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Research Article

A Novel Hybrid Model for the Evaluation of Industry 4.0 Technologies' Applicability in Logistics Centers

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The application of Industry 4.0 (I4.0) in the field of logistics leads to the emergence and development of the concept of logistics 4.0. Many I4.0 technologies have been applied in the field of logistics. The goal of this research is to analyze the applicability of nine key I4.0 technologies in logistics centers (LC). For this purpose, an integrated MEREC (MEthod based on the Removal Effects of Criteria)—fuzzy MARCOS (Measurement of Alternatives and Ranking according to COmpromise Solution) model was developed. The applicability of nine I4.0 technologies was evaluated based on 15 subcriteria within three main groups of criteria, namely, technological, social and political, and economic and operative. Using the MEREC method, the weight values of the criteria and subcriteria were determined, while the technologies were ranked using the fuzzy MARCOS method. Based on the results obtained by applying this integrated MCDM (multicriteria decision-making) model, CC was identified as the best alternative, i.e., the technology that is most applicable in logistics centers, followed by IoT and big data. An analysis of the sensitivity of the obtained results to the change in the importance of the criteria was carried out, which shows certain changes in the ranking when the importance of the most important criterion changes.

1. Introduction

The interest in logistics is growing every day, i.e., the great importance and impact of logistics on the countries' economies are attracting growing attention. The efficiency of logistics systems significantly affects the success of trade [1]. In addition, logistics contributes to the "attraction" of direct foreign investments [2], has a positive impact on the growth of the gross domestic product [3], and ultimately contributes to sustainable economic growth [4]. Logistics centers (LCs) are home to many and diverse processes and activities, such as storage, transportation of goods, handling, reassembly, clearing, dismantling, quality control, and social services [5]. LCs are of great importance in optimization of logistics chains because they determine the quality of stock distribution and the efficiency of order fulfillment. Realization of logistics activities through the LC enables better cooperation and better access to high value-added services [6]. Creating value in logistics services to meet customer expectations is becoming more important than ever to maintain competitiveness in the market. The ultimate goal is to provide logistics services that will maximally satisfy the demands and needs of clients. It sounds simple, but with increasingly complex and longer supply chains, the task of satisfying the increasing demands of customers with minimal costs becomes very complex and complicated. Consequently, it is necessary to follow key trends, introduce various innovations, and apply the latest modern technologies in all logistics processes and systems. Industry 4.0 (I4.0) enables a new and more efficient way of realizing activities within the supply chain through the connection of different parts and processes of the supply chain and the implementation of new modern technologies [7]. In the last few years, in many areas including logistics, I4.0 technologies such as Internet of Things (IoT), autonomous vehicles (AVs) and automated guided vehicles (AGVs), artificial intelligence (AI), virtual reality (VR) and augmented reality (AR), big data, blockchain, electronic and mobile marketplace, cloud computing (CC), and 3D printing are increasingly used. The previously mentioned technologies are being applied more and more every day in the field of logistics, which leads to the development of the concept of Logistics 4.0. The application of the previously mentioned technologies in the field of logistics provides logistics service providers with many advantages such as significantly lower costs, significant increase in efficiency, better delivery service (delivery on time and quality of delivery), reduced workload of employees, reduced susceptibility to errors, reliable forecasts, more precise planning of demand and deployment of all resources, very high flexibility, reduction of negative impact on the environment, and increased transparency along the entire logistics chain. Therefore, logistics 4.0 actively uses modern technology to strengthen organizational agility, logistics capabilities, and competitiveness [8].

I4.0 technologies experienced a skyrocketing demand after the outbreak of the 2020 pandemic. COVID-19 has made reliable delivery more important than ever before and logistics management a little more complicated. But with the help of automation, it is possible to perform complex logistics operations that end with reliable order fulfillment and satisfied customers. Today, the IoT and advanced ERP (enterprise resource planning) software simplify challenging logistics operations with real-time data and information flow. Using new technologies, many companies are developing cyber-physical systems that can change the competitive environment [9]. For the efficient development of logistics processes and activities, i.e. for the achievement of efficient supply chains, logistics networks play a key role. These networks consist of nodes, that is, LCs of different categories and sizes and connections between them, which are realized by different modes and technologies of transport. Modern LCs increasingly apply various I4.0 technologies to increase the productivity and economy of their operations [10].

1.1. Motivation and Contribution of the Study. According to Moslem et al. [11], the COVID-19 pandemic has adversely affected the transport sector, which has experienced a drastic reduction in passenger traffic across all modes of transport. Also, according to Mićić and Mastilo [12], there is almost no business operation that has not been affected by the pandemic. Freight transport has no such problems. Consequently, the subject and goal of this paper is the analysis of the applicability of key I4.0 technologies in LCs. For this purpose, a new hybrid MCDM model was developed that combines the MEREC and fuzzy MARCOS methods. Given that there is no study in the literature that integrates these two methods, this example presents the main contribution of the work from the methodological aspect. The applicability of this model was verified through an example of assessing the applicability of I4.0 technologies in LCs. Given that a multicriteria model was considered on the example of nine alternatives and 15 subcriteria distributed in an even hierarchical structure, it is possible to conclude that the developed hybrid model provides certain advantages manifested in the remainder of the paper.

The research results indicate that the most applicable I4.0 technologies in LCs are CC, IoT, and big data. In the end, we can conclude that logistics is profitable for all parties and participants. Nevertheless, the concept of I4.0 is still poorly researched in the field of logistics, and there are many areas, systems, and processes of logistics in which it can find application. LCs are systems where the possibilities of applying I4.0 technologies have not been sufficiently explored so far. This study tries to fill those research gaps.

In addition to the introductory considerations given in the first section, the paper is structured through five more sections. The second section defines the concept of I4.0 in more detail and lists and describes the key technologies and their areas of application. The overview of the concept of logistics 4.0, LCs, as well as the methods that make up the hybrid model, are also presented within this section. The third section presents the research methodology based on the MEREC and fuzzy MARCOS methods. The application procedure and basic characteristics of the mentioned methods are explained in detail. In the fourth section, the term LCs 4.0 is defined and the business segments where I4.0 technologies can be applied are identified. In the fifth section, the applicability of key I4.0 technologies in LCs was evaluated using the proposed MCDM model. In addition, a sensitivity analysis of the obtained results was performed. Concluding considerations are given at the end of the paper.

2. Related Works

In this section, the concept of I4.0 is presented and its impact on the entire economy and society is analyzed. In addition, the key I4.0 technologies are presented and analyzed, in order to highlight all the possibilities and effects of the application of these technologies in various fields. I4.0 technologies are widely accepted in many areas which indicate great adaptability of technologies to different and specific needs. In addition, the concept of logistics 4.0 is defined, and the possibilities of applying modern I4.0 technologies in the field of logistics are described. In addition, this part of the paper provides a brief overview of the literature on analyzed problems related to LCs. Afterwards, an overview of the application of the MEREC and fuzzy MARCOS methods for solving various problems concerning LCs, as well as in other areas, was given. Based on the review and analysis of I4.0 and LC, technologies which will be further considered and analyzed in terms of their applicability were singled out.

2.1. I4.0 Concept. I4.0 is a digital revolution that completely changes the way people live and also provides great opportunities in terms of sustainability [13]. The concept of Industry 4.0 refers to a large number of technologies and solutions that enable vertical and horizontal integration of processes and activities, which leads to better performance of companies [14]. Industry 4.0 leads to a significant change in productivity, quality improvement, delivery time, market costs, increased employment, and economic growth [15]. I4.0 provides information and data in real time, which enables more efficient organization and better dynamic control [16]. Using I4.0 technologies, enterprises can increase their organizational agility, flexibility, and resilience to deal with unforeseen circumstances and high competition in the market [17].

The I4.0 technologies are of particular importance for the small and medium-sized enterprises, which play a key role in driving the economy of a country, since they have great potential for improving the efficiency of the supply chain in the industry in which these enterprises operate [18]. Therefore, the implementation of I4.0 technologies has a positive effect on organizational resilience and perceived performance [19], which helps company managers and decision makers to increase organizational resilience, flexibility, efficiency, and competitiveness on the market [20]. I4.0, in addition to affecting economic progress, also has a very large impact on social progress [21]. The development of I4.0 is accompanied by the development of various intelligent and information technologies. In addition to the fact that such technologies increase productivity, they also contribute to a large extent to social and environmental sustainability [22]. In addition, technological innovation has a positive impact on energy efficiency [23], sustainable development of circular economy [24], and reducing the negative impact of business operations on the environment [25]. In addition to the fact that Industry 4.0 brings great technical, organizational, and economic advantages, it is important to note that many experts believe that I4.0 will also bring a large number of disadvantages or threats such as increased unemployment, social stratification, cyber security threats, and privacy violations [26]. Challenges and factors that may occur in I4.0 and thus hinder the spread of its achievements are related to security problems of information technologies, lack of unified leadership that makes integration and coordination between units difficult, inability to react to unforeseen obstacles to information technology implementation that can cause expensive production and downtime, the need to protect industrial knowledge, lack of knowledge about I4.0, suppliers and IT outsourcing partners, lack of the appropriate expertise that would speed up progress towards the full implementation of I4.0 technologies, the fact that companies have a hard time accepting major changes, i.e. lack of courage to initiate a digitization plan, job losses caused by the IT-driven automated processes, etc. [27]. Despite this, I4.0 technologies find wide application in many areas because they enable the compatibility and integration of different processes in the organization due to the attributes of real-time interconnection.

