicles, and parking zones.

Access roads determine how easily transport vehicles can reach the warehouse; narrow, congested, or poorly maintained roads can delay deliveries and increase waiting times. Loading and unloading bays can become bottlenecks, extending vehicle wait times—especially if the bays are inefficiently laid out. The arrangement and operational efficiency of these bays directly affect the speed at which goods can be moved in and out of the warehouse.

Modern solutions, such as automated loading docks and dock scheduling systems, are designed to optimize loading and unloading times. Adequate maneuvering space reduces waiting times and minimizes the risk of accidents or damage to goods and infrastructure. Conversely, tight or poorly designed areas can limit the warehouse's operational capacity, particularly for large trucks. Finally, well-organized waiting zones allow vehicles to queue without creating congestion or obstructing loading and unloading operations. The lack of proper waiting space can result in chaotic situations, with trucks parked along surrounding roads, compromising safety and disrupting traffic flow. In summary, well-designed and managed external infrastructures contribute to reducing waiting times, improving safety, and enhancing the overall productivity of the warehouse (ADB, 2023; Frazelle, 2002; Gu et al., 2010; Richards, 2017; Rouwenhorst et al., 2000; Richards, 2017; Tompkins, 2010; Bartholdi & Hackman, 2016).

4.7. Processes

An important aspect of warehouse design concerns the various operational activities which, once selected, have a significant impact on the (overall) system and are not frequently subject to change. Changes in warehouse operations and processes affect every aspect of warehouse management (Bowersox et al., 2013; Le-Duc, 2005; Tompkins et al., 2010; Frazelle, 2002), including: receiving, put-away, storage, replenishment, picking, shipping. The literature pays particular attention to storage strategy and order picking strategy. Specifically, picking has been the focus of extensive research, as it accounts for nearly 50% of warehouse costs and 50% of the time spent on non-value-added activities, such as traveling between picking locations. Proper warehouse process design improves performance in terms of speed, accuracy, and reduction of operational costs (Beamon, 1999; Chen et al., 2011; Gagliardi et al., 2008; Gu et al., 2007; Lai et al., 2002; Malmborg & Al-Tassan, 2000; Muppani & Adil, 2008; Öztürkoğlu et al., 2014; Pan & Shih, 2008; Parikh & Meller, 2008; Pohl et al., 2009; Rouwenhorst et al., 2000; Van den Berg, 1999).

4.8. Handling Equipment

The efficiency of warehouse processes is largely determined by the performance of the handling equipment and internal transport systems used (Ballou, 1984; Campbell, 1996; Jacyna et al., 2015). A key aspect to consider when evaluating the efficiency of warehouse facilities is the minimization of order fulfillment time and the improvement of customer service levels. A fundamental role is played by the execution time of individual activities, as represented in process flowcharts and transport cycles. This execution time is directly influenced by the appropriate selection of equipment and internal transport systems in relation to the warehouse processes implemented. According to Meade and Sarkis (1998), effective selection of handling equipment and internal transport systems in warehouses should follow three main stages:

- Selection based on functional purpose: choosing equipment appropriate for the specific tasks required.
- Selection for complex tasks: based on the annual volume of goods to be handled.
- Economic evaluation: assessing the cost-effectiveness of the various proposed solutions.

A fundamental criterion is the minimization of expenses and operating costs, often expressed through the so-called operational efficiency coefficient of handling equipment and internal transport systems. An important parameter influencing the workload of warehouse processes is the efficiency of the equipment used. Efficiency is defined as the volume (or mass) of goods transported by a specific piece of equipment or vehicle per unit of time—typically expressed in tons per hour (t/h) or cubic meters per hour (m^3/h) (Pyza & Jachimowski, 2015; Rouwenhorst et al., 2000)

4.9. People

The warehouse is a complex work environment in which people carry out specific activities with the goal of ensuring efficient and timely customer service. Despite technological evolution and increasing automation, the human role remains central, as individuals possess cognitive, decision-making, and adaptive capabilities that machines are still unable to fully replicate. Advanced technologies are transforming the way workers operate within the warehouse, requiring greater interaction with automated systems and collaborative robots (cobots). This trend suggests that, rather than being replaced, workers will need to adapt to new modes of operation by developing skills that complement those of machines. According to the analysis by Frey and Osborne on OECD countries (2013–2016), later expanded by Arntz, Gregory, and Zierahn in 2016, some professions are more susceptible to automation than others—particularly those involving repetitive and standardized tasks.

