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Application of Multi-Criteria Decision-Making Methods in Warehouse: A Brief Review

Medina Taletović[1*]

[1] Faculty of Transport and Traffic Engineering, Doboj, University of East Sarajevo, Vojvode Mišića 52, 74000 Doboj, Bosnia and Herzegovina

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ABSTRACT

This review paper investigates the application of various multi-criteria decision-making (MCDM) methods in the context of warehouse management, considering papers published from 2010 to date. Warehouses often face many challenges, including efficient inventory management, space optimization, proper resource allocation, and optimal supplier selection. This paper focuses on several well-known MCDM methods that are often used in the context of warehouse management. Full consistency method (FUCOM), analytic hierarchy process (AHP), the technique for order of preference by similarity to ideal solution (TOPSIS), weighted aggregated sum product assessment (WASPAS), criteria importance through intercriteria correlation (CRITIC), measurement of alternatives and ranking according to the compromise solution (MARCOS), best worst method (BMW), evaluation based on distance from average solution (EDAS), correlation coefficient and the standard deviation (CCSD), indifference threshold-based attribute ratio analysis (ITARA), and simple additive weighting (SAW) are some of the methods reviewed in the paper, as well as certain fuzzy versions of the methods. This review paper provides a brief comprehensive overview of the application of these methods in the context of warehouse management. Data collection leads to results that tell us that the methods are mainly used in solving problems during the selection of warehouse location, the selection of warehouse equipment, and also in the management of the warehouse itself and the performance of its management. It has also been seen that the methods are useful even in "green" logistics, as well as in inventory management.

1. Introduction

Warehouses are key elements in the supply chain and logistics chain of many organizations. They are physical locations or premises intended to store, organize and manage goods, raw materials, or finished products before they are distributed or further processed. Warehouses are necessary for maintaining adequate stocks, providing support for the delivery of goods and efficient management of logistics flows.

* *Corresponding author.*
E-mail address: medina.taletovic9499@gmail.com

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Efficient warehouse management requires careful planning, organization, and supervision of all activities involved in warehouse operations. This includes space optimization, rack layout, use of technology and information systems, inventory management, shelf-life tracking, transportation management, and staff coordination. The goal is to achieve a balance between minimum storage costs and maximum availability and speed of delivery of goods. Advances in technology and automation have significantly influenced the development of modern storage systems. Warehouses are increasingly equipped with automated systems, robotic arms, computerized inventory management systems, wireless communication, and telematics. This enables faster and more accurate processing, monitoring, and management of warehouse operations.

The application of multi-criteria decision-making (MCDM) methods in the warehouse has a significant impact on the efficiency, productivity, and optimization of operations. These methods provide a structured approach to decision-making in complex storage scenarios, where multiple criteria or factors need to be considered when ranking alternatives. One of the main challenges in warehouse management is achieving a balance between various goals such as cost reduction, space optimization, productivity enhancement, order processing time reduction, inventory accuracy improvement, and customer satisfaction. MCDM methods provide a framework for analyzing these different objectives to make the best possible decision. Using these methods allows warehouses to quantitatively evaluate and rank alternatives based on various criteria, taking into account their importance and interrelationships.

The importance of applying MCDM methods in the warehouse is manifold. First, it enables decision-makers to understand the complexity and interrelationships among different criteria and alternatives and thus better understand their decisions. Second, the application of MCDM methods allows decision-makers to quantify and objectively evaluate various aspects of the warehouse. This helps eliminate subjectivity and make consistent decisions based on relevant data. Third, these methods provide a framework for continuous monitoring and improvement of warehouse performance. Through the use of quantitative data and analysis, weaknesses and areas for improvement can be identified, and measures can be implemented to optimize warehouse operations.

The second part of the review paper is devoted to the methodology of the paper itself, in which it is described which period was considered, and in which journals the papers and publications were found. The third part of the paper presents the results obtained by searching using Google search, i.e. presentation of papers collected by years, presentation of papers collected by journals and conferences, and linguistic description as well as a graph of all methods used in the papers. In the fourth part, a review of literature on the specific topic is given, but from different aspects related to warehouses, such as determining the location of the warehouse using MCDM methods, managing the warehouse using MCDM methods, selecting handling equipment in the warehouse by applying MCDM methods, MCDM methods that are used for inventory management and sorting, as well as methods for "green" logistics. The overview of each paper includes its goal and purpose, where the research was carried out, which criteria were selected for the calculation, and which alternatives were ranked.