2.2. I4.0 Technologies. The following technologies have the large influence on the development of the Logistics 4.0 concept: cyber physical systems (CPS), *T*, big data, cloud computing, blockchain, E-marketplace, artificial intelligence, 3D printing, autonomous and automatically driven vehicles, and advanced robotics.

Cyber physical systems (CPSs) enable the efficient connection of physical reality, computers, and communication infrastructure into one system [28]. Data exchange is the most important feature of the CPS that allows it to send and receive data over the network. The internet-connected CPS is often referred to as the "Internet of Things" [29].

Internet of Things (IoT) represents a network of physical objects which are linked by sensors, software, and other technologies in order to connect and exchange data with other devices and systems via the internet or other communication networks [30]. The application of IoT in business provides many benefits such as the following: effective management of work, increased productivity and business efficiency, creation of new business models and revenue streams, increased safety at work, improved staff productivity and reduction of human labor easily and seamlessly, and connection of the physical business world with the digital world to achieve the set values and goals faster. IoT is applied in many areas such as manufacturing [31], logistics and supply chains [32, 33], automotive industry [34], trade [35], construction industry [36], health care [37], and "smart houses" [38]. Technologies that are often implemented in the IoT domain are machine-to-machine (M2M) communication and radio frequency identification (RFID) [39]. RFID is a technology that uses a reader to communicate through radio frequency (RF) signals and tags for unique identification. RFID technologies are widely adopted in retail, agriculture, transportation, logistics, and healthcare [40].

Big data technology is a software utility created with the goal of more efficient analysis and processing of information from extremely complex and large data sets. The data obtained in this way greatly facilitate decision-making in companies. Big data technologies are necessary in order to be able to analyze huge amounts of data in real time and reach conclusions and predictions in order to reduce risks in future business [41].

Cloud computing is the delivery of different services via the internet. CC is a popular option for people and companies for many reasons [42]. CC in I4.0 can provide computing power needed to apply machine learning and AI approaches, but also other smart technologies.

Blockchain is a distributed database that is shared among the nodes of a computer network. The innovation of blockchain is that it provides fidelity and security of data records and creates trust without the need for a trusted third party [43, 44].

E-marketplace enables the exchange of products and/or services via digital networks which mean integration of innovative information and communication with the aim of harmonizing supply and demand, i.e., connecting the seller and the buyer. [45]. *M*-marketplace is nothing but a subset of e-commerce and includes mobile commerce. In short, *M*-marketplace means providing an optimal e-commerce experience for mobile users [46].

Artificial intelligence is the simulation of human intelligence processes by computer systems. AI implies the ability of computers to execute tasks usually performed by intelligent beings, primarily observations, inferences, problem solving, learning, and communication [47].

3D printing is a manufacturing process that is widely used to describe additive manufacturing [48].

Automated guided vehicles are driverless vehicles that move with an automatic control system [49]. AGV vehicles are primarily used in industrial transport, i.e., internal transport, while their wider application in external transport is still under development. It is very important to distinguish between automatically driven vehicles and autonomous vehicles.

Advanced robotics: some of the advantages of advanced robotics are faster performance of work tasks, greater safety and security during work, as well as precision, increased productivity, and higher quality [50].

I4.0 technologies are widely accepted in many areas such as agriculture [51], medicine [52], logistics/supply chains [53, 54], smart homes/cities [55], trade [56], public sector [57], education [58], tourism [59], retail [60], and civil engineering [61].

2.3. Concept of Logistics 4.0. Through the 4th industrial revolution, technological solutions and tools have become available today and enabled the progress of logistics systems in which the whole supply chain can be managed automatically [62]. Logistics 4.0 implies the active use of modern logistics technologies, i.e., I4.0 technologies with the aim of increasing the efficiency and effectiveness of logistics systems and achieving the best results with minimal costs [8]. Logistics 4.0 or as many call it "smart logistics" is a system that affects the increase in the flexibility of the supply chain and the level of satisfaction of customer requirements.

I4.0 technologies that have found the widest application in logistics are autonomous vehicles, tracking and decision-making systems capable of maintaining inventory control, cloud-supported networks to improve information flow, real-time vehicle big data analytics, various IoT technologies for vehicle location and optimal routing, and autonomous collaborative robots which, in cooperation with humans, efficiently perform various tasks such as picking, palletizing, and AGV [63–65]. It is important to note that only through the successful implementation of Logistics 4.0 can companies create the necessary foundations for overcoming the future challenges of Industry 4.0.

Thanks to these types of innovations, a total savings of 34.2% in costs and additional revenues of 33.4% based on logistics activities are expected [66]. Customers and employees also benefit from networked and automated processes. It is worth noting the following advantages: significantly lower costs, significant gain in efficiency, better delivery service (on-time delivery and quality of delivery), reduced workload of employees, reduced susceptibility to errors, reliable forecasts, more accurate demand and scheduling planning, very high flexibility, reduction of over- and under-delivery, less negative impact on the environment, and transparency along the entire logistics chain. On the other hand, there is a lack of digital competence on the part of companies or individuals, as well as nonacceptance of new technologies or fundamentally changed processes—obstacles that can be overcome with training, best practices, and strict adherence to compliance rules.

2.4. Logistics Centers. Logistics transformation has led to the creation of large logistics operation centers near major cities. These areas, also known as logistics zones and hubs, cargo areas, and industrial parks, are specifically designed to concentrate logistics and transport activities [67]. Rimiene and Grundey [68] distinguish the following six types of LCs in relation to the functions and scope of activities in freight transport and logistics: logistics hub, freight settlement, logistics center, transport terminal, distribution center, and warehouse. According to the primary mode of transport, Leitner and Harrison [69] list the following types of LCs: inland waterway ports, air cargo ports, maritime feeder inland ports, trade and transportation centers, and inland ports. Based on the above, we can conclude that depending on the characteristics and characteristics that the authors observe during the analysis, there are numerous different ways of categorizing LCs in the literature. LCs are the subject of numerous researches and studies with the aim of optimizing various business segments, as well as solving numerous problems that arise in the LC due to the complexity of the processes, activities, and flows that it encompasses. Therefore, numerous problems related to LCs are solved in the literature, such as choosing the optimal location [70, 71], optimization of warehouse operations [72], application of digital technologies and analysis of their business opportunities [73], prioritization of development characteristics when planning and designing an LC [74], selection of efficient types of LCs [75], analysis and selection of quality function deployment tools through the development projects [76], analysis of the potential of mass LCs [77], identification of typical LC structures [78], analysis of the effects of LCs on the volume of trade [79], and analysis of the factors of efficient logistics of high-risk cargo in ports [80]. It is evident that there are many problems that are solved in the area of LC operations, and the vast majority of these problems are solved by applying various MCDM methods. However, the possibilities of applying the key I4.0 technologies in LCs have been poorly explored. In addition, it is necessary to point out the fact that effective models for assessing and evaluating the applicability of the I4.0 technologies in the LC have not yet been developed. This paper attempts to fill those gaps by developing a new integrated MCDM model.

2.5. Applications of the MCDM Methods in Logistics and Transport. As stated above, the new integrated MEREC-fuzzy MARCOS model for evaluating the applicability of I4.0 technologies in LCs is developed in this paper. The MEREC is an objective method for determining weighted criteria values developed by Keshavarz-Ghorabaee et al. [81]. The

MEREC is a newer method that gives more reliable and stable results compared to other methods. Although it is a relatively new method, in combination with other MCDM methods, the MEREC found its application when solving problems such as assessment and selection of the distribution center location [82], selection of pallet forklifts [83], development of a model for increasing the resistance of transport systems [84], and selection of food waste treatment technology [85].

The fuzzy MARCOS was developed by Stanković et al. [86] based on its crisp version [87, 88]. The advantage of fuzzy MARCOS compared to other methods is that it shows more significant and greater stability and reliability of results. Bakır and Atalık [89] apply fuzzy MARCOS to evaluate the quality of e-services in the airline industry and Büyüközkan et al. [90] to analyze the digital transformation strategy in the airline industry. Puška et al. [91] use this method when selecting sustainable suppliers. Tadić et al., [92] evaluate intermodal transport scenarios using fuzzy, and Kovač et al. [93] use it to evaluate concepts of urban logistics based on drones. Apart from the field of logistics, this method has also found application when solving problems in other fields, e.g., to determine the performance of insurance companies in the COVID-19 pandemic in terms of health services [94] and to determine the competitiveness of spa centers [95].

Some other researchers applied different MCDM methods to evaluate the transport sector. The two-stage model including picture fuzzy AHP and linear assignment has been applied for the assessment of public transport in Budapest. Kutlu Gündoğdu et al. [96] have concluded that, changing timetable is the best solution using the mentioned hybrid MCDM model. A similar study in Budapest has been performed in [97], where a combination of AHP and MOORA methods was used. In the paper [98], the first real-data application of Pareto-efficiency testing on a public transport development decision problem is introduced. For this purpose, the AHP method has been used.

3. Methodology

The detailed methodology developed within this paper is shown in Figure 1. It consists of four main steps. All steps and activities within them are defined and described in more detail in the following.

