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A Novel Two-Stage Methodological Approach for Storage Technology Selection: An Engineering–FAHP–WASPAS Approach

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Abstract: Storage technology selection is a very important design decision that greatly affects the future performance of a warehouse; for example, it greatly affects its costs. In making this decision, the designer is faced with a complex issue. It is necessary to select the appropriate option from a wider set of available technologies, taking into account numerous influencing factors. In design practice, solving this problem is primarily based on the experience of designers and the recommendations of manufacturers of these technologies. In the academic literature, this problem has not been properly posed and solved, so there are no papers that comprehensively address this complex design problem. The main goal of this paper is to fill that gap. The presented approach consists of two basic stages. In the first stage, starting from the definition of the project task, potential technologies are generated and critical factors are considered, in order to arrive at a set of acceptable technologies. In the second stage, these technologies are ranked, and a basis for decision making is created. This stage is based on multi-criteria decision making: the Fuzzy Analytic Hierarchy Process (FAHP) method is used to determine the weights of the criteria, and the Weighted Aggregated Sum Product Assessment (WASPAS) method is used to obtain the rankings. The application of the defined approach is tested on real assignments (distribution warehouse, production warehouse, and holding warehouse) and is proven to be applicable to solving these types of problems. The results obtained for the three tested examples prove the suitability of the application of the proposed approach in terms of the aspects of both the quality of the solution and the speed of obtaining it. Considering the practical application of the suggested and filling the recognized literature gap, evident contributions are achieved.

Keywords: warehouse; methodological approach; selection of storage technology; fuzzy AHP; WASPAS; decision making

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1. Introduction

A warehouse is an important and indispensable component of supply chains. This enables the processes and flows of goods to be realized in a more efficient and economical way. To meet this goal, different types of warehouses with specific roles and tasks have emerged. The general task of a warehouse, in the most simplified view, involves receiving, storing, and shipping certain goods in a certain quantity. To fulfill its task, the warehouse must be properly designed and managed. In all this, the technological design of each warehouse has special importance. The design process, that is, the creation of a technological solution, is a multi-phase iterative process that involves making a number of design decisions of different characters and levels. In terms of long-term scope and degree of detail, they are hierarchically structured to make decisions of a strategic, tactical, and operational nature [1–3].

One of the key strategic design decisions is the selection of storage technology. This decision significantly determines the future functionality of the warehouse. The selection and implementation of a certain storage technology should enable the fulfillment of the set requirements with the desired system performance. When solving this problem, designers follow a standard engineering approach, whose basic stages are as follows [4]:

1. Defining the problem;
2. Analyzing the problem, generating alternatives, ranking the alternatives, and choosing the best one;
3. Implementation.

Each of these stages has its own importance and specifics.

Starting from the defined problem, the designer collects and processes relevant information in order to create a suitable basis for decision-making, generating a list of a certain number of alternative technologies, which, in the further steps of this approach, are compared and ranked. The generation and selection of technologies is a complex task. What complicates the decision-making/selection process is that, as a rule, it is carried out in the presence of conflicting goals, requirements, limitations, etc., all of which possess many potentially applicable technologies. In design practice, the generation of alternative technologies depends on the designer's understanding of the characteristics of the requirements, their knowledge of potentially applicable technologies, and their ability to combine them and fit them into a unique solution. In solving this design problem, designers are usually guided by previous experiences (implemented solutions to similar systems) and recommendations from the producers of these technologies. To aid the selection of different technologies for measuring their characteristics, some tools are used, such as lists, matrices, tables, or decision trees [5–7], which help assess the suitability of potential technologies according to various technological requirements and economic measures.

Gu et al. [3] stated that the problem of storage technology selection has not been properly treated. Based on later research, this problem has not yet been overcome. Existing tools are not applicable to comprehensive problem solving; they are only used to treat parts of the problem. With this in mind, it has been concluded that the existing approaches roughly solve the problem of storage technology selection. They do not consider the wide range of factors on which the choice depends nor the complete structure of the problem. This points to the need for a suitable methodological approach as an auxiliary "tool" for solving this complex task. The approach presented in this paper, based on the principles of a systemic approach, enables a comprehensive and systematic solution to this problem. The approach begins with defining the task, which allows us to assess which technology fulfills which set of conditions to a greater or lesser extent for all criteria. After that, the relevant goals, requirements, and limitations of the warehouse are reviewed. All of these steps determine the attributes of existing storage technologies with regard to a number of aspects. Finally, the designer evaluates and ranks the applicable storage technologies. The problem of technology selection was posed and solved for the case of a typical form of storage of pallet unit loads (pallet unit load—PUL). The contributions of this paper are evident. This approach is based on an engineering procedure, which enables its widespread use in practice. In previous papers, only parts of the task were treated, that is, the problem was not comprehensively solved. In addition to the above, the approach can also be applied to solve similar problems in this area.

The approach developed in this paper overcomes the identified gap. The gap refers to the lack of comprehensive methodological approaches for solving the problem of storage technology selection that treats the problem as a whole. This paper's approach takes into account many factors and limitations, the attributes of existing storage technologies, and, modern MCDM approaches.

The paper is structured as follows. After the introduction, Section 2 is devoted to the analysis of reference papers from the literature in the field of storage technology selection. Section 3 is devoted to the approach for storage technology selection based on applying the Fuzzy Analytic Hierarchy Process and Weighted Aggregated Sum Product Assessment (FAHP–WASPAS) methods. Section 4 demonstrates the application of the approach to solving a typical design problem in practice. In Section 5, the concluding considerations and possibilities for further research are given.

2. Literature Review

The literature review focuses on reference papers dedicated to the technology selection issues in warehouses, encompassing storage, handling, and order-picking processes. Special focus is given to papers that cover problems of storage technology selection and decision-making methods. Below is an overview of these papers.

Some papers in the literature deal with a partial solution to the problem of storage technology selection [8–15]. Matson and White [8] compared block-stacking technology, selective pallet racking, and double-deep pallet racking. For comparison, they used analytical models; the criteria they considered were the costs of space and manipulation. Sharp et al. [9] compared storage technologies for small items such as racks for manual storage and retrieval, carousels, mini-load AS/RS, etc. The comparative analysis was based on an analytical (cost) model, and the criteria applied were product size and total costs. In their paper, Luxhoj et al. [10] deal with storage technology selection for PUL. For decision support, they developed a prototype of an expert system. The relevant criteria are inventory level per product, turnover ratio, and investment costs, on the basis of which the most suitable storage technology can be selected. In his paper, Holzhauer [11] conducted a comparative analysis of storage racks for different types of unit loads. They used a matrix/table as a selection tool, and the following criteria were used: investment costs, space utilization, stock rotation policy, number of passes, selectivity, etc. In their paper, Ellenbark and Muller [12] compared storage racks for different types of unit loads. For comparison, they used a technology applicability matrix. The criteria on the basis of which the comparison was made are the type of unit load (pallet or box), product stock level, number of different articles, etc.

Rushton et al. [7] compared PUL storage technologies. They presented an approach based on a decision tree. They were guided by the following criteria: the number of articles, goods flow, and stacking height. In his paper, Indap [13] discussed storage technology selection for PUL: block stacking technology, selective pallet racking, and double-deep pallet racking. The selection was based on the application of the AHP method. The relevant criteria were as follows: equipment price, space utilization, order-picking time, turnover ratio, etc. A study by Zaerpour et al. [14] is devoted to the problem of storage technology selection of PUL regarding the application of automated or manual technologies. They applied a cost model in Excel, in which goods flow, investment, and operating costs appear as relevant criteria. In their paper, Saderova et al. [15] compared selective pallet racking with narrow aisles and pallet flow racks in cold storage. For comparison, they used multi-criteria analysis methods, and the criteria they used were as follows: capacity, space utilization, the area under aisles, selectivity, and investment costs.

A review of the available literature concludes that a relatively small number of studies has been devoted to the problem of storage technology selection, disproportionately to the importance it has for the technological design of warehouses. These papers addressed certain aspects of the problem, but there is still considerable room for further research. The analyzed papers on storage technology selection do not fully address the key questions for designers: how to generate alternative technologies for the given characteristics of the design task and how to select the preferred alternative. The majority of authors, as evidenced in the cited papers, base their analyses on a limited number of criteria. Usually, they refer to costs, goods flow, space utilization, etc. The application of a decision tree [7] is a convenient tool because it essentially follows the way designers think about the selection problem. However, the main drawback of this approach is that it does not include the majority of possible scenarios (combinations of criteria and their values), so its application would be suitable only in the stage of generating applicable alternatives.