2. Methodology

To write this review paper, papers on the topic "application of MCDM methods in the warehouse", published in the period from 2010 to 2023, have been considered to provide information about the latest knowledge and research in this area, with the focus on papers which directly or indirectly discuss the application of MCDM methods in a warehouse context. The Google search engine was primarily used for the search to reach these papers, The search was done by following key terms: MCDM methods in general or separately, warehouse, warehouse location, forklift, warehouse management, and performance measurement. We analyzed how the methods were applied, which criteria and alternatives were considered, as well as which results, conclusions, and discussions were obtained from those research papers. The methodology is shown in Figure 1.

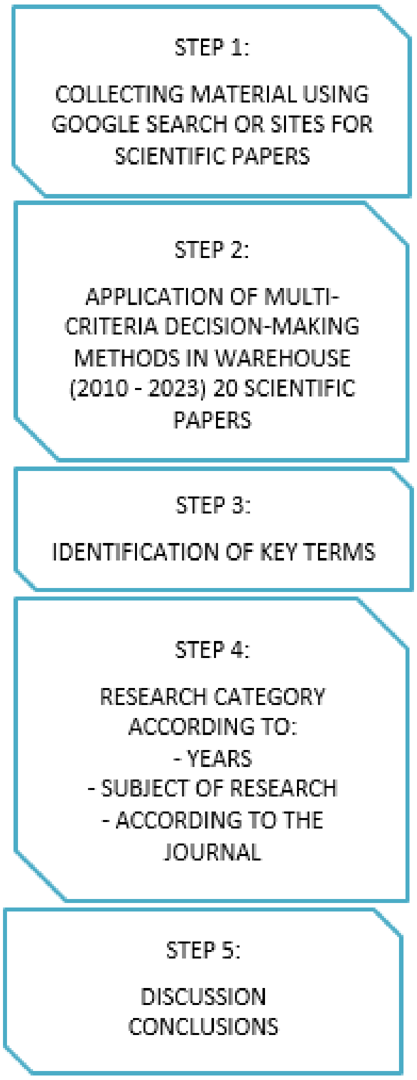

Fig. 1. Methodology

2.1 Number of Papers Collected by Years

Figure 2 shows the number of papers collected by years of publication related to the application of MCDM methods in the context of warehouses. This graph provides insight into research trends and interest in this topic over the years. As can be seen, research papers focusing on the application of warehouse methods have gradually increased over recent years. For 2010, no paper related to this topic has been collected, which indicates less interest or limited availability of relevant literature at that time. In the following years, the number of collected papers begins to grow. For 2011, 2012, 2013, and 2014, one paper has been collected per year. After 2014, the number of collected papers varies between one and three papers per year. There is some oscillation in the number of papers during this period, but, overall, a stable trend with somewhat greater interest in the topic compared to earlier periods can be observed. The years 2015, 2020, and 2021 have the most scientific papers found for this review paper, while for 2022 and 2023 that number is two papers per year. It is important to note that Figure 2 only shows the number of collected papers, not their quality or depth of research. However, it can be concluded that the interest in the application of multi-criteria methods in the warehouse has gradually grown in the last few years, which points to the importance of this area of research and the need for further research in the future.

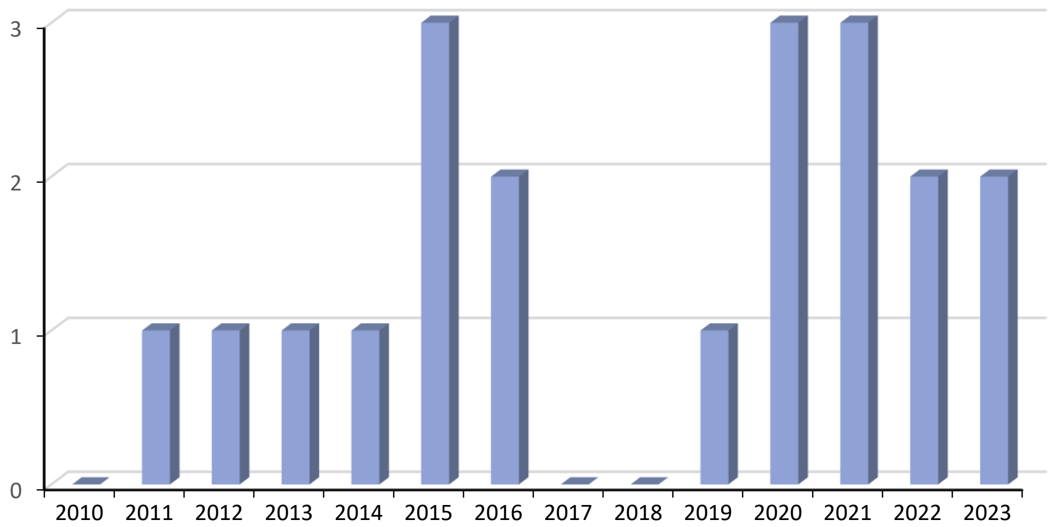

Fig. 2. Number of papers collected by years

2.2 Papers by Journals and Conferences

Table 1 shows the number of papers published in certain journals and conferences, together with their percentage share in the total number of papers.