The first step contains the following: forming the list of alternatives and criteria, selecting scales for their evaluation, and selection of the methods for evaluating the criteria weights and for ranking the alternatives. The applicability of the next 9 I4.0 solutions in LCs was analyzed: (IoT)-A1, (AGV)-A2, autonomous vehicles (AV)-A3, (AI)-A4, big data (BD)-A5, blockchain (BC)-A6, (CC)-A7, (E/M marketplace)-A8, and advanced robotics-A9. Based on a review of previous research and studies in this area [99–101], 15 subcriteria were defined, which were grouped into three main categories. Table 1 presents the criteria that were used to evaluate the technologies in this paper.

3.1. MEREC Method. The next steps are used to calculate objective weights by the MEREC [81, 82, 102]. The method description partly reproduces the wording of the previously mentioned authors.

Step 1: construct the decision matrix. The elements of this matrix are denoted by x_{ij}, and there are n alternatives and m criteria:

$$X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1j} & \cdots & x_{1m} \\ x_{21} & x_{22} & \cdots & x_{2j} & \cdots & x_{2m} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{i1} & x_{i2} & \cdots & x_{ij} & \cdots & x_{im} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{nj} & \cdots & x_{nm} \end{bmatrix}. \tag{1}$$

Step 2: normalize the decision matrix (N).

$$n_{ij}^{x} = \begin{cases} \dfrac{\min_k x_{kj}}{x_{ij}}, & \text{if} \quad j \epsilon B, \\ \\ \dfrac{x_{ij}}{\max_k x_{kj}}, & \text{if} \quad j \epsilon C. \end{cases} \tag{2}$$

Step 3: computation of the overall performance of the alternatives ($\mathbf{S_i}$).

$$S_i = \ln\left(1 + \left(\frac{1}{m}\sum_j \left|\ln\left(n_{ij}^{x}\right)\right|\right)\right). \tag{3}$$

Step 4: calculate the performance of the alternatives by removing each criterion. Let us denote by S_{ij}' the overall performance of the ith alternative concerning the removal of the jth criterion:

$$S_{ij}' = \ln\left(1 + \left(\frac{1}{m}\sum_{k,k\neq j} \left|\ln\left(n_{ik}^{x}\right)\right|\right)\right). \tag{4}$$

Step 5: calculation summation of absolute deviations:

$$E_j = \sum_i \left|S_{ij}' - S_i\right|. \tag{5}$$

Step 6: determine the final weights of the criteria:

$$w_j = \frac{E_j}{\sum_k E_k}. \tag{6}$$

3.2. Fuzzy MARCOS Method. The fuzzy MARCOS method consists of the next procedure [86, 103]. The method description partly reproduces the wording of the previously mentioned authors.

Step 1: forming an initial fuzzy decision-making matrix.

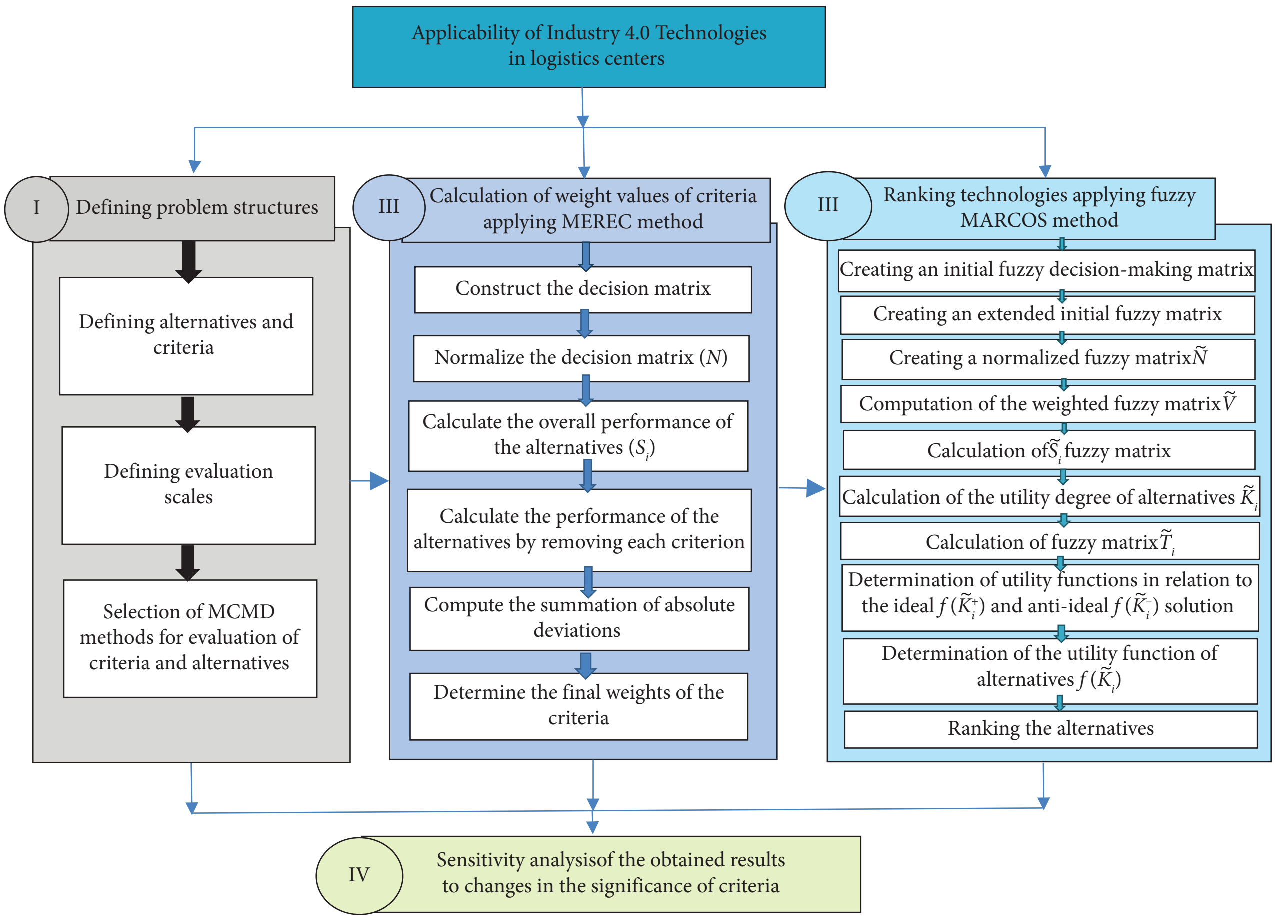

Figure 1: Applied methodology.

Step 2: forming an extended initial fuzzy matrix by creating the fuzzy anti-ideal $\tilde{A}(AI)$ and fuzzy ideal $\tilde{A}(ID)$ solution.

$$\tilde{A}(\mathrm{AI}) = \min_i \bar{x}_{ij} \text{ if } j \in B \text{ and } \quad \max_i \bar{x}_{ij} \text{ if } j \in C, \tag{7}$$

$$\tilde{A}(\mathrm{ID}) = \max_i \bar{x}_{ij} \text{ if } j \in B \text{ and } \quad \min_i \bar{x}_{ij} \text{ if } j \in C. \tag{8}$$

Step 3: forming the normalized fuzzy matrix.

$$\tilde{n}_{ij} = \left(n_{ij}^l, n_{ij}^m, n_{ij}^u\right) = \left(\frac{x_{id}^l}{x_{ij}^u}, \frac{x_{id}^l}{x_{ij}^m}, \frac{x_{id}^l}{x_{ij}^l}\right) \text{ if } j \in C, \tag{9}$$

$$\tilde{n}_{ij} = \left(n_{ij}^l, n_{ij}^m, n_{ij}^u\right) = \left(\frac{x_{id}^l}{x_{id}^u}, \frac{x_{ij}^m}{x_{id}^u}, \frac{x_{ij}^u}{x_{id}^u}\right) \text{ if } j \in B. \tag{10}$$

Step 4: computation of the weighted fuzzy matrix.

$$\bar{v}_{ij} = \left(v_{ij}^l, v_{ij}^m, v_{ij}^u\right) = \tilde{n}_{ij} \otimes \tilde{w}_j = \left(n_{ij}^l \times w_j^l, n_{ij}^m \times w_j^m, n_{ij}^u \times w_j^u\right). \tag{11}$$

Step 5: calculation of the $\tilde{S}_i$ fuzzy matrix.

$$\tilde{S}_i = \sum_{i=1}^{n} \bar{v}_{ij}. \tag{12}$$

Step 6: calculation of the utility degree of alternatives $\tilde{K}_i$.

$$\tilde{K}_i^- = \frac{\tilde{S}_i}{\tilde{S}_{ai}} = \left(\frac{s_i^l}{s_{ai}^u}, \frac{s_i^m}{s_{ai}^m}, \frac{s_i^u}{s_{ai}^l}\right), \tag{13}$$

$$\tilde{K}_i^+ = \frac{\tilde{S}_i}{\tilde{S}_{\mathrm{id}}} = \left(\frac{s_i^l}{s_{\mathrm{id}}^u}, \frac{s_i^m}{s_{\mathrm{id}}^m}, \frac{s_i^u}{s_{\mathrm{id}}^l}\right). \tag{14}$$

Step 7: calculation of the fuzzy matrix $\tilde{T}_i$.

$$\begin{aligned} \tilde{T}_i = \bar{t}_i = \left(t_i^l, t_i^m, t_i^u\right) &= \tilde{K}_i^- \otimes \tilde{K}_i^+ \\ &= k_i^{-l} + k_i^{+l}, k_i^{-m} + k_i^{+m}, k_i^{-u} + k_i^{+u}. \end{aligned} \tag{15}$$

Then, it is must to determine a new fuzzy number $\tilde{D}$ as follows:

$$\tilde{D} = \left(d^l, d^m, d^u\right) = \max_i \bar{t}_{ij}. \tag{16}$$

And then, it is necessary to defuzzify the number $\tilde{D}$ as follows:

$$df_{\text{crisp}} = \frac{l + 4m + u}{6}. \tag{17}$$

Table 1: Description of criteria for evaluation of technologies.