However, workers also perform non-routine, decision-making, and interactive tasks that are not easily automated. The 2018 report by PricewaterhouseCoopers, Will robots really steal our jobs? An international analysis of the long-term impact of automation, highlights that, in the long run, automation will not entirely eliminate the need for human labor but will transform its role, requiring new skills and new models of human–machine collaboration. A crucial aspect of increasing warehouse automation is worker safety. The introduction of technologies such as automated picking systems (Pick to Light, Pick by Voice, RF terminals) and autonomous vehicles (AGVs and AMRs) reduces the risk of incidents caused by human error, relieving workers from physically demanding and potentially dangerous tasks. However, human–machine interaction introduces new challenges, such as the need for advanced safety protocols to prevent collisions and ensure an ergonomic working environment.

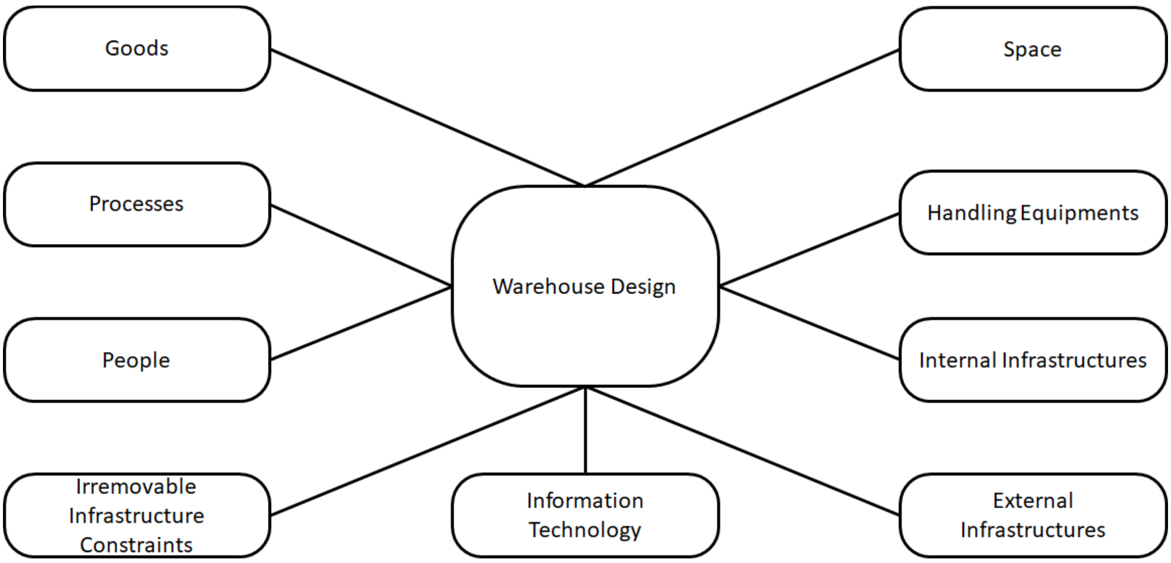

Figure 1. The proposed model

The use of personal protective equipment (PPE), proximity sensors, safety barriers, and real-time monitoring systems is essential to minimize risks and ensure safe integration between people and machines (Mudiyanselage et al., 2021). A 2016 study conducted by Erasmus University Rotterdam analyzed the correlation between personality, motivation, and performance in automated picking processes. The findings of Exploring the role of picker personality in predicting picking performance with pick by voice, pick to light and RF-terminal picking and Aligning order picking methods, incentive systems, and regulatory focus to increase performance demonstrate that, despite the use of advanced technologies, worker performance in picking remains heavily influenced by their ability to adapt and effectively use the tools at their disposal. This confirms that the human factor continues to be a key element in the operational management of warehouses—even in highly automated environments.

Therefore, the evolution of warehouses does not necessarily lead to the replacement of human labor but rather demands a new paradigm of collaboration between people and technology (Lorson et al., 2023). Investing in worker training, implementing ergonomic solutions, and ensuring high safety standards are fundamental factors for improving performance and creating a productive, efficient, and safe work environment.

5. Conclusions

The literature review has made it possible to develop a theoretical and practical model for the design and optimization of warehouses, providing a structured foundation for targeted interventions aimed at improving both operational and managerial performance. The proposed model, shown in Figure 1, proves to be effective in identifying the main factors that influence logistics efficiency, enabling the reduction of operating costs, the improvement of service quality, and the acceleration of warehouse operations.