i. Expert Systems with Applications: One paper was published in this journal thus representing a 5.0 % share.
ii. Tehnički Vjesnik: One paper was published in the journal Tehnički Vjesnik, also with a share of 5.0 %.
iii. Other journals and conferences: Other journals and conferences, such as Symmetry, International Journal of Management Science and Engineering Management, European Journal of Science and Technology, E3S Web of Conferences, etc., also have one paper published in each of them, making a 5.0 % share each in the total number of papers.

Table 1 provides an insight into the diversity of publication sources in the area of using MCDM methods in warehouses, where the mentioned journals and conferences contribute to the overall research consideration, with one published paper in each of them.

2.3 Methods Used in the Scientific Papers

Figure 3 shows the number of papers in which certain methods were used for MCDM analysis in the context of warehouses. These papers represent an important contribution to the research and application of the methods in warehouse management. Analysis of the results reveals several significant trends. The most commonly used methods are the analytic hierarchy process (AHP), the

Table 1
Journals and conferences in which the papers were published

Publication outlet	Numbers	References
Expert Systems with Applications	1	[1]
Tehnički Vjesnik	1	[2]
International Journal of Management Science and Engineering Management	1	[3]
IEEE International Conference on Industrial Engineering and Engineering Management	1	[4]
Faculty of Transport and Traffic Sciences, University of Zagreb	1	[5]
Vezetéstudomány	1	[6]
European Journal of Science and Technology	1	[7]
Decision Making: Applications in Management and Engineering	1	[8]
Tehnički vjesnik	1	[9]
Symmetry	1	[10]
Technological and economic development of economy	1	[11]
Mathematics	1	[12]
Mechatronics and Intelligent Transportation Systems	1	[13]
Engineering Management in Production and Services	1	[14]
Interdisciplinary Journal of Contemporary Research in Business	1	[15]
E3S Web of Conferences	1	[16]
Prosperitas	1	[17]
Scientific Journal on Traffic and Transportation Research	1	[18]
Arabian Journal for Science and Engineering	1	[19]
Decision Science Letters	1	[20]

technique for order of preference by similarity to ideal solution (TOPSIS), and fuzzy AHP, which are implemented in the largest number of papers. AHP is a well-known method that was used in five scientific papers, TOPSIS is used to rank alternatives based on the distance from the ideal and anti-ideal solution, which was used in seven scientific papers. Fuzzy AHP was used in six scientific papers. Fuzzy TOPSIS and "elimination et choix traduisant la realité-elimination and choice expressing reality" (ELECTRE) are slightly less used methods, with their implementation in three scientific papers each. MCDM methods that were used in two scientific papers or conferences each are as follows: criteria importance through intercriteria correlation (CRITIC), measurement of alternatives and ranking according to the compromise solution (MARCOS), weighted aggregated sum product assessment (WASPAS), and full consistency method (FUCOM).

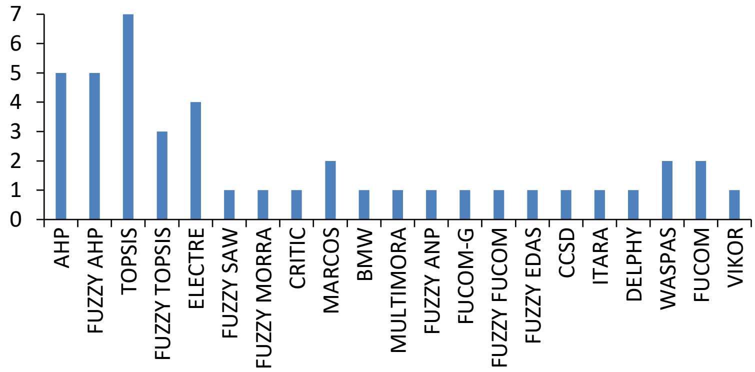

Fig. 3. Methods of multi-criteria research applied in scientific papers on the topic "Application of MCDM methods in the warehouse"

In Figure 3, we can also see which methods are the least represented; i.e., the least implemented in scientific papers related to this review, namely: fuzzy simple additive weighting (SAW), fuzzy multi-objective optimization on the basis of ratio analysis (MOORA), best worst method (BMW), MOORA plus the full multiplicative form (MULTIMOORA), fuzzy ANP, grey FUCOM, fuzzy FUCOM, fuzzy EDAS, correlation coefficient and the standard deviation (CCSD), indifference threshold-based attribute ratio analysis (ITARA), and "visekriterijuska optimizacija i kompromisno resenje" (VIKOR) methods.