Criterion		Description of criteria	Benefit/cost criterion
Technological criteria			
C_1	Level of development	It refers to the level to which the technology is developed	Benefit criterion
C_2	Possibility of integration	It implies the compatibility with other applied technologies, concepts, and organizations	Benefit criterion
C_3	Complexity of implementation	It refers to the amount of effort required to implement the technology	Cost criterion
C_4	Standardization	It refers to the possibilities of standardizing certain technological aspects	Benefit criterion
C_5	Adaptability	It implies the possibility of modifying and/or improving the technology in order to adapt to changes in the environment	Benefit criterion
Socio-political criteria			
C_6	Safety	It refers to the degree to which technology positively affects the well-being of those involved in the processes	Benefit criterion
C_7	Labor market impact	It refers to the effect that technology has on creating new jobs and increasing employment	Benefit criterion
C_8	Environmental impact	It refers to the effects of technology on the environment in terms of noise, vibration, particulate emissions, waste generation, and the like	Cost criterion
C_9	Cultural framework	It refers to tradition, value system, way of life, business, and care for the environment	Benefit criterion
C_{10}	Political framework	It refers to the actions taken by administrations at different levels in order to promote or degrade certain technologies	Benefit criterion
Economic-operational criteria			
C_{11}	Implementation costs	They include the costs of equipment, software, technology development, and implementation	Cost criterion
C_{12}	Energy consumption efficiency	It refers to the protection of limited energy resources, i.e. the use of alternative and renewable energy sources	Benefit criterion
C_{13}	Security	It refers to the vulnerability of technology in terms of theft, manipulation, or deletion of data required for the operation of technology	Benefit criterion
C_{14}	Organizational readiness	It determines the number of changes within the organization that are needed to reach the full potential of the technology	Cost criterion
C_{15}	Logistics service quality	It refers to the impact of technology on the reliability, flexibility, availability, accuracy, visibility, and traceability of flows in the LC	Benefit criterion

Step 8: determination of utility functions in relation to the ideal $f(\widetilde{K}_i^+)$ and anti-ideal $f(\widetilde{K}_i^-)$ solution.

$$f\left(\widetilde{K}_i^+\right) = \frac{\widetilde{K}_i^-}{df_{\text{crisp}}} = \left(\frac{k_i^{-l}}{df_{\text{crisp}}}, \frac{k_i^{-m}}{df_{\text{crisp}}}, \frac{k_i^{-u}}{df_{\text{crisp}}}\right), \tag{18}$$

$$f\left(\widetilde{K}_i^-\right) = \frac{\widetilde{K}_i^+}{df_{\text{crisp}}} = \left(\frac{k_i^{+l}}{df_{\text{crisp}}}, \frac{k_i^{+m}}{df_{\text{crisp}}}, \frac{k_i^{+u}}{df_{\text{crisp}}}\right). \tag{19}$$

After that, defuzzification for $\widetilde{K}_i^-$, $\widetilde{K}_i^+$, $f(\widetilde{K}_i^+)$, and $f(\widetilde{K}_i^-)$ and apply the following step:

Step 9: determination of the utility function of alternatives $f(K_i)$.

$$f(K_i) = \frac{K_i^+ + K_i^-}{1 - f(K_i^+)/f(K_i^+) + 1 - f(K_i^-)/f(K_i^-)}. \tag{20}$$

Step 10: ranking the alternatives.

4. Results

4.1. Logistics Center 4.0. Logistics centers as links in the logistics chain represent a link in connecting all participants, thus creating a unique transport system with the possibility of fitting into a single transport market [75, 104]. Logistics centers not only connect certain entities (demanders, providers, and organizers of transport services) into a single transport chain but also solve multiple tasks that rationalize processes and operations. The operation of LCs goes beyond the storage of goods because they directly participate in the following processes of the supply chain: receiving goods (these facilities receive huge quantities of goods from a large number of production centers and suppliers every day, during which the proper organization of the loading area has a great impact on the efficiency of the center's operations), storage (the storage phase should ideally be very short, and the goods should be shipped as soon as possible), internal transport, inventory management (maintaining a minimum stock of high-traffic items is very important), shipping, and distribution of goods (goods are further distributed by different means of transport to the users [105]).

All processes and activities performed within the logistics center, within which the application of I4.0 technologies is possible, can be observed through the following four subsystems, i.e. business segments: cargo handling management, information management, storage management, and transport management [106]. Handling management includes all cargo movement flows within the LC, cargo storage, and control, while information management ensures the interaction and exchange of information among order processing, inventory control, cargo units, warehouse operations, and accounting. Warehouse management includes goods receipt, storage, order-picking, and dispatch of goods [107]. Transport management includes all activities of planning and control of transport activities such as routing of transport means, consolidation, scheduling and revision of cargo, as well as information exchange with LC management systems [108]. Therefore, by applying numerous I4.0 technologies in the previously defined business segments of the LC, the new concept of the logistics center 4.0 is emerging and being developed (Figure 2).

The implementation of these technologies is spreading increasingly in LCs by areas of activity. IoT enables vehicle-to-vehicle communication, which facilitates various processes such as location determination, toll collection, avoiding traffic jams, and finding the optimal route [109]. The introduction of new software and IoT technologies has made it possible to increase the cooperation and exchange of information between suppliers, carriers, and customers because all information about stocks, i.e. the quantity, location, and condition of goods, is available in real time. These innovations have made it possible to achieve levels of efficiency that were previously unattainable. IoT in combination with RFID sensors enables the digitization of the entire storage and transport system. RFID sensors can identify each individual item in the warehouse and all storage and transportation equipment and assets and regulate the entrances, exits, and passage of operators and conveyors in different areas of the LC. In this way, every operator can have an insight into the stock situation in real time [110]. Collection and accumulation of raw data through various devices such as RFID readers are made on a large scale. However, that information gains importance only when important data are processed, analyzed, and extracted. Then, it is necessary to apply technology such as big data, which will realize all this in a fast and efficient way.

Big data is used for predictive analysis of transport where it helps management to predict and estimate cargo volume by days, weeks, or months. It then enables the various types of data necessary for better decision-making. In addition, big data technology allows insight into routes and can be used as a tool to predict the time required for each load and therefore plan further operations accordingly. Big data can also be used to analyze information coming from customers in the entire market, which would allow the LC to continuously develop its service in order to satisfy the customers, thus increasing customer loyalty [111]. Big data analysis can improve the transparency and quality of LC service management [112].

In order to establish a good information platform of the LC, the integration of big data and cloud computing technologies is necessary. In this way, the LC can have full control over the life cycle of data through the analysis and integration of data extracted from big data systems. Furthermore, a complete logistics information platform can collect data and information that will influence the supplier and the customer to improve mutual understanding. The supplier and the customer can get a better logistics service through the exchange of information, agreement, and integration of the logistics solution plan using this platform. By tracking shipments and collecting data on new traffic conditions, the application of modern technologies enables more efficient routing and utilization of the capacity of transport means.

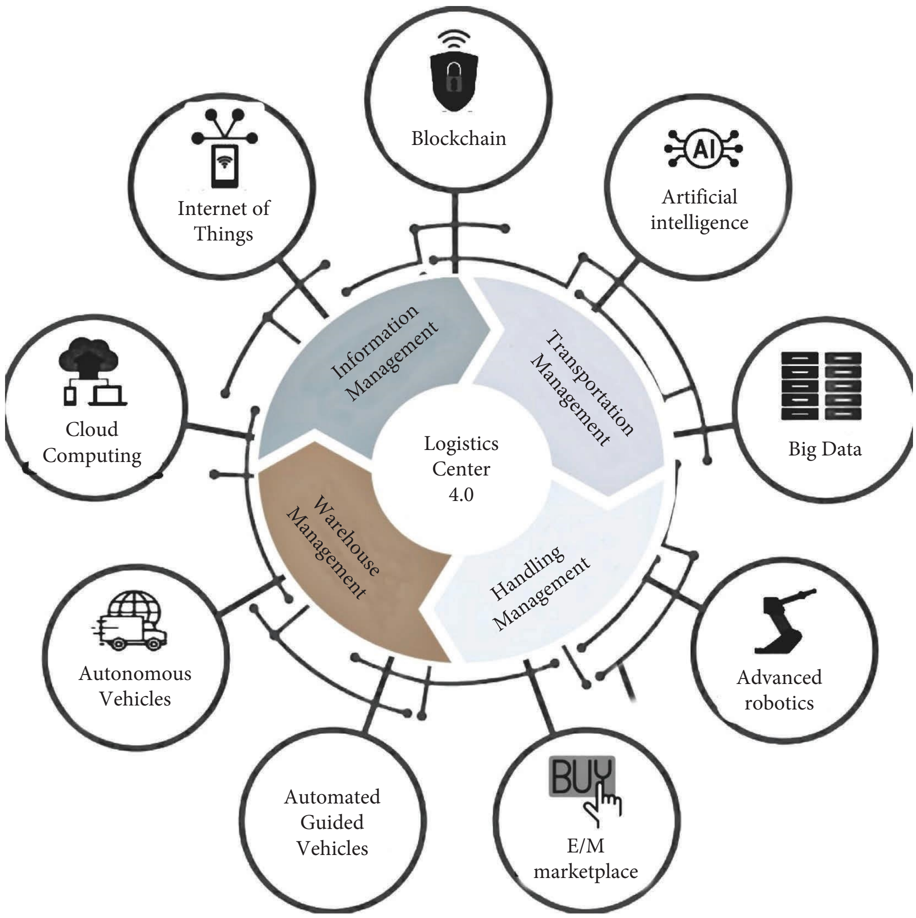

Figure 2: The logistics center 4.0.