The proposed model has clear practical implications for warehouse professionals and logistics managers. By using the checklist of nine design factors, practitioners can carry out structured assessments of existing facilities or plan new warehouse layouts with a comprehensive view of operational needs. For example, when planning an intervention in an outdated warehouse, the model can guide decisions on how to integrate automation without disrupting workflows, or how to reorganize spaces while considering fixed physical constraints such as pillars or outdated loading docks. Moreover, small and medium-sized enterprises (SMEs), often lacking structured engineering support, can adopt this model as a reference tool to prioritize improvements based on available resources. For instance, SMEs might start by upgrading information systems (such as implementing a WMS or barcode/RFID tracking systems) or improving material handling processes before investing in advanced automation technologies. Additionally, the model's flexibility allows it to be adapted to different industrial contexts—whether food distribution, manufacturing, or e-commerce—making it suitable for developing warehouse strategies aligned with market demands and expected service levels.

Listing the main factors thus makes it possible to develop comprehensive and cross-functional projects that do not neglect any aspect of warehouse operations. The model therefore becomes a decision-support tool for strategic planning and the management of warehouse operations. In other words, improved warehouse performance results from synergistic actions on internal and external infrastructures, item identification systems, goods and personnel management, while properly evaluating the main physical constraints within the infrastructure. At the same time, the proposed model serves as a valuable reference for the academic community, providing a conceptual and operational basis for further studies and empirical validations. The possibility of breaking down the model's various components allows for a detailed analysis of the impact of each factor on overall warehouse performance, paving the way for quantitative research and real-world experimentation.

The model developed is based on the integration of well-established approaches found in the literature—such as those proposed by Straka and Jacyna et al.—and expands upon them by identifying new factors that had not yet been systematized. The added value of this research lies precisely in its contribution to expanding the theoretical framework, introducing key elements that influence warehouse dynamics and deserve deeper analysis. The elements identified in the model include:

- Goods – Type, characteristics, and storage requirements of handled units.
- Information Technology – IT systems for managing logistics flows and operational control.
- Space – Physical layout and organization of storage and handling areas.
- Irremovable Infrastructure Constraints – Structural and architectural limitations affecting warehouse design.
- Internal Infrastructures – Structures, facilities, and equipment located within the warehouse.
- External Infrastructures – Access roads, parking areas, maneuvering spaces, and logistical connections.
- Handling Equipment – Vehicles and tools used for internal and external transportation of goods.
- Processes – Operational flows and procedures for warehouse management.
- People – Role and skills of operators in managing logistics activities.

Although the proposed model represents a step forward in systematizing the critical factors for the design of efficient warehouses, a more in-depth literature review may reveal additional relevant elements or improve understanding of the interactions among the components. Future studies may focus on empirically analyzing the model through case studies, experimentation in business environments, and advanced simulations in order to validate its effectiveness and identify potential improvements.

References

Amiri, A. (2006). Designing a distribution network in a supply chain system: Formulation and efficient solution procedure. *European Journal of Operational Research, 171*(2), 567–576. https://doi.org/10.1016/j.ejor.2004.09.017

Asian Development Bank. (2023). *The developers' guide to planning and designing logistics centers in CAREC countries*. Asian Development Bank.

Ballou, R. H. (1984). Displan: A multiproduct plant/warehouse location model with nonlinear inventory cost. *Journal of Operations Management, 5*(1), 25–39.

Bartholdi, J. J., & Hackman, S. T. (2008). Allocating space in a forward pick area of a distribution center for small parts. *IIE Transactions, 40*(11), 1046–1053. https://doi.org/10.1080/07408170802165895

Bartholdi, J. J., & Hackman, S. T. (2016). *Warehouse & distribution science*. The Supply Chain and Logistics Institute, Georgia Tech.

Beamon, B. M. (1999). System reliability and congestion in a material handling system. *Computers & Industrial Engineering, 36*(3), 673–684.

Bowersox, D. J., Closs, D. J., Cooper, M. B., & Bowersox, J. C. (2013). *Supply chain logistics management* (4th ed.). McGraw-Hill.

Campbell, J. F. (1996). Hub location and the p-hub median problem. *Operations Research, 44*(6), 923–935.