3. Literature Review

In the research Tuncay and Sakir [1], AHP, TOPSIS, ELECTRE, and grey theory methods were compared in terms of decision theory characteristics, presenting their advantages and disadvantages. After that, the authors have considered the application of these methods to the warehouse selection problem, which is one of the key topics of logistics management with a wide application of MCDM methods. The problem of selecting a warehouse location was investigated in a case study in the retail sector, and TOPSIS and ELECTRE methods were applied to solve that problem. However, when using these methods, the criteria were evaluated according to two basic goals (i.e., maximization and minimization), while ignoring the fact that criteria such as storage capacity must define a certain lower limit, optimal value, and upper limit. For this purpose, the grey theory was applied to the warehouse location selection problem to correct the shortcoming of the TOPSIS and ELECTRE methods.

The warehouse system is a key component of an efficient management system of the entire supply chain. The barcode system provides information on the quantity of products in stock and is widely used due to its simplicity and low cost. In the research Turan and Gulin [2], the AHP and fuzzy AHP methods were used to select the best warehouse data collection system between barcode and RFID. Four criteria were considered: costs, functionality, sustainability, and performance. According to AHP, barcode was preferred in 68 % of cases, while RFID was preferred in 32 % of cases. In the fuzzy AHP comparison results, barcode was preferred in 72 % of cases, while RFID was preferred in 28 % of cases. Also, in Chang's method, the sustainability criterion was the most important compared to other criteria. These results indicated that the barcode system was chosen as the best data collection system in the company's warehouse.

In the research Balaram *et al*. [3], three new extended MCDM methodologies with fuzzy factors were proposed for warehouse location evaluation and selection. The classic normalization technique was used to evaluate objective criteria. Subjective and objective factors were integrated by the Brown and Gibson model to calculate the warehouse location selection index. The goal of the research was to increase the efficiency and profitability of the supply chain so that managers were provided with a strategic solution for selecting a warehouse location. The proposed methods were applied to two different examples to demonstrate their applicability and potential.

Decision-makers strive to quickly learn which decisions have the greatest impact on overall warehouse performance. The paper Khan *et al.* [4] discussed the evaluation of warehouse performance and the importance of efficient use of space, customer satisfaction, quality of goods storage and transportation services, inventory levels, and environmentally friendly delivery. The authors of the paper proposed an integrated fuzzy AHP approach that connected operational and strategic criteria, based on which a warehouse performance measurement system would be created. Also, the authors pointed out that it was important to adjust the criteria and measurement methods according to the characteristics of each warehouse and industrial segment. In the example of a numerical model in the paper, the overall performance of the warehouse was shown. In the first scenario, storage performance improves from 36.5 % to 43.9 %, and in the second from 36.0 % to 46.8 %. Therefore, it can be said that the main contribution of this paper was the proposed approach, which allowed decision-makers and managers to understand the impact of their long-term decisions on short-term decisions and overall warehouse performance.

Storage features depend on the type of forklift being used, and they have different features necessary to perform specific tasks. Technical characteristics play a key role in the manipulation of cargo, which may be outside the pallets. Mujagić [5] emphasized the importance of selecting the right forklift for handling cargo in warehouses. The research aimed to describe and analyze the characteristics of the most common types of forklifts and compare them to select the most suitable one. In this paper, five criteria were used for the selection of forklifts: C_1-price, C_2-maximum lifting height, C_3-maximum load capacity, C_4-energy consumption, and C_5-speed of movement. Each criterion was chosen arbitrarily. The AHP method was used to compare and rank those criteria. After the calculations, it was determined that the most important criterion was the price, followed by the maximum lifting height, maximum load capacity, energy consumption, and speed of movement. The results showed that forklift "D" is considered the most suitable solution due to the lowest price, which was determined as the most important criterion. However, the decisions of companies may differ depending on needs and priorities, and it is possible to select a forklift with better technical characteristics, even if it is more expensive.