CC solutions allow all authorized persons' access regardless of time and location with a high level of data security, which enables the connection of all decentralized LC facilities into one efficient system [113]. These software solutions aim to optimize various logistics activities, so for example TMS generally enables planning, control, monitoring, and optimization of transport networks and logistics chains, while WMS enables simpler monitoring and control of all activities and flows in the warehouse [107].

The possibilities of blockchain technologies in the LC are many. The development of big data technology has influenced the development of blockchain technology. The advantage of blockchain technology is that it enables more secure monitoring of all types of transactions, thus reducing the possibility of various errors that can lead to drastic costs and delays in the implementation of important processes [114].

The task of artificial intelligence is to connect numerous data generated in logistics processes, analyze them, and recognize inherent patterns. For example, the average travel time depends on the time of day, whether the total available capacity of storage space corresponds to the actual demand, and whether the locations are evenly used. By evaluating the enormous amount of data, the intelligent system can predict future developments with extreme reliability and adjust logistics processes accordingly. By applying AI, it is possible to achieve an enviable degree of automation of warehouse activities, and in this way, we can achieve better performance and greater efficiency when receiving and shipping goods, keeping records of goods, handling goods, etc. [115]. In addition, AI technologies eliminate the need for intensive training of workers and help overcome language barriers in all business segments of the LC.

By applying intelligent robots in internal transport and storage, significant improvements are achieved. Therefore, advanced robotics has so far been mainly used for collecting, ordering, and sorting goods. Certain studies show that robots are three times more efficient when picking small goods in a warehouse compared to humans [116].

Automated guided vehicles can reduce labor costs, speed up and facilitate processes in given subsystems, and increase safety, accuracy, and productivity. However, the technology of autonomous vehicles is somewhat newer, which, unlike AGVs, are mainly used in external transport. AVs are predicted to have a major change in the way transportation systems work around the world and their impact on traffic safety and traffic congestion. The development of the E/M-marketplace platforms led to the intensive development of the logistics market. Logistics service markets are actually becoming part of electronic markets because the customer now automatically buys the logistics service with the purchase of the product.

4.2. Evaluation of the I4.0 Technologies Applicability in LCs. In this section, the procedure for evaluating the applicability of 9 I4.0 solutions in LCs is presented. Applicability of the following technologies was assessed: IoT-A1, AGV-A2, autonomous vehicles-A3, AI-A4, big data-A5, blockchain-A6, CC-A7, E/M marketplace-A8, and advanced robotics-A9. These technologies were evaluated on the basis of three groups of criteria that include a total of 15 subcriteria, which are previously explained in more detail in Table 2. At the very beginning, the calculation of weight values of the criteria using the MEREC method was presented, followed by the evaluation process, i.e. the ranking of technologies using the fuzzy MARCOS method. Expert evaluations of alternatives based on defined criteria as well as the results of the previously mentioned model are presented as follows.

Table 2: The initial matrix of the main criteria group evaluations.

	Linguistic ratings			Numerical ratings		
	C_T	C_{SP}	C_{EO}	C_T	C_{SP}	C_{EO}
A_1	VH	M	EH	8	5	9
A_2	H	FH	VH	7	6	8
A_3	VH	H	VH	8	7	8
A_4	EH	H	H	9	7	7
A_5	EH	VH	EH	9	8	9
A_6	H	FH	VH	7	6	8
A_7	EH	H	VH	9	7	8
A_8	FH	VH	H	6	8	7
A_9	VH	VH	H	8	8	7

4.2.1. Criteria Weight Calculation Using the MEREC Method. The MEREC is an objective method that is implemented through six simple steps, which have been defined in Section 3.1. At the beginning, an initial decision-making matrix was formed for the three groups of criteria, i.e. technological criteria—CT, social and political criteria—CSP, and economic and operational criteria—CEO (Table 2), followed by the initial matrix for all 15 subcriteria (Table 3). It is important to note that the weight values of the main criteria are determined separately, and then the values of the subcriteria are determined individually within each group to which the criteria belong. At the end, the obtained values are combined to obtain the final weight of criteria, i.e. subcriteria. The obtained results are presented as follows:

In the second step, by applying (2), the values of the normalized matrix for the subcriteria were obtained and are presented in Table 4.

By applying equation (3), the total effect of alternatives S_i was calculated (Table 5), and then by applying equation (4), the performance of alternatives was calculated by removing each criterion S_{ij}' (Table 6).

Afterwards, the sum of absolute deviations E_j was calculated using equation (5) and the weight of criteria w_j using equation (6). The following E_j values were obtained:

$$\begin{aligned} &E1 = 0.746; E2 = 0.710; E3 = 0.642; E4 = 0.642; E5 = 0.609;\\ &E6 = 0.255; E7 = 1.626; E8 = 0.462; E9 = 0.674; E10 = 0.644;\\ &E11 = 0.526; E12 = 0.545; E13 = 0.289\colon\ E14 = 0.850; E15 = 0.803. \end{aligned} \tag{21}$$

The following criteria/subcriteria weights were obtained:

$$\begin{aligned} &C_T = 0.382; C_{SP} = 0.453; C_{EO} = 0.165;\\ &w_1 = 0.223; w_2 = 0.212; w_3 = 0.192; w_4 = 0.192; w_5 = 0.182;\\ &w_6 = 0.070; w_7 = 0.444; w_8 = 0.126; w_9 = 0.184; w_{10} = 0.176;\\ &w_{11} = 0.175; w_{12} = 0.181; w_{13} = 0.096; w_{14} = 0.282; w_{15} = 0.266. \end{aligned} \tag{22}$$

After combining the previous criteria and subcriteria values, the following final subcriteria weights are obtained:

$$\begin{aligned} &w_1 = 0.085; w_2 = 0.081; w_3 = 0.073; w_4 = 0.073; w_5 = 0.069;\\ &w_6 = 0.032; w_7 = 0.201; w_8 = 0.057; w_9 = 0.083; w_{10} = 0.080;\\ &w_{11} = 0.029; w_{12} = 0.030; w_{13} = 0.016; w_{14} = 0.046; w_{15} = 0.044. \end{aligned} \tag{23}$$

Table 3: The initial matrix of the subcriteria evaluations.

	Technological					Socio-political					Economic-operational				
	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}
Linguistic ratings															
A_1	VH	EH	H	M	EH	VH	FH	VH	L	H	FH	H	M	H	EH
A_2	EH	M	FL	FH	L	H	L	FL	FH	VH	FL	VH	M	M	H
A_3	L	L	L	M	L	M	L	M	FH	FL	L	M	FL	FL	FH
A_4	L	H	FL	L	FH	FH	FL	H	H	M	M	FH	FH	H	FH
A_5	FH	FH	VH	FH	VH	H	H	FL	FL	FH	FH	H	M	EH	VH
A_6	H	VH	FH	FH	VH	FH	VH	L	FL	M	FH	VH	H	VH	H
A_7	H	VH	VH	H	EH	FH	VH	L	M	M	H	H	FH	H	H
A_8	VH	FL	VH	M	FL	M	VL	H	H	H	M	M	FL	M	L
A_9	M	L	L	M	L	H	N	FL	H	L	FH	FL	M	L	FL
Numerical ratings															
A_1	8	9	3	5	9	8	6	2	3	7	4	9	5	3	9
A_2	9	5	6	6	3	7	3	6	6	8	6	8	5	5	7
A_3	3	4	7	5	3	5	3	5	6	4	7	5	4	6	6
A_4	3	7	6	3	6	6	4	3	7	5	5	6	6	3	6
A_5	6	6	2	6	8	7	7	6	4	6	4	7	5	1	8
A_6	7	8	4	6	8	6	8	7	4	5	4	8	7	2	7
A_7	7	8	2	7	9	6	8	7	5	5	3	7	6	3	5
A_8	8	4	2	5	4	5	2	3	7	7	5	5	4	5	3
A_9	5	3	7	5	3	7	1	6	7	3	4	4	5	7	4

Table 4: The normalized matrix for the MEREC method.

	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9
C_1	0.375	0.333	1.000	1.000	0.500	0.429	0.429	0.375	0.600
C_2	0.333	0.600	0.750	0.429	0.500	0.375	0.375	0.750	1.000
C_3	0.429	0.857	1.000	0.857	0.286	0.571	0.286	0.286	1.000
C_4	0.600	0.500	0.600	1.000	0.500	0.500	0.429	0.600	0.600
C_5	0.333	1.000	1.000	0.500	0.375	0.375	0.333	0.750	1.000
C_6	0.625	0.714	1.000	0.833	0.714	0.833	0.833	1.000	0.714
C_7	0.167	0.333	0.333	0.250	0.143	0.125	0.125	0.500	1.000
C_8	0.286	0.857	0.714	0.429	0.857	1.000	1.000	0.429	0.857
C_9	1.000	0.500	0.500	0.429	0.750	0.750	0.600	0.429	0.429
C_{10}	0.429	0.375	0.750	0.600	0.500	0.600	0.600	0.429	1.000
C_{11}	0.571	0.857	1.000	0.714	0.571	0.571	0.429	0.714	0.571
C_{12}	0.444	0.500	0.800	0.667	0.571	0.500	0.571	0.800	1.000
C_{13}	0.800	0.800	1.000	0.667	0.800	0.571	0.667	1.000	0.800
C_{14}	0.429	0.714	0.857	0.429	0.143	0.286	0.429	0.714	1.000
C_{15}	0.333	0.429	0.500	0.500	0.375	0.429	0.600	1.000	0.750

Table 5: The total effect of alternatives S_i.