Canen, A. G., & Williamson, G. H. (1998). Facility layout overview: Towards competitive advantage. *Facilities, 16*(7/8), 198–203.

Caron, F., Marchet, G., & Perego, A. (2000). Optimal layout in low-level picker-to-part systems. *International Journal of Production Research, 38*(1), 101–117. https://doi.org/10.1080/002075400189608

Chan, F. T. S., & Chan, H. K. (2011). Improving the productivity of order picking of a manual-pick and multi-level rack distribution warehouse through the implementation of class-based storage. *Expert Systems with Applications, 38*(3), 2686–2700. https://doi.org/10.1016/j.eswa.2010.08.043

Choi, S. H., Hong, K. M., & Kim, H. J. (2018). A study on needs of the logistics technology in Korea. *Korea Maritime Institute*.

Dukic, G., & Opetuk, T. (2014). Warehouse layouts. In *Warehousing in the global supply chain: Advanced models, tools and applications for storage systems* (pp. 37–60). Springer. https://doi.org/10.1007/978-1-4471-2274-6_3

Emmett, S. (2008). *Riadenie zásob*. Computer Press.

Faber, N., de Koster, R. B., & van de Velde, S. L. (2002). Linking warehouse complexity to warehouse planning and control structure: An exploratory study of the use of warehouse management information systems. *International Journal of Physical Distribution & Logistics Management, 32*(5), 381–395. https://doi.org/10.1108/09600030210434194

Frazelle, E. H. (2002). *World-class warehousing and material handling*. McGraw-Hill.

Gagliardi, J. P., Renaud, J., & Ruiz, A. (2012). Models for automated storage and retrieval systems: A literature review. *International Journal of Production Research, 50*(24), 7110–7125.

Gagliardi, J., Renaud, J., & Ruiz, A. (2008). Space allocation and stock replenishment synchronization in a distribution center. *International Journal of Production Economics, 115*(1), 19–27.

Ghazali, J. M., Rushdi, N. N. H. N., & Sapry, H. R. (2024). Effective warehouse space and layout management: A case study of DHL Express. In A. Ismail, F. N. Zulkipli, B. A. Baharudin, & A. Öchsner (Eds.), *Technological innovation and transformation*. Springer.

Golari, M., Fan, N., Jin T. (2017). Multistage stochastic optimization for production-inventory planning with intermittent renewable energy. *Production and Operations Management, 26*(3), 409–425. https://doi.org/10.1111/poms.12635

Gu, J., Goetschalckx, M., & McGinnis, L. F. (2010). Research on warehouse design and performance evaluation: A comprehensive review. *European Journal of Operational Research, 203*(3), 539–549. https://doi.org/10.1016/j.ejor.2009.07.031

Hassan, M. (2002). A framework for the design of warehouse layout. *Facilities, 20*(13/14), 432–440. https://doi.org/10.1108/02632770210454377

Heragu, S. S. (2008). *Facilities design* (3rd ed.). CRC Press.

Huertas, J. I., Díaz Ramírez, J., & Trigos Salazar, F. (2007). Layout evaluation of large capacity warehouses. *Facilities, 25*(7/8), 259–270. https://doi.org/10.1108/02632770710742185

Hwang, H. S., & Cho, G. S. (2006). A performance evaluation model for order picking warehouse design. *Computers & Industrial Engineering, 51*(2), 335–342.

Jacyna, K., Lewczuk, M., & Kłodawski, M. (2015). Technical and organizational conditions of designing warehouses with different functional structures. *Journal of KONES Powertrain and Transport, 22*(3), 49–58.

Jacyna, M., Wasiak, M., Lewczuk, K., & Kłodawski, M. (2014). Simulation model of transport system of Poland as a tool for developing sustainable transport. *Archives of Transport, 31*(3), 23–35.

Javaid, M., Haleem, A., Singh, R. P., & Suman, R. (2022). Artificial intelligence applications for Industry 4.0: A literature-based study. *Journal of Industrial Integration and Management, 7*(1), 83–111.

Kocifaj, M. (2013). Modelling of infrastructure for warehouse simulation. *Journal of Information Control and Management Systems, 11*(1), 15–22.