The goal of the research Ajripour [6] was to apply MCDM in warehouse management. The authors stated that the management could be influenced by the organization's performance. They also stated that the main goal of applying the methods in this research was how to classify the spare parts in a given warehouse. The hybrid BMW-AHP-TOPSIS method was used. Eight experts selected 12 spare parts for classification. The following criteria were used to classify the alternatives: cost, lead time, consumption rate, and critical (inventory sensitivity in three aspects: production, environment, and safety). After that, the decision-makers made a comparative analysis between the best one and other criteria, and between other criteria and the worst one. A scale of one to five was used. With a score of 0.54, the critical criterion was obtained as the most important, and the least desirable was the lead time with a value of 0.09. After that, the AHP method was applied, and the results show that spare part no. 38 has the highest value, and no. 27 has the lowest. Then after applying the TOPSIS method, spare part no. 29 had the highest value, while spare part no. 28 had the lowest value. To obtain more accurate values, an integrated method called "max-min square mean" was used, and spare part no. 29 also had the highest value, and spare part no. 28 was the lowest. The final results after applying the ABC analysis are such that, based on the final ranking of the alternatives and taking into account the Pareto principle, the two spare parts with the highest point values were classified in group A, the next five spare parts with lower scores were classified in group B, while the remaining five spare parts were classified in group C.

During the COVID-19 pandemic, the research by Hallak and Ozkurt [7] was conducted in Syria. One of the priorities of the residents and the authorities was how to increase laboratory capacity, protect healthcare workers and make people aware of the pandemic itself. These stated priorities led the authors to the idea of conducting research related to humanitarian warehouses for the distribution and storage of medical equipment. The main goal was to determine the location of the warehouse. Fuzzy AHP was used to determine the weights of the criteria, and some versions of the MOORA method were used to rank the alternatives. Three experts with knowledge of supply chains determined the criteria for this research, which were: C_1-warehouse expenses, C_2-labor cost, C_3-availability of labor (economic criteria), C_4-proximity to demand camps, C_5-proximity to major roads, C_6-distance from clash lines (operating criteria), C_7-availability of water and electricity, C_8-availability of safety equipment, and C_9-capacity of the warehouse (infrastructural criteria). After ranking by all versions of the MOORA method, the final ranking was performed using the MULTIMOORA method.

The research in the paper Fazlollahtabar *et al.* [8] was dedicated to the selection of a side loader to meet the needs of the Euro-Roal company. The FUCOM-WASPAS model, which was mentioned for the first time in the literature, was used for the calculation. FUCOM was used to obtain the weights of the criteria, while WASPAS was used to rank the alternatives, which were forklifts in that case. The weights were determined depending on the importance of experts and company employees. The criteria were as follows: C_1-purchase price, C_2-year of production, C_3-working hours, C_4-maximum load capacity, C_5-maximum lift height, C_6-ecological factors, and C_7-procurement of spare parts, whose values were as follows: 0.082, 0.91, 0.410, 0.186, 0.108, 0.059, and 0.068, respectively. For decision-maker one, the working hours criterion (C_3) was the most important criterion. The following values were obtained for the second decision-maker: 0.094, 0.140, 0.398, 0.115, 0.116, 0.064, and 0.077. For this decision-maker, the most important criterion was the working hours (C_3). For decision-maker three, the following values were obtained: 0.095, 0.170, 0.481, 0.110, 0.112, 0.050, and 0.065. For the third decision-maker, C_3 also was the most important criterion. Ten alternative forklifts were used for the calculation. The results showed that for the needs of the company, the most suitable alternative with the highest value was A_8; i.e., BAUMANN EHX 30/14/ forklift model.

The aim of the paper Apak *et al.* [9] was to provide decision support through the model, for the evaluation of the warehouse management system. Thus, numerous factors that affect the determination of the criteria were taken into account. This paper also presented the application of MCDM methods to solve the aforementioned evaluation, and the methods used were: fuzzy AHP, fuzzy ANP, and fuzzy TOPSIS. In the paper, the criteria were as follows: warehouse and bin configuration, receiving and quality control, business process, decision support and reporting, security, inventory control, inventory optimization, cycle time analysis and optimization, cycle count, packing and shipping, put away and picking, labor allocation and optimization, yard management, web order entry, and return material authorization. After determining the criteria, a questionnaire was formulated to compare each criterion with the format of the AHP questionnaire, where a nine-point scale was used. The expert team evaluated each module according to their system capabilities. Then ANP and TOPSIS methods were applied. In the paper, the results were as follows: after calculation using the ANP method, alternative A_1 was considered the most important because of the highest priority compared to the others (i.e., 0.1802). The same results were obtained by applying the TOPSIS method.