Numerous papers are dedicated to material handling equipment (MHE) selection in intralogistics. According to the papers' topics and space limitations, only characteristic papers [16–23] that are of interest from the perspective of the selection method are listed here. Chan et al. [16] conducted an MHE selection in a warehouse using the AHP method for valuation. The criteria included flexibility, quality, and costs. Mathew and Sahu [17] compared several different conveyors and automated guided vehicles (AGVs). For comparison, a number of MCDM methods were applied, such as EDAS (Evaluation based on Distance from Average Solution), CODAS (COmbinative Distance-based Assessment), and MOORA (Multi-Objective Optimization on the basis of Ratio Analysis). The criteria taken into consideration included costs, speed, flexibility, etc. In their paper, Zubair et al. [18] compared forklifts, belt conveyors, and AGVs. In order to compare and rank technologies, they used the AHP method, which uses four criteria groups: technical, economic, operational, and strategic. In their paper, Fazlollahtabar et al. [19] dealt with the selection of a specific type of forklift. They used the FUCOM (Full Consistency Method) method to determine the weights of the criteria and the WASPAS method to obtain the ranking. They were guided by the following criteria: purchase price, production year, number of working hours, maximum capacity, maximum lifting height, environmental factors, and supply of spare parts. Finally, a comparative analysis of the model was performed, in which the solution was compared with the solutions obtained using SAW (Simple Additive Weighting) and ARAS (Additive Ratio Assessment) methods.

Satoglu and Türkekul [20] used several methods of intralogistics to rank the selected alternatives, employing the AHP method to obtain the weights of the criteria and the MOORA method to acquire the final ranking. The considered criteria included handling convenience, carrying capacity, flexibility in terms of appearance, costs, etc. In their paper, Horňáková et al. [21] addressed the problem of MHE selection for forklifts, AGV forklifts, and autonomous mobile robots. For comparison, they used the AHP method, applying the following criteria: investment costs, flexibility, return on investment, number of employees, service level, safety, and intensity of implementation. Telek and Koštal [22] considered potential technologies, such as bridge cranes, cantilever cranes, articulated cantilever cranes, collaborative robots, and conveyors. To solve the selection problem, a three-stage decision-making algorithm was developed: (i) identification of potentially applicable technologies at a specific workplace; (ii) review of physical parameters and limitations for a specific workplace; (iii) comparison of potentially applicable technologies. The following relevant criteria were applied: vertical and horizontal movements, as well as limitations related to capture and disposal. Telek [23] extended prior research by incorporating a broader range of potentially applicable technologies, classified by operational characteristics related to surface coverage.

Papers dedicated to the MHE selection substantially support the application of MCDM methods in response to the complexity of the task in terms of goals and constraints. This can serve as an exemplification and indicates the possibility of applying these methods to storage technology selection tasks, given their similar problem nature.

Within the literature devoted to the selection of technologies in the warehouse, the selection by order-picking technology represents a special group of problems. In this article, for expedient reasons, the analysis included only a selection of representative papers [24–29]. A comprehensive overview of papers in this domain was provided by Jaghbeer et al. [30]. Sharp et al. [24] addressed the shaping of the order-picking area for broken-case units. They considered shelves, flow shelves, carousels, mini-load AS/RS, and drawers. The authors identified seven factors influencing the selection: material characteristics, transaction data, storage policies, applied equipment specifications, system requirements (throughput, capacity, accuracy, and system response time), facility layout constraints, and budget constraints. The paper provides recommendations for specific technologies in relation to various parameters, such as flow and order volume, costs, etc. Yoon and Sharp [25], expanding upon the preceding work, provided an approach for designing and shaping a picking area for box picking considering the same factors. Đurđević and Miljuš [26] solved the problem of the type of order-picking area. In order to find the answer, the authors proposed a methodological approach based on the key performance of the system and the analysis of specific costs. The same authors, Đurđević and Miljuš [27], proposed an empirical solution approach based on the selection of authoritative criteria for making partial decisions to address the selection problem. Zapata et al. [28] dealt with the selection by using pick-assist technologies in the warehouse. They compared the traditional picking method (pick by list), pick by voice, pick by light, and pick by vision. The methods they used were AHP and artificial neural networks. The selection was made based on the following criteria: costs (hardware and software), performance (productivity and accuracy), and technological characteristics (trainability, functionality, and flexibility). Van der Gaast and Weidinger [29] applied a model based on neural networks to solve the problem of technology selection in the order-picking area.

Based on the review of the literature, it can be concluded that diverse approaches can be employed for the selection of order-picking technology from recommendations and the application of MCDM methods to the application of artificial intelligence. This paper's selection methodology is based on the utilization of the FAHP and WASPAS methods. The FAHP method is used because of the multitude of qualitative criteria, whereas the WASPAS method has shown its effectiveness in previous applications. In the following paper we analyzed papers that combine these methods. Alam et al. [31] were among the first authors to combine the mentioned methods. They had a selection of services in the cloud. Six services were identified, which were evaluated and ranked based on the following criteria: reliability, ability to help and support, efficiency, safety, flexibility, security, user experience, etc. The aim of the paper by Otay et al. [32] was to show the possibilities of combining methods, and they demonstrated a new method for the evaluation and selection of manufacturers. Three alternatives were defined, which were compared based on seven criteria. Bouchraki et al. [33] developed a decision-support methodology based on these methods for a water plant. The goal was to improve the quality of customer service. Three scenarios (aspects) were defined, which were compared based on four criteria. The weights of the criteria in all papers were obtained using the FAHP method, and the final ranking was obtained using the WASPAS method.

In addition to the significant achievements of the analyzed papers, the lack of an appropriate methodological approach for solving the problem of storage technology selection was noted and emphasized. In order to overcome this shortcoming, a novel approach adapted to the needs of practical solutions to the problem of storage technology selection was presented, which is shown in the next section of the paper.

3. Methodological Approach for Storage Technology Selection

To solve the problem of storage technology selection, a methodological approach was developed, the structure of which is illustrated in Figure 1. Following the logic of problem solving, the approach is organized into the following two primary stages:

1. Generating potentially applicable technologies;
2. Ranking potentially applicable technologies.

The first stage encompasses five steps, resulting in the collection of potentially applicable technologies. Likewise, the second stage consists of five methodological steps, and the outcome of this stage is the ranking of alternatives. The following steps are carried out within the first stage (as shown in Figure 1):

1. Defining the task;
2. Identification of available *Ti* storage technologies;
3. Identification and introduction of critical factors;
4. Defining a set of applicable technologies;
5. Determine the number of applicable technologies.