Koster, R. de, Le-Duc, T., & Roodbergen, K. J. (2007). Design and control of warehouse order picking: A literature review. *European Journal of Operational Research, 182*(2), 481–501. https://doi.org/10.1016/j.ejor.2006.07.009

Lai, K. K., Jue, X., & Guoqing, Z. (2002). Layout design for a paper reel warehouse: A two-stage heuristic approach. *International Journal of Production Economics, 75*(3), 231–243. https://doi.org/10.1016/S0925-5273(01)00095-0

Lambert, D. M., & Cooper, M. C. (2000). Issues in supply chain management. *Industrial Marketing Management, 29*(1), 65–83. https://doi.org/10.1016/S0019-8501(99)00113-3

Larson, T. N., March, H., & Kusiak, A. (1997). A heuristic approach to warehouse layout with class-based storage. *IIE Transactions, 29*, 337–348.

Le-Anh, T., & Koster, M. B. M. (2006). A review of design and control of automated guided vehicle systems. *European Journal of Operational Research, 171*(1), 1–23.

Le-Duc, T. (2005). *Design and control of efficient order picking processes* (Doctoral dissertation). RSM Erasmus University, The Netherlands.

Lee, J. W. (2015). East Asian logistics trends, 2015: 92–101.

Lerher, T., Šraml, M., & Tollazzi, T. (2010). Travel time models for automated warehouses with aisle transferring storage and retrieval machine. *European Journal of Operational Research, 205*(3), 571–583. https://doi.org/10.1016/j.ejor.2010.01.025

Malmborg, C. J., & Al-Tassan, K. (2000). An integrated performance model for order picking systems with randomized storage. *Applied Mathematical Modelling, 24*(2), 95–111.

Marasová, D., & Šaderová, J. (2019). Possibilities to increase the warehouse capacity: Case study. In *Proceedings of the 8th Carpathian Logistics Congress on Logistics, Distribution, Transport and Management (CLC 2018)* (pp. 633–638). Tanger.

Meade, J., & Sarkis, J. (1998). Strategic analysis of logistics and supply chain management systems using the analytical network process. *Transportation Research Part E: Logistics and Transportation Review, 34*(3), 201–215.

Mikusova, M., Abdunazarov, J., Zukowska, J., & Jagelcak, J. (2020). Designing of parking spaces on parking taking into account the parameters of design vehicles. *Computation, 8*, Article 71.

Mudiyanselage, R. V.; Lee, K.; Hassani, A. (2021). Integration of IoT Sensors to Determine Life Expectancy of Face Masks. Sensors, 22, 9463. https://doi.org/10.3390/s22239463

Muppani, V. R., & Adil, G. K. (2008a). A branch and bound algorithm for class-based storage location assignment. *European Journal of Operational Research, 189*(2), 492–507.

Muppani, V. R., & Adil, G. K. (2008b). Efficient formation of storage classes for warehouse storage location assignment: A simulated annealing approach. *Omega, 36*(4), 609–618.

Önüt, S., Tuzkaya, U. R., & Saip, S. (2008). A particle swarm optimization algorithm for the multiple-level warehouse layout design problem. *Computers & Industrial Engineering, 54*(4), 783–799. https://doi.org/10.1016/j.cie.2007.10.001

Öztürkoğlu, Ö., Gue, K. R., & Meller R. D. (2014). A constructive aisle design model for unit-load warehouses with multiple pickup and deposit points. *European Journal of Operational Research, 236*(1), 382–394. https://doi.org/10.1016/j.ejor.2013.12.023

Pan, J., & Shih, P. (2008). Evaluation of the throughput of a multiple-picker order picking system with congestion consideration. *Computers & Industrial Engineering, 55*(2), 379–389.

Parikh, P. J., & Meller, R. D. (2008). Selecting between batch and zone order picking strategies in a distribution center. *Transportation Research Part E: Logistics and Transportation Review, 44*(5), 696–719. https://doi.org/10.1016/j.tre.2007.07.002

Parikh, P. J., & Meller, R. D. (2010). A travel-time model for a person-onboard order picking system. *European Journal of Operational Research, 200*(2), 385–394.

Pohl, L. M., Meller, R. D., & Gue, K. R. (2009). Optimizing the fishbone aisle design for dual-command operations in a warehouse. *Naval Research Logistics, 56*(5), 389–403.

Pohl, L. M., & Kevin, R. G. (2009). An analysis of dual-command operations in common warehouse designs. *Transportation Research Part E: Logistics and Transportation Review, 45*(3), 367–379. http://10.1016/j.tre.2008.09.010

Pyza, D., & Jachimowski, R. (2015). Modelling of parcels' transport system. In *Proceedings of the 19th International Scientific Conference, Transport Means 2015* (pp. 659–664). Kaunas University of Technology.