The authors of the research Popović *et al.* [10] stated that the warehousing system was one of the most important within a company, which was the focus of this paper. The grey FUCOM method and SWOT analysis were applied to implement barcodes in the Natron Hayat company. The SWOT matrix was formed with 27 elements to determine the strengths (7), weaknesses (9), opportunities (7), and threats (4) of the given company. Then, grey FUCOM was applied to determine the weights for the factors assigned by the SWOT analysis, and that task was conducted by company employees who were experts in the observed area using a scale from one to nine. Since the SWOT analysis was divided into two levels, thus a separate calculation of grey FUCOM was applied for each level. It was found that the most important element in the dimension of strength was a good organization of work within the work unit, which was the result of the company that invested in the training of its employees. To confirm the results obtained, a comparison was made with the classic FUCOM method, where similar results were obtained, but with certain deviations; i.e., grey FUCOM considered certainty and uncertainty in information, while the classic model ignored it. The most important element of the weakness dimension was found to be: a problem with the methodology of justifying the material taken and the excessive periods between taking the material and its justification, while the most important elements of the opportunity dimension were the following two: the elimination of errors when typing requests and a faster way of justifying the use of goods by users. Then after the calculation for the dimension of threats, the most important element obtained was the provision of funds. In the final ranking of all dimensions, the most important element was good work organization within the work unit.

For a company to maintain its business and competitiveness in the market, the relationship between marketing and other subsystems of the company is of great importance. That is why it is important to focus management on key resources. The authors in the paper Vukasović *et al.* [11] created a fuzzy model, an integration of fuzzy FUCOM and fuzzy EDAS methods, for sorting 78 products. The used criteria were the following: quantity, unit price, annual procurement costs, and demand. The second model represented the integration of the fuzzy FUCOM method and the ABC analysis. The company in which the research was carried out is located in Bosnia and Herzegovina and its main activity was trade, but they also started their production. The company owned a closed warehouse covering an area of 1120 m^2 and an open warehouse for products that were not sensitive to weather conditions. The data referred to the year 2019. First, criteria weights were determined by the fuzzy FUCOM method, with the following values: w_1 = 0.224, w_2 = 0.188, w_3 = 0.326, and w_4 = 0.263. Then, EDAS was applied, through PDA and NDA matrices. The results of the ABC analysis were as follows: there were 18 products classified in group A, which was 23.08 %. Products of group B accounted for 26.91 %; i.e., 21 products. The largest number of products belonged to group C and accounted for 50.0 %. This fulfilled the constraint A < B < C. Developing a new fuzzy model was the greatest contribution of this paper, which provided insight into stocks. The authors also stated that the combination of fuzzy multi-criteria methods, ABC analysis, and XYZ analysis could be one of the directions for future research on accurate inventory management.

Recently, MCDM methods have been increasingly applied and developed, thanks to a large number of scientific papers and publications based on them. Also, they are thought to help solve complex problems. The aim of the paper Ulutas *et al.* [12] was to develop an MCDM model that was used in the selection of equipment in the logistics system. In the paper, the integration of the CCSD and ITARA methods, which were used to determine the weights of the criteria, and the MARCOS method, which was used to rank the alternatives, was carried out. The following five criteria were determined: C_1-price of stacker, C_2-capacity, C_3-lift height, C_4-warranty period, and C_5-fork length. The results obtained from the CCDS and ITARA methods were combined to achieve a more objective significance of the criteria. The authors concluded that the presented model was very reliable in terms of application in any part of the logistics system, especially in the selection of equipment, as in the case of stackers.

In today's transportation processes, forklifts are considered one of the most important means of handling equipment. They are very important in terms of internal transport, as well as efficiency. The goal and purpose of the paper Huskanović *et al.* [13] was to develop a model that would help in selecting the best solution. The CRITIC method was used to determine the weights of the criteria, while the MARCOS method was used for ranking; i.e., the selection of the most convenient forklift. The criteria were C_1-purchase price, C_2-load capacity, C_3-lifting height, C_4-lifting speed, C_5-lowering speed, C_6-driving speed, C_7-battery capacity, C_8-noise level, and C_9-supply of spare parts. By analyzing the data collected, using the MARCOS method, the most favorable alternative was forklift A_4, while the worst forklift was A_1.

The warehouse is a key infrastructure in the supply chain, so selecting a warehouse location becomes an important decision-making process. The topic of the paper Ocampo *et al.* [14] was the application of MCDM methods when solving the problem of selecting a location for the construction of a new warehouse. The TOPSIS method was applied to solve the problem of selecting a warehouse location in a group decision-making environment with a large number of criteria. The research was conducted at ABC-G Enterprises, which was believed to be the distributor of one of the largest breweries in the Philippines. Two warehouses were considered, one location (Talamban) is 10 km away from their current headquarters and had an area of approximately 380 m^2. The other alternative (Compostela) had an area of approximately 300 m^2 and was located at a distance of 9 km. In this paper, three scenarios were investigated, depending on the importance of the people who conducted the evaluation. The evaluation was carried out with the following criteria: unit price per square meter of land, transportation cost, logistics cost, proximity to the leading supplier, proximity to customers, availability of customers, availability of sufficient free space, accessibility to the road, accessibility to the seaport, accessibility to the airport, the existence of various modes of transportation, quality and reliability of modes of transportation, telecommunication systems, zoning and construction plan, industrial regulations and laws, security of the region, access to transportation infrastructure, political stability, social stability, economic stability, and impact on ecological landscape and condition of public facilities. A scale from one to 10, where the greatest weight was marked with 10, was used. The criteria that carried the most weight were unit price per square meter of land, proximity to the leading supplier, transportation cost, proximity to customers, access to transportation infrastructure, accessibility to the road, availability of sufficient free space, quality and reliability of modes of transportation, security of the region, and availability of customers and condition of public facilities. By applying the TOPSIS method, for group decision-making, the final result was that the most suitable location for the new warehouse was "Talamban".