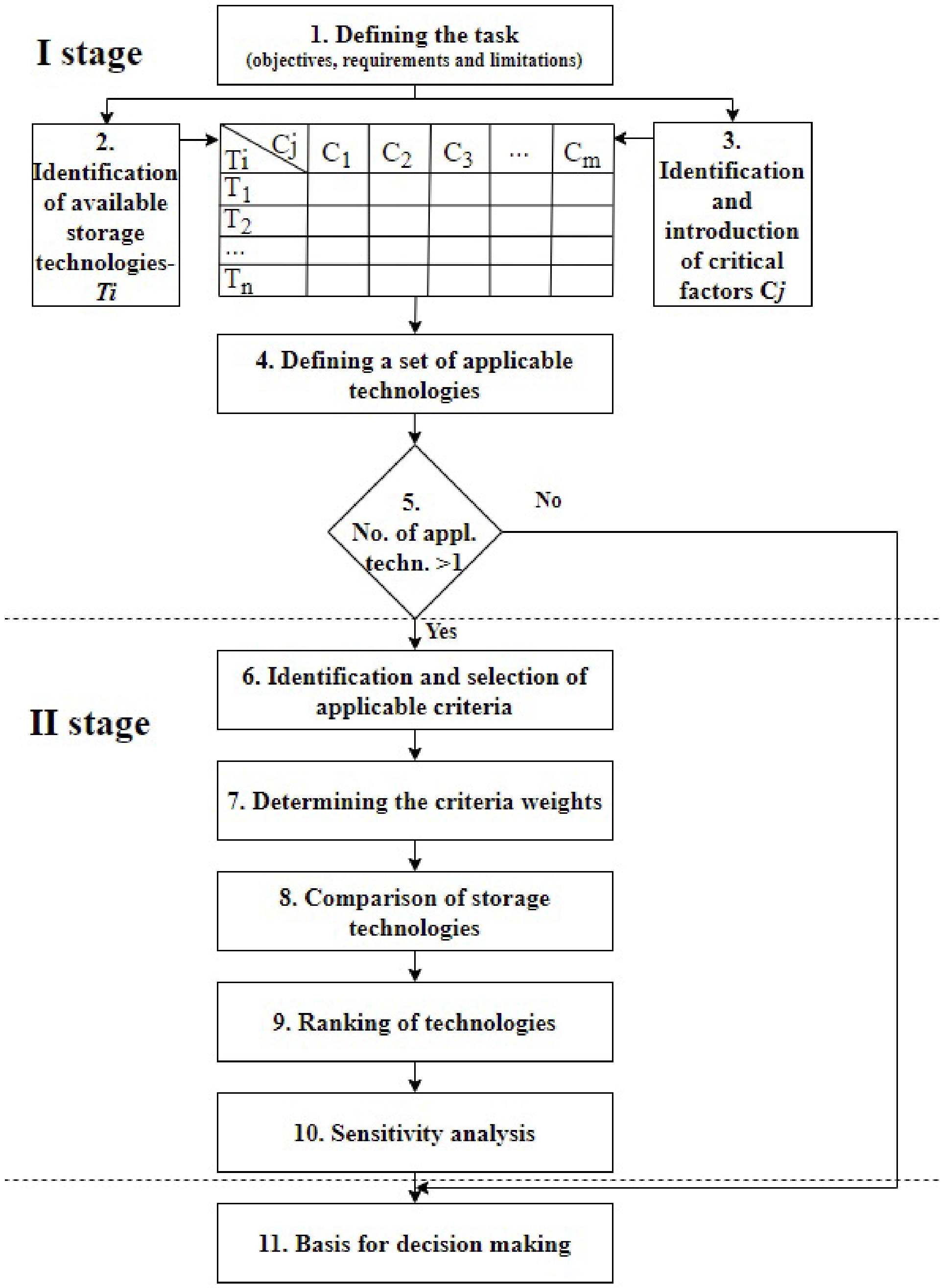

Figure 1. Methodological approach for storage technology selection.

In the first step, it is necessary to define a task that contains objectives, requirements, and constraints. Subsequently, in the second step, the identification of available storage technologies (Ti) is recognized, totaling "n". In the third step, the critical factors are identified and introduced. The next step involves defining a set of applicable technologies. In the fourth step, the available technologies are tested to see if they satisfy all the critical factors. Should the technology meet all the critical criteria, it is incorporated into the set of applicable technologies. However, if it does not satisfy at least one factor, the technology is rejected. Completing this step, which is the fifth step, ascertains the number of potentially applicable technologies. If that number is equal to one, the algorithm bypasses the second stage, that is, steps 6 to 10 due to the solution's uniqueness. Otherwise, the algorithm progresses to compare and rank the potentially applicable technologies. The second stage consists of five methodological steps (Figure 1) as follows:

6. Identification and selection of applicable criteria;
7. Determination of criteria weights;
8. Comparison of storage technologies;
9. Ranking of technologies;
10. Sensitivity analysis.

This stage is only executed if two or more technologies emerge from the previous stage. In step six, it is necessary to select the appropriate criteria from the already available criteria. The selection criteria depend on the characteristics of a specific task. Given that each criterion holds varying significance for the task, determining its respective importance is essential (step 7).

The FAHP method was used to determine the criterion weights. Its application was favored because it substantially reduces the decision maker's subjectivity. In addition, there are numerous qualitative criteria that favor the application of this method. Subsequently, in step eight, the technologies were compared using the WASPAS method. The WASPAS method has proven to be very effective in previous papers, and, as such, will be applied to the ranking of technologies in this paper. The output from this step is the technology ranking (step 9). The algorithm's tenth step is the sensitivity analysis. Within this step, the coefficient λ is corrected, and the rank shifts under the new coefficient values. Based on this, it can be concluded whether a change in the weight value results in a change in rank or not. The stability and suitability of the method are confirmed for use in solving this type of problem if no significant rank changes occur. The final step of the algorithm represents the groundwork for decision making. The following is a comprehensive description of this approach's pivotal steps.

3.1. Defining the Task

The effective design of a warehouse requires the proper definition of the design task. Defining the design task is one of the key steps in the design solution process, but it is often inadequately addressed. To define the task correctly, it is necessary to comprehensively analyze all aspects that affect the functioning of the future warehouse: its place and role of the warehouse in the logistics system, corporate goals, the company's business plan, supply chain strategy, laws, regulations, etc. The warehouse's place and role must be precisely defined as they significantly influence the criteria for storage technology selection. Corporate objectives mirror the company's business policy: commitment to clients, working conditions of employees, environmental protection, etc. This indicates that seemingly the same warehouses can have different requirements and limitations. A company's business plan includes factors such as market expansion. This leads to room for expansion in the future or flexibility in terms of the product range. Supply chain strategy affects all components of the supply chain, including warehousing. The strategy affects the goods flow in the warehouse, the method of inventory management, etc. Laws and regulations represent a special aspect that should be considered when designing a warehouse. There are numerous regulations in different areas: fire protection, employee health protection, environmental protection, and food safety, and a specific task is set when it comes to dangerous goods. Failure to consider the aforementioned aspects can initiate a whole series of problems during warehouse exploitation. A qualitatively set warehouse task is a *Conditio sine qua non* in the design process, and it implies a clear specification of essential tasks, system elements, and the relations between them [7,26,34–36].

At the beginning of the task analysis phase, it is necessary to identify the place and role of the warehouse in the logistics system. Its position in the SC significantly affects other characteristics of the task. When comparing the two types of warehouses, the characteristics of production, shipping, and distribution warehouses differ significantly according to certain parameters. As a rule, the product range in the shipping warehouse is narrow, but the stock level per product is high. For a distribution warehouse, the opposite is true. In the framework of the distribution warehouse, there are requests for the processing of goods, whereas in the production and dispatch warehouses, there are no requests. The data necessary for the description of the warehouse design task can be divided into four groups: supply data, goods data, shipping data (users), and system requirements.

Supply data are obtained by identifying and analyzing incoming flows, which aim to determine the relevant requirements for receiving, storing, and shipping stocks within a certain product range. First of all, it is necessary to look at the law of encountering vehicles, the load of a vehicle, the need for processing at the entrance to the warehouse, etc.

When it comes to goods data, it is particularly important to look at the type of unit load, quantity (weight and volume), number of different goods, stock level per product, trends of changes in the assortment over time, the number of pieces of smaller logistics units in larger ones (if picking is done per box or per piece), the fragility of goods, the necessity of temperature conditions, the existence of a processing process, turnover ratio, etc. By applying an appropriate analytical approach, it is necessary to provide relevant task parameters related to storage conditions, stock rotation policies, etc. The type of unit load defines a certain group of storage technologies. In this paper, the group was narrowed down to PUL. The quantity of goods affects the required storage capacity. Weight affects the carrying capacity of the storage technology. The size of the assortment and the stock level per product significantly influence the elimination of certain technologies from further consideration. Depending on the combination of these two parameters, potential technologies can be identified that will be superior to others in the stage of generating potentially applicable technologies. If trends of change in the product range are observed, it is very important to consider the possibility of adapting technologies to the resulting changes—flexibility. If the dominant characteristic of the goods is fragility, it affects the elimination of storage technologies where shocks and vibrations are pronounced (push-back and flow racks) or technologies where loads are stacked on top of each other (block stacking technology). If the goods require temperature conditions, the maximum utilization of space is sought, which leads to a certain group of technologies. The need for a certain type of processing in the warehouse affects not only the increase in required areas but also the number of employees required in the warehouse. This has an impact on the investment and operating costs of the warehouse itself. The turnover ratio determines certain technologies that correspond to a given coefficient to a greater or lesser extent. In the warehouse, goods are often divided according to classes in relation to this ratio, and different classes require different storage technologies [7,24,26].

The third group of data refers to the shipment of goods to the users. These data should indicate the way goods leave the warehouse in terms of the type of unit load, quantity, stock rotation policy, etc. The number of purchase orders in a time interval (hour or day) or the size of the order (number of different lines, number of pieces, total weight, or total volume) can be viewed here. It is important to look at the frequency of the type of unit load of goods in purchase orders as well as the quantity of goods that appear per purchase order. In addition, the type of unit load, weight, and volume of the goods should be considered, as with the previous groups, as well as the level of service. An important parameter that appears in this group of data is the acceptable service interval, which affects the organizational aspect of the system and the order-picking method [7]. This group of parameters affects not only the flow but also the picking strategy applied. These data are obtained by forecasting or analyzing historical data (if available). By analyzing the previous data, it is possible to arrive at different classes of tasks that the storage system needs to fulfill. In addition, it also refers to different technologies that can be used for the same class of tasks.