	$C_{\text{technological}}$	$C_{\text{socio-political}}$	$C_{\text{economic-operational}}$
A_1	0.646	0.627	0.535
A_2	0.400	0.502	0.372
A_3	0.148	0.394	0.194
A_4	0.292	0.562	0.430
A_5	0.622	0.521	0.617
A_6	0.595	0.478	0.578
A_7	0.696	0.505	0.491
A_8	0.509	0.499	0.165
A_9	0.186	0.237	0.194

4.2.2. Technologies Ranking by Applying the Fuzzy MARCOS Method. Fuzzy MARCOS is implemented by applying ten steps, previously explained in Section 3.2. The first step entails the formation of the initial decision matrix, which is presented in Table 7.

Afterwards, it was necessary to form an extended initial decision matrix by applying equations (7) and (8), respectively. Further, it was necessary to calculate the normalized values using equations (9) and (10). The obtained values of the normalized matrix are presented in Table 8.

The next step was the calculation of the weighted fuzzy matrix by applying equation (11) and previously obtained criteria weight. The values of the weighted fuzzy matrix are presented in Table 9.

$\widetilde{S}_i$ was calculated using equation (12). Afterwards, the utility degree of each alternative was determined based on ideal and anti-ideal solutions, applying equations (13) and (14). Then, it was necessary to summarize the ideal and anti-

Table 6: Obtained values of the S'_{ij}.

	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9
C_1	0.537	0.240	0.148	0.292	0.545	0.496	0.608	0.384	0.097
C_2	0.523	0.329	0.097	0.157	0.545	0.480	0.593	0.474	0.186
C_3	0.553	0.379	0.148	0.269	0.478	0.531	0.562	0.346	0.186
C_4	0.591	0.302	0.056	0.292	0.545	0.515	0.608	0.446	0.097
C_5	0.523	0.400	0.148	0.183	0.511	0.480	0.580	0.474	0.186
C_6	0.576	0.461	0.394	0.541	0.480	0.455	0.483	0.499	0.183
C_7	0.415	0.360	0.234	0.390	0.258	0.179	0.216	0.411	0.237
C_8	0.484	0.484	0.348	0.461	0.502	0.478	0.505	0.390	0.212
C_9	0.627	0.415	0.296	0.461	0.486	0.441	0.441	0.390	0.094
C_{10}	0.532	0.376	0.355	0.502	0.435	0.412	0.441	0.390	0.237
C_{11}	0.467	0.351	0.194	0.385	0.555	0.513	0.382	0.106	0.097
C_{12}	0.435	0.272	0.157	0.376	0.555	0.497	0.420	0.126	0.194
C_{13}	0.509	0.341	0.194	0.376	0.593	0.513	0.440	0.165	0.157
C_{14}	0.431	0.325	0.168	0.313	0.382	0.427	0.382	0.106	0.194
C_{15}	0.398	0.248	0.073	0.336	0.505	0.478	0.427	0.165	0.145

Table 7: The initial decision matrix of the fuzzy MARCOS method.

	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9
Linguistic ratings									
C_1	VG	EG	P	P	MG	G	G	VG	M
C_2	EG	M	P	G	MG	VG	VG	MG	P
C_3	G	MP	P	MP	VG	MG	VG	VG	P
C_4	M	MG	M	P	MG	MG	G	M	M
C_5	EG	P	P	MG	VG	VG	EG	MP	P
C_6	VG	G	M	MG	G	MG	MG	M	G
C_7	MG	P	P	MP	G	VG	VG	VP	EP
C_8	VG	MP	M	G	MP	P	P	G	MP
C_9	P	MG	MG	G	MP	MP	M	G	G
C_{10}	G	VG	MP	MP	MG	M	M	G	P
C_{11}	MG	MP	P	M	MG	MG	G	M	MG
C_{12}	G	VG	M	MG	G	VG	G	M	MP
C_{13}	M	M	MP	MG	M	G	MG	MP	M
C_{14}	G	M	MP	G	EG	VG	G	M	P
C_{15}	EG	G	MG	MG	VG	G	G	P	MP
Ratings with TFNs									
C_1	(7, 7, 9)	(7, 9, 9)	(1, 3, 3)	(1, 3, 3)	(5, 5, 7)	(5, 7, 7)	(5, 7, 7)	(7, 7, 9)	(3, 5, 5)
C_2	(7, 9, 9)	(3, 5, 5)	(1, 3, 3)	(5, 7, 7)	(5, 5, 7)	(7, 7, 9)	(7, 7, 9)	(5, 5, 7)	(1, 3, 3)
C_3	(1, 3, 3)	(5, 5, 7)	(5, 7, 7)	(5, 5, 7)	(1, 1, 3)	(3, 3, 5)	(1, 1, 3)	(1, 1, 3)	(5, 7, 7)
C_4	(3, 5, 5)	(5, 5, 7)	(3, 5, 5)	(1, 3, 3)	(5, 5, 7)	(5, 5, 7)	(5, 7, 7)	(3, 5, 5)	(3, 5, 5)
C_5	(7, 9, 9)	(1, 3, 3)	(1, 3, 3)	(5, 5, 7)	(7, 7, 9)	(7, 7, 9)	(7, 9, 9)	(3, 3, 5)	(1, 3, 3)
C_6	(7, 7, 9)	(5, 7, 7)	(3, 5, 5)	(5, 5, 7)	(5, 7, 7)	(5, 5, 7)	(5, 5, 7)	(3, 5, 5)	(5, 7, 7)
C_7	(5, 5, 7)	(1, 3, 3)	(1, 3, 3)	(3, 3, 5)	(5, 7, 7)	(7, 7, 9)	(7, 7, 9)	(1, 1, 3)	(1, 1, 1)
C_8	(1, 1, 3)	(5, 5, 7)	(3, 5, 5)	(1, 3, 3)	(5, 5, 7)	(5, 7, 7)	(5, 7, 7)	(1, 3, 3)	(5, 5, 7)
C_9	(1, 3, 3)	(5, 5, 7)	(5, 5, 7)	(5, 7, 7)	(3, 3, 5)	(3, 3, 5)	(3, 5, 5)	(5, 7, 7)	(5, 7, 7)
C_{10}	(5, 7, 7)	(7, 7, 9)	(3, 3, 5)	(3, 3, 5)	(5, 5, 7)	(3, 5, 5)	(3, 5, 5)	(5, 7, 7)	(1, 3, 3)
C_{11}	(3, 3, 5)	(5, 5, 7)	(5, 7, 7)	(3, 5, 5)	(3, 3, 5)	(3, 3, 5)	(1, 3, 3)	(3, 5, 5)	(3, 3, 5)
C_{12}	(5, 7, 7)	(7, 7, 9)	(3, 5, 5)	(5, 5, 7)	(5, 7, 7)	(7, 7, 9)	(5, 7, 7)	(3, 5, 5)	(3, 3, 5)
C_{13}	(3, 5, 5)	(3, 5, 5)	(3, 3, 5)	(5, 5, 7)	(3, 5, 5)	(5, 7, 7)	(5, 5, 7)	(3, 3, 5)	(3, 5, 5)
C_{14}	(1, 3, 3)	(3, 5, 5)	(5, 5, 7)	(1, 3, 3)	(1, 1, 1)	(1, 1, 3)	(1, 3, 3)	(3, 5, 5)	(5, 7, 7)
C_{15}	(7, 9, 9)	(5, 7, 7)	(5, 5, 7)	(5, 5, 7)	(7, 7, 9)	(5, 7, 7)	(5, 7, 7)	(1, 3, 3)	(3, 3, 5)

ideal utility degrees of the alternatives, i.e. to apply equation (15) to obtain the fuzzy matrix $\widetilde{T}_i$. The results obtained by applying equations (12)–(15) are presented in Table 10.

Afterwards, a new fuzzy number $\widetilde{D}$ was calculated using equation (16), as well as its crisp value using equation (17).

$$\widetilde{D} = \left(d^l, d^m, d^u\right) = \max_i \bar{t}_{ij} = (2.466, 3.458, 7.243).$$

$$df_{\text{crisp}} = \frac{l + 4m + u}{6} = 3.924. \tag{24}$$

Table 8: The normalized matrix of the fuzzy MARCOS method.