Ashrafzadeh *et al.* [15] presented an MCDM approach for selecting a warehouse location by taking into account partial or incomplete information. The research was carried out in Iran, at the Entekhab company, while the locations were determined by five experts. The calculation was performed using the fuzzy TOPSIS method, and the calculation was divided into two parts. In the first part, the criteria that were important when selecting a warehouse location were determined; i.e., labor costs, transportation costs, handling costs, land cost, skilled labor, availability of labor force, land availability, climate, the existence of modes of transportation, telecommunication systems, quality and reliability of modes of transportation, quality and reliability of utilities, proximity to customers, proximity to suppliers or producers, as well as lead times and responsiveness. Further, the alternatives were as follows: A_1-Isfahan, A_2-Arak, A_3-Rasht, A_4-Urmia, and A_5-Tabriz. After the calculation, the recommended warehouse location was the alternative one (i.e., Isfahan), because it had the highest value of 0.5485.

In the field of modern logistics, automated storage is of great importance. The paper Zeng *et al.* [16] dealt with some of the principles related to the allocation of space in the warehouse, and different methods and models of storing goods. The paper studied and applied the TOPSIS method. The authors stated that they were trying to develop the following types and methods of storage: ST_1-storage mode of fixed goods space, ST_2-storage mode of random (not-fixed) goods space, ST_3-storage mode of classified fixed goods space, ST_4-storage mode of classified random (not-fixed) goods space, and ST_5-composite storage mode. Based on these five ways, it was necessary to consider comprehensively the principle of location layout for multiple pieces P = {P_1, P_2, P_3, P_4, P_5}. After the calculation, the results obtained showed that ST_4 was the closest to the ideal point. Therefore, it was concluded that the solution suitable for the warehouse management of the automated warehouse was the storage mode of classified random (not-fixed) goods space.

"Green logistics" aims to preserve the environment. The goal of logistics is to minimize costs and save time while increasing reliability and flexibility with green logistics. One of the main goals of the paper by Jakimovska and Vasileva [17] was to provide a new overview and new guidelines for logistics in warehouses by applying an MCDM method. In the paper, the TOPSIS method, as a potential tool for displaying and analyzing the problem, was used. The paper contained three alternatives: A_1-clean energy, A_2-smart technology, and A_3-self-produced energy, as well as four criteria: C_1-efficiency, C_2-

costs, C_3-payback time, and C_4-implementation difficulty level (easy, medium, and hard). The alternative with the highest value was ranked as the best, and in this case, it was A_2; i.e., smart technology.

There are various types of forklifts, the characteristics of which depend on the type of cargo, as well as the type and size of the warehouse for which they are intended. The purpose of the paper Atanasković *et al.* [18] was to select the best forklift that would meet the needs for carrying out operations in the warehouse. The Delphi method, which was based on data obtained through a survey and statistical data processing, was applied for calculation. A survey form was created and filled out by 20 experts. The following criteria were taken into account: C_1-purchase price, C_2-average maintenance costs, C_3-maximum bearing capacity, C_4-maximum load weight, C_5-fuel consumption, C_6-service network, C_7-manufacturer's warranty, C_8-movement speed (with and without load), C_9-speed of lifting/lowering load, and C_{10}-supply of spare parts. However, to reduce the dominance of certain criteria, the original number of 10 criteria was reduced to seven criteria. The ranking of alternatives was done using the VIKOR method, and the alternatives were represented by five forklift models of different manufacturers. The calculation indicated that the best choice was alternative A_2. The following conclusions were drawn: a) according to the min-max strategy, the best solution was alternative A_5; b) according to the compromise strategy, the best solution was alternative A_2; and c) according to the major benefit, the best solution was alternative A_2. The example used in this paper showed that the lowest market price of a forklift was not a key factor that should be considered when making decisions about purchasing it.