System requirements and constraints represent a very important component when defining a task. Some of them are throughput in the warehouse; the capacity of the warehouse and technological elements; the level of service; the availability and price of labor; the availability and price of land and buildings; the equipment costs (storage technology); and others. The throughput represents the theoretical maximum amount of goods that can be delivered to users in a given time interval. The required capacity of a storage facility affects the potentially applicable storage equipment. Labor is an important component in the selection of storage technology. Under conditions of no workload or small workload, only automated storage systems can be considered. Available capital is often a major limitation when selecting storage technology.

Generally, when defining the design task, a large number of factors appear to be the subject of analysis. The relevance of certain factors largely depends on the specific task that is set during the specific design of the warehouse. Relevant factors are most often the flow, the size of the assortment, and the level of stock per product. By combining different values of these factors, different task classes can be defined. For some of these classes, the approach for storage technology selection was carried out.

3.2. Potentially Applicable Storage Technologies for PUL

Typical technologies for the storage of PUL are selective pallet racking, double-deep pallet racking, mobile pallet racking, gravity flow racking, push-back racking, drive-through racking, drive-in racks, block-stacking technology, modified block stacking technology, radio shuttle system, selective pallet racking with a very narrow aisle (VNA storage), and AS/RS storage systems. For the purposes of this paper, the review of PUL storage technologies is limited in terms of the relevant attributes. The presentation of the mentioned technologies with attributes is presented in Table 1, which was created by combining information from a large body of literature. Additional information on PUL storage technologies and their attributes can be found in the literature [7,11,34,36,37]. It should be pointed out that the combination of different storage technologies with MHE constitutes a typical technology. Their combination affects the values of certain criteria.

Table 1. Characteristics (attributes) of typical storage technologies for PUL [7,10,11,36–38].

Storage Technology	Throughput	Assortment	Stock Level per Product	Stock Rotation Policy	Material Handling Equipment
Selective rack	High	Large	Low	FIFO	Stacker, reach, or counterbalance
Double-deep rack	High/Medium	Medium	Medium	FIFO/LIFO	Specific reach
Mobile rack	Low	Large	Low	FIFO	Reach or counterbalance
Flow rack	High	Medium	High	FIFO	Reach, counterbalance, or three-sided
Push-back rack	Medium	Medium	Medium	LIFO	Reach or counterbalance
Drive-trough rack	Medium	Small	Very high	LIFO	Reach or counterbalance
Drive-in rack	Low	Small	Very high	LIFO	Reach or counterbalance
Block stacking	High	Small	Very high	LIFO	counterbalance
Modified block stacking	Medium	Medium	High	LIFO	counterbalance
Shuttle system	High	Medium	High	LIFO	Stacker crane or pallet transfer car
VNA	High	Large	Low	FIFO	Bilateral or trilateral stack
AS/RS	High	Large	Low	FIFO	Stacker crane

3.3. Selection of Criteria for Storage Technology Selection Based on Task Parameters

After defining alternatives in the design process, it is necessary to rank them in terms of reaching one or more target performances, i.e., set criteria. The selection is made on the basis of the selected criteria. Criteria can be of a quantitative or qualitative nature, and they are defined by the decision maker. The relative importance of certain criteria varies depending on the specific task, and certain criteria conflict with each other in terms of productivity and costs. The criteria selection greatly affects the quality of the solution obtained, so it is very important to select criteria that are relevant to a specific problem.

When designing a distribution warehouse, the aim is to achieve the highest possible throughput and service level, whereas when designing a holding warehouse, the aim is to minimize the required space and increase the storage density. Some of the criteria on the basis of which alternatives can be evaluated are costs, space utilization, throughput, selectivity, safety, flexibility, etc. According to the defined criteria, it can be observed that they match the attributes of the technologies. When looking at the attributes of technologies, the criteria act decisively; that is, they exclude alternatives from further consideration, and in this step, those criteria are used to evaluate the alternatives and compare them with each other.

3.3.1. Quantitative Criteria

The most frequently applied quantitative criteria are costs, space utilization, maximum stacking height, throughput, selectivity, etc. **Costs** are a very important and unavoidable criterion. Within the costs, two components can be distinguished: **investment and operating costs**. Investment costs include the costs of construction of the facility, the purchase of land, the purchase and installation of storage technology, material handling equipment, and other necessary equipment. Building and land construction costs are expressed in monetary units per unit area. Different racks require different spaces, so they affect the size of the building and therefore the required area of the plot for the building. Storage technology installation costs are expressed in monetary units per pallet space, and forklift costs are expressed in monetary units per asset. It is convenient to express these costs on an annual basis. This is obtained by dividing the resulting cost of each component by its lifetime. Operating costs include the costs of labor for employees, energy, and maintenance of the facility and equipment. Employee expenses represent the product of the number of employees and their annual income. Energy costs primarily refer to electricity costs. They are most influenced by the area of the warehouse that needs to be lit, the number of electric forklifts, and the number of devices for achieving the temperature conditions, if they exist. Maintenance costs represent the cost of replacing certain parts of racks and equipment that are worn out during their exploitation (e.g., rollers for gravity flow racks, tires for forklifts, etc.). All these costs need to be brought to the same unit in order to be able to add them up. It is convenient to present them on an annual basis. In this paper, the costs are obtained analytically for a defined warehouse layout, and the judgment estimates of these costs can be found in the existing literature [11,14,36].

In addition, one of the criteria can be **space utilization**, with the attributes of surface and volume utilization, as well as storage density. Surface and volume utilization are expressed as percentages in relation to the total area of the storage, that is, the volume. The storage density is expressed as the number of pallets per unit area. The values of these criteria are obtained analytically for specific warehouse layouts and can also be found in the literature for typical warehouse layouts. The space utilization in distribution warehouses is low, and this is a consequence of the desire for increased selectivity. In another warehouse, where the assortment is smaller, technologies that use space much better can be applied. Criteria such as the **maximum stacking height** or **maximum storage depth** can also be considered, the values of which can be found in the equipment manufacturer's prospectuses [11]. These technologies that allow greater height, that is, stacking depth, are preferred.

Throughput belongs to a set of quantitative criteria. It is expressed as the amount of shipped goods per unit of time. Throughput can be determined by analyzing existing data or by simulation. **Selectivity** represents the ability to access each storage unit. It can be expressed as a percentage of the storage capacity. If all units in the warehouse can be accessed, the selectivity is 100%, whereas if push-back racks with a depth of five pallets are applied, the selectivity is 20% [11]. The values of these criteria can be determined analytically.

3.3.2. Qualitative Criteria

The most frequently applied qualitative criteria are flexibility, quality of the service, safety, suitability for the application of automated picking technologies, the possibility of integration with the order-picking area, environmental factors, etc. Some authors mention numerous qualitative criteria as relevant. They are more difficult to evaluate than quantitative ones, and therefore, to make a selection. Some of these criteria include flexibility, service quality, risk, efficiency, and safety. **Flexibility** refers to the ability of the system to adjust if there are changes in the level of stock per product. Alternatives that can be adjusted to different inventory levels receive higher ratings. In addition, flexibility in terms of capacity expansion can also be considered. Under this criterion, technologies that enable capacity expansion without large investments in facility expansion receive a higher score. **Quality of service** is directly related to errors that occur in the order-picking process, that is, the delivery. Errors are calculated as the ratio of the number of incorrectly realized deliveries to the total number of deliveries. Certain systems require error-free delivery, so the introduction of modern systems is necessary. To some extent, it is influenced by the storage equipment, i.e., the additional equipment that is installed on the pallet racks. According to the **safety** criterion, storage technology with a lower probability of the pallet falling out of the rack receives a higher score. The aforementioned criteria are expressed in linguistic grades. **Suitability for the application of automated picking technologies** can be a criterion in storage technology selection. This criterion is gaining considerable importance because all processes in the warehouse are moving towards automation and robotization [6,37]. **The possibility of integration with the order-picking area** can be a very important criterion for some warehouses. According to this criterion, the highest score is given to the technology where the storage zone can be integrated with the order-picking area, thereby reducing the space required for the order-picking area. This criterion is very important in the design of distribution warehouses, and values can be obtained from expert judgments. **The environmental factor** has become increasingly important in recent years. Technologies that require less number of MHE and those that require less space receive the highest rating. The reason for this is the reduction in electricity consumption [37]. The values of the previously mentioned criteria can be obtained from expert judgments or the literature [36,37].