	C_1	C_2	...	C_{14}	C_{15}
AI	(0.111, 0.333, 0.333)	(0.111, 0.333, 0.333)	...	(0.143, 0.143, 0.200)	(0.111, 0.333, 0.333)
A_1	(0.778, 0.778, 1.000)	(0.778, 1.000, 1.000)	...	(0.33, 30.333, 1.000)	(0.778, 1.000, 1.000)
A_2	(0.778, 1.000, 1.000)	(0.333, 0.556, 0.556)	...	(0.200, 0.200, 0.333)	(0.556, 0.778, 0.778)
A_3	(0.111, 0.333, 0.333)	(0.111, 0.333, 0.333)	...	(0.143, 0.200, 0.200)	(0.556, 0.556, 0.778)
A_4	(0.111, 0.333, 0.333)	(0.556, 0.778, 0.778)	...	(0.333, 0.333, 1.000)	(0.556, 0.556, 0.778)
A_5	(0.556, 0.556, 0.778)	(0.556, 0.556, 0.778)	...	(1.000, 1.000, 1.000)	(0.778, 0.778, 1.000)
A_6	(0.556, 0.778, 0.778)	(0.778, 0.778, 1.000)	...	(0.333, 1.000, 1.000)	(0.556, 0.778, 0.778)
A_7	(0.556, 0.778, 0.778)	(0.778, 0.778, 1.000)	...	(0.333, 0.333, 1.000)	(0.556, 0.778, 0.778)
A_8	(0.778, 0.778, 1.000)	(0.556, 0.556, 0.778)	...	(0.200, 0.200, 0.333)	(0.111, 0.333, 0.333)
A_9	(0.333, 0.556, 0.556)	(0.111, 0.333, 0.333)	...	(0.143, 0.143, 0.200)	(0.333, 0.333, 0.556)
ID	(0.778, 1.000, 1.000)	(0.778, 1.000, 1.000)	...	(1.000, 1.000, 1.000)	(0.778, 1.000, 1.000)

Table 9: The weighted fuzzy MARCOS matrix.

	C_1	C_2	...	C_{14}	C_{15}
AI	(0.009, 0.028, 0.028)	(0.009, 0.027, 0.027)	...	(0.007, 0.007, 0.009)	(0.005, 0.015, 0.015)
A_1	(0.066, 0.066, 0.085)	(0.063, 0.081, 0.081)	...	(0.015, 0.015, 0.046)	(0.034, 0.044, 0.044)
A_2	(0.066, 0.085, 0.085)	(0.027, 0.045, 0.045)	...	(0.009, 0.009, 0.015)	(0.024, 0.034, 0.034)
A_3	(0.009, 0.028, 0.028)	(0.009, 0.027, 0.027)	...	(0.007, 0.009, 0.009)	(0.024, 0.024, 0.034)
A_4	(0.009, 0.028, 0.028)	(0.045, 0.063, 0.063)	...	(0.015, 0.015, 0.046)	(0.024, 0.024, 0.034)
A_5	(0.047, 0.047, 0.066)	(0.045, 0.045, 0.063)	...	(0.046, 0.046, 0.046)	(0.034, 0.034, 0.044)
A_6	(0.047, 0.066, 0.066)	(0.063, 0.063, 0.081)	...	(0.015, 0.046, 0.046)	(0.024, 0.034, 0.034)
A_7	(0.047, 0.066, 0.066)	(0.063, 0.063, 0.081)	...	(0.015, 0.015, 0.046)	(0.024, 0.034, 0.034)
A_8	(0.066, 0.066, 0.085)	(0.045, 0.045, 0.063)	...	(0.009, 0.009, 0.015)	(0.005, 0.015, 0.015)
A_9	(0.028, 0.047, 0.047)	(0.009, 0.027, 0.027)	...	(0.007, 0.007, 0.009)	(0.015, 0.015, 0.024)
ID	(0.0660.085, 0.085)	(0.063, 0.081, 0.081)	...	(0.046, 0.046, 0.046)	(0.034, 0.044, 0.044)

Table 10: Results of the steps 5–7 of the fuzzy MARCOS method.

	$\widetilde{S}_i$	$\widetilde{K}_i^-$	$\widetilde{K}_i^+$	$\widetilde{T}_i$
AI	(0.141, 0.273, 0.296)			
A_1	(0.529, 0.688, 0.839)	(1.790, 2.522, 5.936)	(0.529, 0.761, 1.187)	(2.319, 3.283, 7.124)
A_2	(0.401, 0.529, 0.604)	(1.356, 1.937, 4.275)	(0.401, 0.584, 0.855)	(1.757, 2.521, 5.130)
A_3	(0.250, 0.385, 0.454)	(0.847, 1.410, 3.213)	(0.250, 0.425, 0.643)	(1.097, 1.835, 3.856)
A_4	(0.377, 0.463, 0.642)	(1.276, 1.697, 4.544)	(0.377, 0.512, 0.909)	(1.653, 2.209, 5.453)
A_5	(0.550, 0.669, 0.794)	(1.861, 2.452, 5.619)	(0.550, 0.740, 1.124)	(2.411, 3.192, 6.742)
A_6	(0.556, 0.651, 0.791)	(1.880, 2.387, 5.601)	(0.556, 0.720, 1.120)	(2.436, 3.107, 6.721)
A_7	(0.563, 0.725, 0.853)	(1.903, 2.657, 6.036)	(0.563, 0.801, 1.207)	(2.466, 3.458, 7.243)
A_8	(0.383, 0.517, 0.667)	(1.294, 1.896, 4.722)	(0.383, 0.572, 0.944)	(1.676, 2.468, 5.667)
A_9	(0.247, 0.381, 0.404)	(0.836, 1.395, 2.859)	(0.247, 0.421, 0.572)	(1.083, 1.816, 3.431)
ID	(0.706, 0.905, 1.000)			

Further, the utility function in relation to the ideal $f(\widetilde{K}_i^+)$ and anti-ideal $f(\widetilde{K}_i^-)$ solution is calculated using equations (18) and (19), as well as the utility function of alternatives $f(K_i)$ using equation (20). The results obtained by applying the last three steps of the fuzzy MARCOS method are presented in Table 11.

Based on the results, it can be concluded that the best ranked alternative is A7, i.e., cloud computing, while the worst ranked alternative is A9, i.e., advanced robotics.

5. Discussion and Sensitivity Analysis

An analysis of the obtained results' sensitivity to the changes in the weights of the five most important criteria was performed. The weights of the criteria were changed in the range of 15–90% and by applying the following equation:

$$W_{n\beta} = (1 - W_{n\alpha}) \frac{W_\beta}{(1 - W_n)}. \tag{25}$$

All simulated criteria weights through the newly formed 30 scenarios are presented in Table 12. The simulated criteria weights are then used to obtain rankings of the alternatives. The obtained results are shown in Figure 3.

As it can be concluded on the basis of Figure 3, when changing the importance of criteria, there are certain changes in the ranking of alternatives, i.e. I4.0 technologies. The $A7$ alternative, which was in the first place in the original model takes the second place in the $S5$ and $S6$ scenarios, while the best ranked is the $A1$. In these two scenarios, the

Table 11: Final results of the fuzzy MARCOS method.

	$\mathbf{f}(\tilde{\mathbf{K}}_{\mathbf{i}}^{-})$	$\mathbf{f}(\tilde{\mathbf{K}}_{\mathbf{i}}^{+})$	$K-$	$K+$	fK−	fK+	Ki	Rank
A_1	(0.135, 0.194, 0.303)	(0.456, 0.643, 1.513)	2.969	0.793	0.202	0.757	0.714	2
A_2	(0.102, 0.149, 0.218)	(0.346, 0.494, 1.089)	2.230	0.599	0.153	0.568	0.387	6
A_3	(0.064, 0.108, 0.164)	(0.216, 0.359, 0.819)	1.616	0.432	0.110	0.412	0.195	8
A_4	(0.096, 0.130, 0.232)	(0.325, 0.433, 1.158)	2.102	0.556	0.142	0.536	0.335	7
A_5	(0.140, 0.188, 0.286)	(0.474, 0.625, 1.432)	2.881	0.772	0.197	0.734	0.671	3
A_6	(0.142, 0.184, 0.285)	(0.479, 0.608, 1.428)	2.838	0.759	0.194	0.723	0.648	4
A_7	(0.143, 0.204, 0.308)	(0.485, 0.677, 1.538)	3.094	0.829	0.211	0.789	0.785	1
A_8	(0.098, 0.146, 0.241)	(0.330, 0.483, 1.204)	2.267	0.602	0.154	0.578	0.396	5
A_9	(0.063, 0.107, 0.146)	(0.213, 0.356, 0.729)	1.546	0.417	0.106	0.394	0.179	9

Table 12: Simulated criteria weights in the newly formed 30 scenarios.