The "turret truck" or electric high-rack stacker is very useful for specific operations in the warehouse, because of its outstanding capabilities and principles, compared to other handling equipment. However, the cost of holding (i.e., the inactivity of these machines) can be extremely high. In the paper Zolfani *et al.* [19], a hybrid model consisting of FUCOM and WASPAS methods was applied, with the help of fuzzy Dombi aggregation operators. The criteria for this research were determined with the help and approval of experts and professionals, and they were the following 10 criteria: C_1-capacity, C_2-width, C_3-lift height, C_4-length, C_5-corridor width, C_6-turning diameter, C_7-vehicle engine power, C_8-lift engine power, C_9-speed, and C_{10}-acceleration. After that, eight alternatives were determined as A_1-Linde, A_2-Clark, A_3-Jungheinrich, A_4-BT, A_5-Crown, A_6-Rocla, A_7-Hyster, and A_8-Yal. Then, criteria weights were determined using the FUCOM method. After that, the decision-makers evaluated each alternative considering the criteria, using a linguistic scale, and the positive and negative distance measures were calculated.

For companies to survive in today's global business, they are suggested to examine the drivers of optimization of logistics systems. Selecting an optimal warehouse location becomes a problem due to the increased number of alternatives and conflicting criteria. Fuzzy MCDM methods were used in the research of Karmaker and Saha [20] to aid in location and distribution decisions. Five locations for a warehouse in Bangladesh were compared. The fuzzy AHP method was used to determine the weights of the criteria, and the TOPSIS and fuzzy TOPSIS methods were used to rank the locations. The paper consisted of five criteria and each of them had sub-criteria. They were: C_1-responsiveness (C_{11}-lead time and responsiveness and C_{12}-providing relevant information), C_2-transportation condition (C_{21}-quality of transportation, C_{22}-existence modes of transportation, and C_{23}-telecommunication), C_3-cost-related factors (C_{31}-land cost, C_{32}-handling cost, C_{33}-labor cost, and C_{34}-transportation cost), C_4-location properties (C_{41}-climate, C_{42}-land availability, C_{43}-quality and reliability of utilities, C_{44}-proximity to producers, and C_{45}-proximity to customers), and C_5-favorable labor climate (C_{51}-skilled labor and C_{52}-availability of labor force). The weights of both criteria and their sub-criteria were determined. For the calculation of the fuzzy TOPSIS method, fuzzy linguistic variables were transformed into fuzzy numbers, while for the TOPSIS method, a decision matrix made of numerical values was created. The ranking was based on both techniques, where location A_1, with a value of 0.6615, was ranked first with the TOPSIS method, and alternative A_2, with a value of 0.2439, was ranked first with the fuzzy TOPSIS technique. The combination of techniques was found very suitable and favorable for group decision-making since it was difficult to reach a common opinion.

4. Conclusions

The purpose of this review paper was to present how and in which areas MCDM methods were used, but with a focus on the warehouse area. Twenty scientific papers, related to the period from 2010 to 2023, were collected. Throughout the period, researchers have published their papers in numerous journals, which contributed significantly to the development of MCDM methods and techniques. To explain better this review paper, it was graphically shown how many papers on the specific topic were published each year, as well as which journals were useful for finding papers and publications on the topic. All the methods used by other authors to solve their problems during the research of a certain area were also shown graphically.

The largest number of papers considered the application of MCDM methods in determining a warehouse location, which turned out to be a good solution to the problem. Then, the authors paid great attention to MCDM methods when they had a problem with the selection of warehouse equipment, for example, when selecting forklifts, stackers, electric high-rack stackers, and the like. Several papers addressed the topic of warehouse performance, where it could be concluded that research showed that these methods provided useful tools and guidelines for analyzing, evaluating, and improving performance in a warehouse environment. MCDM methods are also useful in "green" logistics and inventory management.

The application of MCDM methods in the warehouse has a significant impact on the efficiency, productivity, and optimization of operations [21]. These methods provide a structured approach to decision-making in complex storage scenarios, where multiple criteria or factors need to be considered when ranking alternatives. The importance of applying MCDM methods in the warehouse is manifold. First, it enables decision-makers to understand the complexity and interrelationships among different criteria and alternatives and thus better understand their decisions. Second, the application of MCDM methods allows decision-makers to quantify and objectively evaluate various aspects of the warehouse. This helps eliminate subjectivity and make consistent decisions based on relevant data. Third, these methods provide a framework for continuous monitoring and improvement of warehouse performance. Through the use of quantitative data and analysis, weaknesses and areas for improvement can be identified and measures can be implemented to optimize warehouse operations.

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Conflicts of Interest

The author declares no conflicts of interest.

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