3.4. Determining the Weights of the Criteria Using the FAHP Method

Determining the weights of the criteria is a methodological step in the proposed approach, whose goal is to determine the relative importance of a selected set of criteria. In addition, it seeks to eliminate the subjectivity of the decision maker. In this paper, the FAHP method is used to determine the weights of the criteria. There are several variations of this method, and "Logarithmic Fuzzy Preference Programming" (LFPP) [39,40] will be described. This was created by extending the fuzzy preference programming (FPP) method. The first step in the FPP method is to form a fuzzy comparison matrix ($\widetilde{M}$) with triangular fuzzy numbers $\widetilde{m} = (a_{ij}, b_{ij}, c_{ij})$. Wang and Chin [39] in the LFPP method take the logarithmic values of the fuzzy numbers $\widetilde{m}_{ij}$ from the matrix $\widetilde{M}$ using the following equation:

$$\ln \widetilde{m}_{ij} \approx \left(\ln a_{ij}, \ln b_{ij}, \ln c_{ij}\right), \; i, j = 1, 2, \ldots, n \tag{1}$$

The membership function of the logarithmic fuzzy number can be approximated using Equation (2):

$$\mu_{ij}\left(\ln\left(\frac{w_i}{w_j}\right)\right) = \begin{cases} \frac{\ln\left(w_i/w_j\right) - \ln a_{ij}}{\ln b_{ij} - \ln c_{ij}}, \ln\left(\frac{w_i}{w_j}\right) \leq \ln b_{ij} \\ \frac{\ln c_{ij} - \ln\left(w_i/w_j\right)}{\ln c_{ij} - \ln b_{ij}}, \ln\left(\frac{w_i}{w_j}\right) \geq \ln b_{ij} \end{cases} \tag{2}$$

$\mu_{ij}\left(\ln\left(\frac{w_i}{w_j}\right)\right)$ is the membership function $\ln\left(\frac{w_i}{w_j}\right)$, which is close to the triangular fuzzy number $\ln\widetilde{m}_{ij}$ = ($\ln a_{ij}$, $\ln b_{ij}$, $\ln c_{ij}$)

w_i is the crisp value of the priority vector

$$W = (w_1, w_2, \ldots, w_n)^T > 0,\ \sum_{i=1}^{n} w_i = 1 \tag{3}$$

It is necessary to find the crisp value of the priority vector in order to determine the maximum of the minimum membership function based on it.

$$\theta = min\left\{\mu_{ij}\left(h\left(\frac{w_i}{w_j}\right)\right)\middle| i = 1, 2, \ldots, n-1, j = i+1, \ldots, n+1\right\} \tag{4}$$

The model can be set as follows:

$$\max\theta \tag{5}$$

$$s.t.\begin{cases}\mu_{ij}\left(\ln\left(\frac{w_i}{w_j}\right)\right) \geq \theta, i = 1, 2, \ldots, n-1, j = i+1, \ldots, n \\ w_i > 0,\ i = 1, 2, \ldots, n\end{cases} \tag{6}$$

Or:

$$\max(1-\theta) \tag{7}$$

$$s.t.\begin{cases}\ln w_i - \ln w_j - \theta\ln\left(\frac{b_{ij}}{a_{ij}}\right) \geq \ln a_{ij},\ \ i = 1,\ 2,\ \ldots,\ n-1,\ j = i+1,\ \ldots,\ n \\ -\ln w_i + \ln w_j - \theta\ln\left(\frac{c_{ij}}{b_{ij}}\right) \geq -\ln c_{ij},\ \ i = 1,\ 2,\ \ldots,\ n-1,\ j = i+1,\ \ldots,\ n \\ w_i > 0,\ i = 1, 2,\ \ldots,\ n\end{cases} \tag{8}$$

The goal is to ensure that the deviations from the variable values are minimal. Therefore, the following non-linear model for determining the criteria weights of the FAHP method based on the LFPP model is proposed:

$$\min J = (1-\theta)^2 + C * \sum_{i=1}^{n-1}\sum_{j=i+1}^{n}\left(\alpha_{ij}^2 + \beta_{ij}^2\right) \tag{9}$$

$$s.t.\begin{cases} z_i - z_j - \theta\ln\left(\frac{b_{ij}}{a_{ij}}\right) + \alpha_{ij} \geq \ln a_{ij}, i = 1, 2, \ldots, n-1, j = i+1, \ldots, n \\ -z_i + z_j - \theta\ln\left(\frac{c_{ij}}{b_{ij}}\right) + \beta_{ij} \geq -\ln c_{ij}, i = 1, 2, \ldots, n-1, j = i+1, \ldots, n \\ \theta, z_i \geq 0, i = 1, 2, \ldots, n \\ \alpha_{ij}, \beta_{ij} \geq 0,\ i = 1, 2, \ldots, n-1, j = i+1, \ldots, n \\ z_i = \ln w_i, i = 1, 2, \ldots, n\end{cases} \tag{10}$$

C is a certain, large constant (for example 10^3)

Let $z_i(\ i = 1,\ 2,\ \ldots,\ n)$ be the optimal solution of the objective Function (9). The normalized values of the weights of the matrix $\widetilde{M} = \left(\widetilde{a}_{ij}\right)_{nxn}$ can be calculated as follows:

$$w_i^* = \frac{exp\left(z_i^*\right)}{\sum_{j=1}^{n} exp\left(z_j^*\right)}, i = 1, 2, \ldots, n \tag{11}$$

exp() is an exponential function, $exp\left(z_i^*\right) = e^{z_i^*}$

3.5. Storage Technology Selection Using the WASPAS Method

Comparison of storage technologies is a step with the goal of obtaining a ranking of the selected technologies, which are the subject of evaluation and ranking. For the purposes of this paper, the WASPAS method was applied and consists of the following steps [41,42]:

Step 1: Defining the initial decision matrix: This matrix was obtained in the previous step.

Step 2: Normalization of the decision matrix: Depending on the type of criterion (max or min), it is necessary to use Formulas (12) and (13), respectively.

$$x_{ij}^{*} = \frac{x_{ij}}{\max\limits_{i}(x_{ij})}, i = 1, 2, \ldots, m \; i \;\; j = 1, 2, \ldots, n \tag{12}$$

$$x_{ij}^{*} = \frac{\min\limits_{i} x_{ij}}{x_{ij}}, i = 1, 2, \ldots, m \; i \;\; j = 1, 2, \ldots, n \tag{13}$$

x_{ij}^{*} is the normalized value of the *i-th* alternative in relation to the *j-th*

Step 3: Determining the total relative importance of alternatives based on WSM: The overall relative importance is determined using Equation (14).

$$Q_i^{(1)} = \sum_{j=1}^{n} x_{ij}^{*} * w_j \tag{14}$$

Step 4: Determining the total relative importance of alternatives based on WPM: The overall relative importance is determined using Equation (15).

$$Q_i^{(2)} = \prod_{j=1}^{n} \left(x_{ij}^{*}\right)^{w_j} \tag{15}$$

Step 5: Determination of the total relative importance of alternatives (Q_i): To determine Q_i, the decision maker needs to define the coefficient λ, which is in the range from 0 to 1. Alternatives are ranked according to Q_i. The best alternative is the one with the highest value of Q_i.

$$Q_i = \lambda Q_i^{(1)} + (1 - \lambda) Q_i^{(2)} \tag{16}$$

4. Practical Application of the Approach for Storage Technology Selection

The aim of this section is to perform testing of the defined approach in warehouse design. The approach was tested on the basis of characteristic classes of tasks that appear in practice. These tasks are achieved by providing previously described, relevant data and conducting certain target analyses. Following such an approach, three classes of typical tasks whose characteristics are given in Table 2 are distinguished here. A five-point scale was used (very low/small, low/small, medium, high/large, and very high/large).

Table 2. Characteristics of different task classes.