Rafie-Majd, Z., Pasandideh, S. H. R., et al. (2018). Modelling and solving the integrated inventory-location-routing problem in a multi-period and multi-perishable product supply chain with uncertainty: Lagrangian relaxation algorithm. *Computers and Chemical Engineering, 109*, 9–22.

Ramaa, A., Subramanya, K. N., & Rangaswamy, T. M. (2012, September). Impact of warehouse management system in a supply chain. *International Journal of Computer Applications, 54*(1), 14–20.

Richards, G. (2017). *Warehouse management: A complete guide to improving efficiency and minimizing costs in the modern warehouse*. Kogan Page Publishers.

Rodriguez, V., Laporte, G., & Martel, A. (2007). Hub location under capacity constraints. *Transportation Research Part E: Logistics and Transportation Review, 43*(5), 495–505. https://doi.org/10.1016/j.tre.2006.10.005

Roodbergen, K. J., & De Koster, R. (2001). Routing methods for warehouses with multiple cross aisles. *International Journal of Production Research, 39*(9), 1865–1883.

Roman, E.-A., Stere, A.-S., Roşca, E., Radu, A.-V., Codroiu, D., & Ilie, A. (2025). *State of the art of digital twins in improving supply chain resilience*. *Logistics, 9*(1), 22. https://doi.org/10.3390/logistics9010022

Rouwenhorst, B., Reuter, B., Stockrahm, V., van Houtum, G. J., Mantel, R. J., & Zijm, W. H. M. (2000). Warehouse design and control: Framework and literature review. *European Journal of Operational Research, 122*(3), 515–533. https://doi.org/10.1016/S0377-2217(99)00020-X

Shouman, M. A., Khater, M., & Boushaala, A. A. (2005). Comprehensive survey and classification scheme of warehousing systems. In V. Kachitvichyanukul, U. Purintrapiban, & P. Utayopas (Eds.), *Proceedings of the 2005 International Conference on Simulation and Modeling* (May). Cancun, Mexico.

Strack, G., & Pochet, Y. (2010). An integrated model for warehouse and inventory planning. *European Journal of Operational Research, 204*(1), 35–50.

Tavana, M., Abtahi, A. R., et al. (2018). An integrated location-inventory-routing humanitarian supply chain network with pre- and post-disaster management considerations. *Socio-Economic Planning Sciences*. (in press)

Tompkins, J. A., White, J. A., Bozer, Y. A., & Tanchoco, J. M. A. (2010). *Facilities planning* (4th ed.). Wiley.

Van den Berg, J. P. (1999). A literature survey on planning and control of warehouse systems. *IIE Transactions, 31*(8), 751–762.

Van Gils, T., Ramaekers, K., Caris, A., & De Koster, R. B. (2018). Designing efficient order picking systems by combining planning problems: State-of-the-art classification and review. *European Journal of Operational Research, 267*(1), 1–15.

Ventura, J. A., & Lee, C. (2001). A study of the tandem loop with multiple vehicles configuration for automated guided vehicle systems. *Journal of Manufacturing Systems, 20*(3), 153–165.

Vis, I., & Roodbergen, K. (2011). Layout and control policies for cross docking operations. *Computers & Industrial Engineering, 61*(4), 911–919.

Vrijhoef, R., & Koskela, L. (2000). The four roles of supply chain management in construction. *European Journal of Purchasing & Supply Management, 6*(3–4), 169–178. https://doi.org/10.1016/S0969-7012(00)00013-7

Wan, J., Li, X., Dai, H. N., Kusiak, A., Martinez-Garcia, M., & Li, D. (2020). Artificial-intelligence-driven customized manufacturing factory: Key technologies, applications, and challenges. *Proceedings of the IEEE, 109*(4), 377–398.

Wasiak, M. (2011). Formal notation of a logistic system model taking into consideration cargo stream transformations. *Archives of Transport, 23*(1), 91–110.

Worobel, R., Capek, J., Kovacova, L., Bubenik, P., & Krajcovic, M. (2018). Improving business processes using simulation tools. *MM Science Journal, 2018*(01), 2244–2251.

Zhen, L., & Li, H. (2022). A literature review of smart warehouse operations management. *Frontiers of Engineering Management, 9*, 31–55. https://doi.org/10.1007/s42524-021-0177-2