Characteristics	Class 1	Class 2	Class 3
Throughput	High	High	Low
Assortment	Large	Small	Small
Stock level per product	Medium	High	High

4.1. Class 1—HLM Class

Based on the parameters of the Class 1 task, it can be assumed that the characteristics of the task correspond to those of a distribution warehouse. However, this does not necessarily have to be correct because, in the distribution warehouse, a larger number of tasks can be identified, which can be solved individually. The primary role of a distribution warehouse is to provide retail stores. A high throughput is required in this warehouse. As a rule, the number of articles is large, often over several thousand articles, and the stock level is medium, from 5 to 10 pallets per article. The processing of goods is dominant, and picking is the most pronounced. The warehouse is of the ambient type; that is, the goods do not require temperature regimes, unlike goods in cold chains, which can appear in warehouses of this type. In this case, the goods are stored in special parts of the warehouse that meet special conditions, whereby the problem of storage technology selection can be considered for a specific case. The turnover ratio of articles is very high, and there is also a frequent change in the assortment.

In accordance with the critical factors introduced, the application of the table within the first stage (Figure 1) of the approach resulted in the following set of applicable technologies: selective pallet racks; storage technologies based on AS/RS systems; and VNA warehouses. Given that the attributes of no technology fully corresponded to the description of the task, the selected technologies were taken with the possibility of deviating from one criterion by one degree on the scale. Bearing in mind that the number of applicable technologies is greater than one, it is necessary to implement the second stage of the approach. For a specific warehouse, the authors suggest the following criteria as relevant: total costs; space utilization; the possibility of integration with the picking area; safety; and environmental factors. The values of the variant technologies according to the criteria are shown in Table 3. The values of the variant technologies according to the cost and space utilization criteria were obtained analytically for standard warehouse layouts and applied MHE, whereas the values for the other three criteria were obtained by expert judgments and from the literature [6,11,36,37,43]. The standard warehouse layout represents a warehouse that forms one block; that is, there are cross aisles only at the ends of the block. There are aisles between them. The costs were calculated for a warehouse with a capacity of 6000 pallets, whereas the number of forklifts and employees required was estimated for the specific task.

Table 3. Value of variant technologies according to the criteria for HLM class of problem.

Storage Technologies\Criteria	Total Costs (EUR)	Space Utilization (%)	Safety	Environmental Factors	Possibility of Integration with the Picking Area
Selective pallet rack *	435,200.9	30	Low	Low	Very High
AS/RS	539,470.4	51	High	High	Medium
VNA	495,093.4	47	High	Medium	Low

* with reach truck.

In the next step, the criteria weights were determined using the FAHP method. The weights obtained are presented in Table 4. From the table, it is evident that the costs and the possibility of integration with the picking area are dominant. The reason is that cost minimization is set as the objective function while satisfying certain conditions. The picking area is an inseparable part of the distribution warehouse, so the resulting weight is justified.

Table 4. Criteria weights for HLM class of problem.

Criteria	Total Costs	Space Utilization	Safety	Environmental Factors	Possibility of Integration with the Picking Area
Criteria weights	0.418	0.084	0.05	0.029	0.418

A comparison of the applicable storage technologies was conducted using the WASPAS method. The resulting order is shown in Table 5. Selective pallet racks, which are dominant in practice when it comes to distribution warehouses, received the best rating. The other alternatives did not receive the best rating because they had lower ratings according to the preferential criteria.

Table 5. A ranking of applicable storage technologies for the HLM class of problem.

Storage Technologies	Rank
Selective pallet rack	1
AS/RS	2
VNA	3

The sensitivity analysis is shown in Figure 2. It can be seen from the figure that the obtained solution is stable. Changes in the value of the parameter λ do not affect the obtained solution. The applied approach proved to be effective in this example.

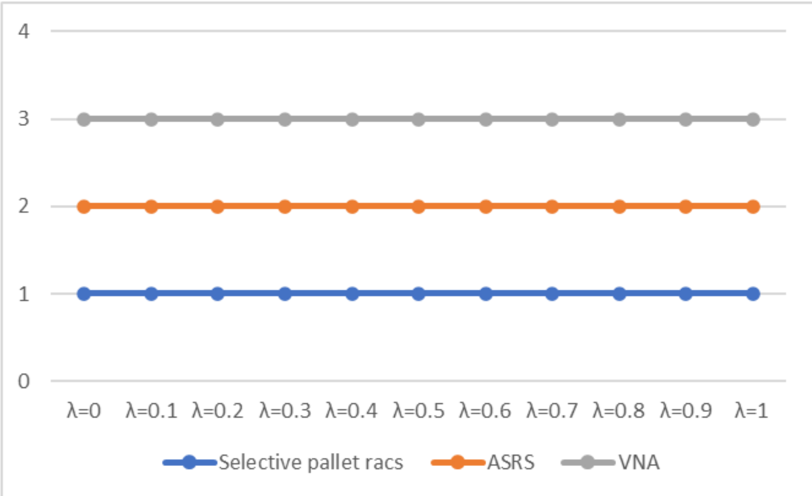

Figure 2. Sensitivity analysis for the HLM class of problem.

4.2. Class 2—HSH Class

Based on the parameters of the Class 2 task (shown in Table 2), it can be assumed that it is a production warehouse. This warehouse is located within the industry and stores finished articles that are intended for further use. The throughput of this warehouse is high, the assortment is narrow, and the stock level per article is high. In this warehouse, the processing processes are not expressed, and the assortment is not frequently changed.

Based on the characteristics of the task for the production warehouse, as presented in Table 2, and the implementation of the first stage of the approach for the storage technology selection (shown in Figure 1), the following set of applicable technologies narrows down to the following: block-stacking technology; storage technologies based on shuttle systems; flow racks; and drive-in racks. Given that the attributes of no technology fully correspond to the description of the task, the selected technologies were taken with the possibility of deviating from one criterion by one degree on the scale. Bearing in mind that the number of applicable technologies is greater than 1, it is necessary to implement the second stage of the approach. For a specific warehouse, the authors suggest the following criteria as relevant: total costs, storage density, safety, environmental factors, and flexibility. The values of the variant technologies according to the criteria are shown in Table 6. The values of the variant technologies according to the cost and storage density criteria were obtained analytically for standard warehouse layouts and applied MHE, whereas the values for the other three criteria were obtained by expert judgments and from the literature [6,11,36,37,43]. The costs were calculated for a warehouse with a capacity of 6000 pallets, while the number of forklifts and employees required was estimated for a specific task.

Table 6. Value of variant technologies according to criteria for the HSH class of problem.

Storage Technologies\Criteria	Total Costs (EUR)	Storage Density (no. pallet/m^2)	Safety	Environmental Factors	Flexibility
Block stacking system *	485,227.8	1.84	Low	High	Very High
Shuttle system	529,387.8	3.59	High	Low	Medium
Flow rack flow *	528,187.5	2.92	Medium	Medium	Medium
Drive-in racs *	507,777.2	2.94	Medium	Medium	Low

* with counterbalance forklift.

In the next step, criteria weights were determined using the FAHP method. The obtained criteria weights are presented in Table 7. It can be seen that the dominant criterion is cost, followed by storage density and flexibility. The company's goal is to minimize costs while meeting set requirements, such as higher storage densities and ensuring quick adaptability to changes in the assortment.

Table 7. Criteria weights for the HSH class of problem.

Criteria	Total Costs	Storage Density	Safety	Environmental Factors	Flexibility
Criteria weights	0.602	0.214	0.054	0.023	0.107

The comparison of applicable storage technologies was conducted using the WASPAS method. The resulting order is shown in Table 8. The best-ranked technology is based on shuttle devices. Although this variant solution has the worst value according to the dominant criterion, it is still the best solution. This is because the costs differ slightly, and according to other criteria, it is generally a better technology than the others.

Table 8. A ranking of applicable storage technologies for the HSH class of problem.

Storage Technologies	Rank
Block stacking system	2
Shuttle system	1
Flow rack	3
Drive-in racs	4

The sensitivity analysis is shown in Figure 3. From the figure, it can be seen that the solution is stable regardless of the change in the value of the parameter λ.

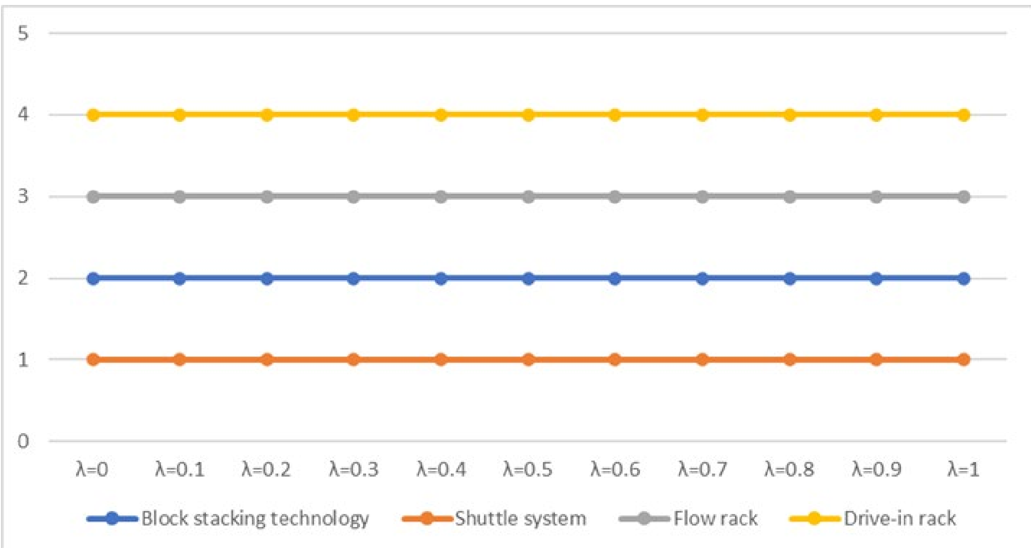

Figure 3. Sensitivity analysis for the HSH class of problem.

4.3. Class 3—LSH Class

The characteristics of the third task class match the characteristics of the holding warehouse. In this warehouse, goods are stored in case of emergency situations such as droughts, floods, etc. In addition, goods are stored in this warehouse for the purpose of state intervention when there is a sudden increase in prices. In these cases, goods are released to the market, and their prices decrease. The turnover ratio and, at the same time, the flow of goods are low. The assortment is narrow and the stock level per article is high. In this warehouse, the dominant process is the storage of goods; there are no processing processes, and different types of goods are present.

If the first stage of the storage technology selection approach is applied, there is only one technology in the set of applicable technologies: drive-in racks. Bearing in mind that there are no other technologies with which the input racks would be compared, it also represents an output from the algorithm because the second stage is skipped.

In such a case, the developed approach defines its entire practicality in a real-world application. According to the existing approaches in the literature, addressing this type of problem appears far more complex. Existing methods consider a large number of variant technologies, many of which might be irrelevant, as they do not align with the specific task's characteristics. Furthermore, numerous criteria that would be applied would have a value of 0. In contrast to these methods, this approach, right from the initial stage, identifies the optimal solution and provides a basis for further decision making in a straightforward way. This justifies its application in practice since such situations are often encountered when rationalizing existing or designing new warehouses.

4.4. Theoretical and Practical Implications

The results obtained in the previous section indicate the suitability of this approach for application in both theoretical research and practice. The approach itself is not strictly tied to the MCDM methods due to its staged nature. MCDM is applied only in the second stage of the approach, which may not always be implemented. As demonstrated in Section 4.3, the proposed method can, even at its initial stage, pinpoint the most appropriate solution when storage technology is selected in the holding warehouse. This approach stands out due to its distinctive structure, which thoroughly considers the design task, encompassing objectives, requirements, and limitations, which is its primary strength.

The practical contributions of this paper are undeniably clear. The approach is versatile and suitable for various warehouse types, allowing the decision maker to personally outline the task and select essential criteria that must be fulfilled, as well as the criteria on the basis of which the technologies will be ranked (especially when multiple technologies emerge at the conclusion of the initial stage). This method is intuitive and straightforward, making it accessible even for those new to design roles. It offers the designer structured guidance from the initial need for storage technology selection through to the final selection. It unequivocally determines which technologies fit the current scenario and identifies the optimal choice from the set. Moreover, this approach can act as a foundational framework for crafting DSS tools (or software) that bolster designers in their decision-making process, offering solutions based on input parameters.

From a theoretical aspect, this paper provides a good basis for the development of new models in the literature. On the basis of the presented multi-phase and systemic approach, it is possible to develop approaches for solving related problems in the warehouse design process and logistics in general. Beyond this, the approach provides opportunities for application in different case studies. Conversely, this approach invites integration with other MCDM methods for obtaining criteria weights and final rankings while also providing a platform for their validation using the presented results.

5. Conclusions

From the designer's perspective, selecting the optimal storage technology poses significant challenges when creating a technological solution. Though this dilemma is of considerable importance, the current literature has yet to address it comprehensively. The current literature fails to look at the task in a systematic way, marking a significant oversight. The proposed approach introduced here overcomes this shortcoming and, in the initial stage, focuses on the task's relevant characteristics on the basis of which the applicable technologies are further distinguished and outlines the criteria for their selection. Furthermore, the approach is user-friendly, promptly offering solutions to storage technology dilemmas. One distinct advantage of this approach is that it does not strictly rely on MCDM, but the most suitable solution can be reached in the first stage.

The approach is segmented into 10 steps divided into two stages: (i) defining the set of applicable technologies, and (ii) ranking the applicable technologies. The first stage begins with the definition of the task, taking into account relevant characteristics. Subsequently, based on the defined task, the critical factors that influence the narrowing of the set of applicable technologies are identified. Technologies that meet the critical factors enter the pool of applicable technologies, whereas the rest are discarded. If the end of the first stage yields more than one storage technology, the second stage must also be implemented; otherwise, a unique solution is obtained. In the second stage, the ranking of applicable technologies is performed. This begins with the identification and selection of the relevant criteria linked to the task's attributes. Thereafter, the weights are determined based on these criteria. In the next step, these technologies are compared. As an output from this step, the rank of the technologies is obtained. After that, a sensitivity analysis is performed, after which a basis for decision making is obtained.

The defined approach is demonstrated to solve three classes of problems. Within the first and second classes, the approach was carried out in its entirety, whereas in the third class of the task, only the first stage was carried out because only one technology appeared as a way out of it. In the first class of the task, three technologies were compared: single-deep pallet racking, storage technologies based on AS/RS systems, and VNA storage. The criteria used for the ranking are total costs, space utilization, safety, environmental factors, and the possibility of integration with the picking area. Selective pallet racks proved to be the preferred technology, predominantly utilized in practice for this class of task. For the second class of tasks, the following were compared: block-stacking technology, technologies based on shuttle systems, and flow rack racks. The criteria on which they were evaluated are total costs, storage density, safety, environmental factors, and flexibility. The shuttle-based technology turned out to be the best for this class of task. In the third class of the task, during the first stage, the drive-in rack stood out as the singular technology that met the given requirements. Consequently, it also represents the final solution, that is, the output from the approach.

The limitation of the defined approach is tested on a limited number of real problems. Furthermore, it is pivotal to explore the approach across diverse warehouse types, spanning different industries, sizes, levels of automation, etc. However, in complex warehouses, a greater number of classes of tasks appear that can be identified, for which storage technologies can be selected. In order to examine the influence of external factors, it is necessary to carry out the approach in different markets due to the value of the applied criteria. This is particularly relevant when considering the warehouse's geographical placement, impacting both investment (land cost and infrastructure development) and operational costs (labor costs). A parallel exploration should delve into the legislative impacts on warehouse design across a spectrum of nations (developed countries, developing countries, and underdeveloped countries). Augmenting this research could involve validating the existing model using alternate MCDM methods. The DEA method, a data-driven non-parametric approach, presents an intriguing option. Another avenue worth exploring is problem solving via simulation. By applying simulation software, a number of scenarios can be analyzed by entering various data regarding the intensity of the delivery of goods to the warehouse, the time the goods are kept in the warehouse, or the structure of the purchase order. The applicability of the model can be tested on other types of unit loads, such as boxes, plates, pipe material, etc. The input data for the model were obtained via a rough analysis. In further stages of design, more precise criteria values can be taken. The modification and application of the proposed approach could be tested for solving other types of problems in warehouse design, as well as in other areas of logistics.

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References

1. Rouwenhorst, B.; Reuter, B.; Stockrahm, V.; van Houtum, G.J.; Mantel, R.J.; Zijm, W.H. Warehouse design and control: Framework and literature review. *Eur. J. Oper. Res.* **2000**, *122*, 515–533.
2. Baker, P.; Canessa, M. Warehouse design: A structured approach. *Eur. J. Oper. Res.* **2009**, *193*, 425–436.
3. Gu, J.; Goetschalckx, M.; McGinnis, L.F. Research on warehouse design and performance evaluation: A comprehensive review. *Eur. J. Oper. Res.* **2010**, *203*, 539–549.
4. Tompkins, J.A.; White, J.A.; Bozer, Y.A.; Tanchoco, J.M.A. *Facilities Planning*, 4th ed.; Jenny Welter: Don Fowley, NY, USA, 2010.
5. Bastians Solutions. Available online: https://www.bastiansolutions.com/blog/how-much-does-pallet-racking-cost-/ (accessed on 12 March 2023).
6. Dijker, W.; van Kuijk, M.; (Groenewout, Breda, The Netherlands). Personal communication, 2005.
7. Rushton, A.; Croucher, P.; Baker, P. *The Handbook of Logıstıcs & Dıstrıbutıon Management*, 5th ed.; The Chartered İnstitute of Logistics and Transport, Use: Londun, UK, 2014.
8. Matson, J.O.; White, J.A. *Storage System Optimization*; Georgia Institute of Technology: Atlanta, GA, USA, 1981.
9. Sharp, G.P.; Vlasta, D.A.; Houmas, C.G. *Economics of Storage/Retrieval Systems for Item Picking*; Material Handling Research Center, Georgia Institute of Technology: Atlanta, GA, USA, 1994.
10. Luxhoj, J.T.; Suskind, P.B.; Caldwell, R.C.; Jackson, R. Rack selection expert advisor for a consumer products distribution center. *Ind. Eng.* **1994**, *26*, 32–34.
11. Holzhauer, R. Comparing unit load storage racks. *Plant Eng.* **2001**, *55*, 36–41.
12. Elenbark, W.; Muller, R. Interpreting the Numbers: From Data to Design. In Proceedings of the 91st Annual International Supply Management Conference, May 2006. Available online: https://docplayer.net/20596411-Interpreting-the-numbers-from-data-to-design-william-elenbark-consultant-gross-associates-732-636-2666-belenbark-grossassociates.html (accessed on 21 June 2023).
13. Indap, S. Application of the Analytic Hierarchy Process in the Selection of Storage Rack Systems For E-Commerce Clothing Industry. *J. Manag. Mark. Logist.* **2018**, *5*, 255–266. [CrossRef]
14. Zaerpour, N.; Volbeda, R.; Gharehgozli, A. Automated or manual storage systems: Do throughput and storage capacity matter? INFOR. *Inf. Syst. Oper. Res.* **2019**, *57*, 99–120.
15. Saderova, J.; Rosova, A.; Sofranko, M.; Kacmary, P. Example of warehouse system design based on the principle of logistics. *Sustainability* **2021**, *13*, 4492.
16. Chan, F.T.S.; Ip, R.W.L.; Lau, H. Integration of expert system with analytic hierarchy process for the design of material handling equipment selection system. *J. Mater. Process. Technol.* **2001**, *116*, 137–145.
17. Mathew, M.; Sahu, S. Comparison of new multi-criteria decision making methods for material handling equipment selection. *Manag. Sci. Lett.* **2018**, *8*, 139–150. [CrossRef]
18. Zubair, M.; Maqsood, S.; Omair, M.; Noor, I. Optimization of material handling system through material handling equipment selection. *Int. J. Progress. Sci. Technol.* **2019**, *15*, 235–243.
19. Fazlollahtabar, H.; Smailbašić, A.; Stević, Ž. FUCOM method in group decision-making: Selection of forklift in a warehouse. *Decis. Mak. Appl. Manag. Eng.* **2019**, *2*, 49–65. [CrossRef]
20. Satoglu, S.I.; Türkekul, İ. Selection of Material Handling Equipment using the AHP and MOORA. *J. Tek. Ind.* **2021**, *22*, 113–124. [CrossRef]
21. Horňáková, N.; Jurík, L.; Hrablik Chovanová, H.; Cagáňová, D.; Babčanová, D. AHP method application in selection of appropriate material handling equipment in selected industrial enterprise. *Wirel. Netw.* **2021**, *27*, 1683–1691. [CrossRef]

22. Telek, P.; Koštál, P. Material handling equipment selection algorithm for production workplaces. *Adv. Logist. Syst.-Theory Pract.* **2022**, *16*, 37–46.
23. Telek, P. Role of workplace handling parameters in the material handling equipment selection. *J. Prod. Eng.* **2022**, *25*, 53–58. [CrossRef]
24. Sharp, G.P.; Il-Choe, K.; Yoon, C.S. Small parts order picking: Analysis framework and selected results. In Proceedings of the Material Handling '90, Berlin, Germany, 19–21 June 1990.
25. Yoon, C.S.; Sharp, G.P. A structured procedure for analysis and design of order pick systems. *IIE Trans.* **1996**, *28*, 379–389. [CrossRef]
26. Djurdjević, B.D.; Miljuš, M. An approach of order-picking technology selection, In Proceedings of International Conference on Transport Science, Portorož, Slovenija, 27 May 2011.
27. Djurdjević, D.; Miljuš, M. Piece picking technology selection. In Proceedings of the 4th Logistics International Conference, Belgrade, Serbia, 23–25 May 2019.
28. Villarreal-Zapata, G.; Salais-Fierro, T.E.; Saucedo-Martínez, J.A. Intelligent system for selection of order picking technologies. *Wirel. Netw.* **2020**, *26*, 5809–5816. [CrossRef]
29. van der Gaast, J.P.; Weidinger, F. A deep learning approach for the selection of an order picking system. *Eur. J. Oper. Res.* **2022**, *302*, 530–543. [CrossRef]
30. Jaghbeer, Y.; Hanson, R.; Johansson, M.I. Automated order picking systems and the links between design and performance: A systematic literature review. *Int. J. Prod. Res.* **2020**, *58*, 4489–4505. [CrossRef]
31. Alam, K.A.; Ahmed, R.; Butt, F.S.; Kim, S.G.; Ko, K.M. An uncertainty-aware integrated fuzzy AHP-WASPAS model to evaluate public cloud computing services. *Procedia Comput. Sci.* **2018**, *130*, 504–509. [CrossRef]
32. Otay, I.; Kahraman, C.; Öztayşi, B.; Onar, S.Ç. A novel single-valued spherical fuzzy AHP-WASPAS methodology. In Developments of Artificial Intelligence Technologies in Computation and Robotics. In Proceedings of the 14th International FLINS Conference (FLINS 2020), Cologne, Germany, 18–21 August 2020.
33. Bouchraki, F.; Berreksi, A.; Hamchaoui, S. Evaluating the policy of listening to customer claims in a drinking water utility using fuzzy-AHP approach and WASPAS method. *Water Policy* **2021**, *23*, 167–186. [CrossRef]
34. Vukićević, S. *Warehouses*; Preving: Belgrade, Serbia, 1995.
35. Sretenović, M. *Transhipment Mechanization-Transhipment Machines, and Design Reloading Processes*; University Book; University of Belgrade: Belgrade, Serbia, 1996.
36. Richards, G. *Warehouse Management: A Complete Guide to Improving Efficiency and Minimizing Costs in the Modern Warehouse*, 3rd ed.; Kogan Page Publishers: London, UK, 2017.
37. Ten Hompel, M.; Schmidt, T.; Dregger, J. *Materialflusssysteme: Förder-und Lagertechnik*, 4th ed.; Springer: Dortmund, Germany, 2018.
38. Anbiyaa, D.; Setyawan, E.B.; Purba, H.H. Multiple knapsack problem for racking selection model. *IOP Conf. Ser. Mater. Sci. Eng.* **2019**, *508*, 012069. [CrossRef]
39. Wang, Y.M.; Chin, K.S. Fuzzy analytic hierarchy process: A logarithmic fuzzy preference programming methodology. *Int. J. Approx. Reason.* **2011**, *52*, 541–553. [CrossRef]
40. Yu, J.R.; Shing, W.Y. Fuzzy analytic hierarchy process and analytic network process: An integrated fuzzy logarithmic preference programming. *Appl. Soft Comput.* **2013**, *13*, 1792–1799. [CrossRef]
41. Zavadskas, E.K.; Turskis, Z.; Antucheviciene, J.; Zakarevicius, A. Optimization of weighted aggregated sum product assessment. *Elektron. Ir Elektrotechnika* **2013**, *122*, 3–6. [CrossRef]
42. Pajić, V.; Kilibarda, M.; Andrejić, M. A Novel Hybrid Approach for Evaluation of Resilient 4PL Provider for E-Commerce. *Mathematics* **2023**, *11*, 511. [CrossRef]
43. Peters, B.A.; Malmborg, C.; Petrina, G.; Pratt, D.; Taylor, D. An Introduction to Material Handling Equipment Selection. In College-Industry Council on Material Handling Education (CICMHE). 1998. Available online: https://www.mhi.org/downloads/learning/cicmhe/guidelines/equpguid.pdf (accessed on 21 June 2023).