	$W1$	$W2$	$W3$	$W4$	$W5$	$W6$	$W7$	$W8$	$W9$	$W10$	$W11$	$W12$	$W13$	$W14$	$W15$
$S1$	0.088	0.084	0.076	0.076	0.072	0.033	0.171	0.059	0.087	0.083	0.030	0.031	0.016	0.048	0.046
$S2$	0.092	0.087	0.079	0.079	0.075	0.034	0.141	0.062	0.090	0.086	0.031	0.032	0.017	0.050	0.047
$S3$	0.095	0.090	0.082	0.082	0.077	0.035	0.111	0.064	0.093	0.089	0.032	0.033	0.018	0.052	0.049
$S4$	0.098	0.093	0.084	0.084	0.080	0.036	0.080	0.066	0.096	0.092	0.033	0.034	0.018	0.054	0.051
$S5$	0.101	0.096	0.087	0.087	0.083	0.037	0.050	0.068	0.099	0.095	0.034	0.035	0.019	0.055	0.052
$S6$	0.104	0.099	0.090	0.090	0.085	0.039	0.020	0.070	0.102	0.098	0.035	0.037	0.019	0.057	0.054
$S7$	0.072	0.082	0.074	0.074	0.070	0.032	0.204	0.058	0.085	0.081	0.029	0.030	0.016	0.047	0.045
$S8$	0.060	0.083	0.075	0.075	0.071	0.032	0.207	0.059	0.086	0.082	0.030	0.031	0.016	0.048	0.045
$S9$	0.047	0.084	0.076	0.076	0.072	0.033	0.210	0.060	0.087	0.083	0.030	0.031	0.016	0.048	0.046
$S10$	0.034	0.085	0.077	0.077	0.073	0.033	0.212	0.060	0.088	0.084	0.030	0.031	0.017	0.049	0.046
$S11$	0.021	0.087	0.078	0.078	0.074	0.034	0.215	0.061	0.089	0.085	0.031	0.032	0.017	0.050	0.047
$S12$	0.009	0.088	0.079	0.079	0.075	0.034	0.218	0.062	0.090	0.086	0.031	0.032	0.017	0.050	0.048
$S13$	0.086	0.082	0.074	0.074	0.070	0.032	0.204	0.058	0.071	0.081	0.029	0.030	0.016	0.047	0.045
$S14$	0.087	0.083	0.075	0.075	0.071	0.032	0.207	0.059	0.058	0.082	0.030	0.031	0.016	0.048	0.045
$S15$	0.089	0.084	0.076	0.076	0.072	0.033	0.209	0.060	0.046	0.083	0.030	0.031	0.016	0.048	0.046
$S16$	0.090	0.085	0.077	0.077	0.073	0.033	0.212	0.060	0.033	0.084	0.030	0.031	0.017	0.049	0.046
$S17$	0.091	0.087	0.078	0.078	0.074	0.034	0.215	0.061	0.021	0.085	0.031	0.032	0.017	0.050	0.047
$S18$	0.092	0.088	0.079	0.079	0.075	0.034	0.218	0.062	0.008	0.086	0.031	0.032	0.017	0.050	0.048
$S19$	0.086	0.069	0.074	0.074	0.070	0.032	0.204	0.058	0.085	0.081	0.029	0.030	0.016	0.047	0.044
$S20$	0.087	0.057	0.075	0.075	0.071	0.032	0.207	0.059	0.086	0.082	0.030	0.031	0.016	0.048	0.045
$S21$	0.088	0.045	0.076	0.076	0.072	0.033	0.209	0.059	0.087	0.083	0.030	0.031	0.016	0.048	0.046
$S22$	0.090	0.032	0.077	0.077	0.073	0.033	0.212	0.060	0.088	0.084	0.030	0.031	0.017	0.049	0.046
$S23$	0.091	0.020	0.078	0.078	0.074	0.034	0.214	0.061	0.089	0.085	0.031	0.032	0.017	0.050	0.047
$S24$	0.092	0.008	0.079	0.079	0.075	0.034	0.217	0.062	0.090	0.086	0.031	0.032	0.017	0.050	0.047
$S25$	0.086	0.082	0.074	0.074	0.070	0.032	0.204	0.058	0.085	0.068	0.029	0.030	0.016	0.047	0.044
$S26$	0.087	0.083	0.075	0.075	0.071	0.032	0.206	0.059	0.086	0.056	0.030	0.031	0.016	0.048	0.045
$S27$	0.088	0.084	0.076	0.076	0.072	0.033	0.209	0.059	0.087	0.044	0.030	0.031	0.016	0.048	0.046
$S28$	0.090	0.085	0.077	0.077	0.073	0.033	0.212	0.060	0.088	0.032	0.030	0.031	0.017	0.049	0.046
$S29$	0.091	0.086	0.078	0.078	0.074	0.034	0.214	0.061	0.089	0.020	0.031	0.032	0.017	0.050	0.047
$S30$	0.092	0.087	0.079	0.079	0.075	0.034	0.217	0.062	0.090	0.008	0.031	0.032	0.017	0.050	0.047

alternatives, $A9$ and $A3$, originally ranked as eighth and ninth, swapped their rankings. Differences in ranking are also present with alternatives $A8$ and $A2$, which exchange positions with each other in the following scenarios: $S12$, $S15$–$S18$, and $S24$. In addition, alternative $A5$, which was originally ranked as the third, changed ranking in scenarios $S23$ and $S24$, i.e. it was ranked as the second. The biggest changes in ranking occur in scenarios $S5$ and $S6$, when the value of the most important criterion $C7$ is reduced by 75% and 90%, respectively. Generally, it can be concluded that the changes in the scenarios are not significant, i.e., that the originally obtained ranking is stable enough and could therefore be adopted as the final solution.

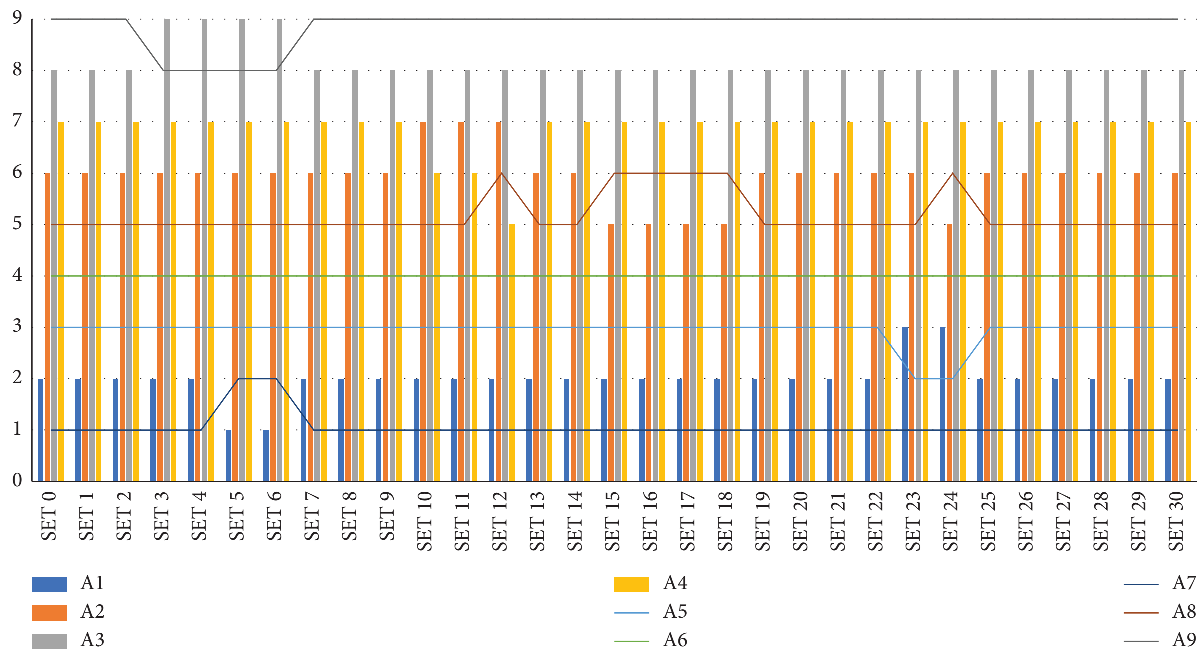

Figure 3: Results of alternatives rankings with new criteria values.

6. Conclusion

The ongoing digital transformation, initiated by the I4.0 initiative, has influenced the development of the new concept of logistics 4.0. Application of technologies I4.0 in the field of logistics brings many advantages for all participants, i.e. it enables greater productivity, agility, speed, quality, competitiveness, profitability, improvement of delivery, vertical and horizontal integration, saving of resources, reduction of operating costs, adaptability, and quality of work. Accordingly, this paper evaluated the applicability of nine I4.0 technologies (IoT, automated guided vehicles, autonomous vehicles, AI, big data, blockchain, CC, E/M marketplace, and advanced robotics) in LCs. The technologies were evaluated based on the technological, social and political, and economic and operational groups of criteria, which included a total of 15 subcriteria. To assess the applicability of technologies based on the defined criteria, a hybrid MCDM model was used, which integrated the MEREC and fuzzy MARCOS methods. By applying the MEREC, the criteria weights were determined, while by applying fuzzy MARCOS, the technologies were ranked. Based on the results obtained, it can be concluded that CC is the best alternative, i.e. most applicable I4.0 technology in LCs, followed by the IoT and Big Data. The advanced robotics resulted as the least applicable technology. CC, IoT, and big data are compatible technologies and very useful for data management. Data are an invaluable asset in logistics, especially today when it is imperative to have access to all data for better decision-making. After evaluating the applicability of I4.0 technologies in LCs, a sensitivity analysis of the obtained results was performed by changing the weights of the five most important criteria ($C7$, $C1$, $C9$, $C2$, and $C10$). The sensitivity analysis showed that the biggest impact on the change in the ranks of the alternatives is a decrease in the value of the most important criterion $C7$ by 75%–90%.

The main contribution of this paper is the establishment of a new integrated MCDM model, which can serve as a tool for experts and decision-makers when deciding on the applicability of various modern technologies in the field of logistics, especially in logistics centers that represent the places of greatest concentration of logistics flows and logistics activities. In addition, the paper provides an extensive overview of the possible applications of I4.0 technologies in various areas of logistics, as well as the advantages that these technologies bring. Although this research provides a great contribution from the theoretical perspective, the practical implications are yet to be confirmed. The future research should perform a detailed analysis of the applicability of I4.0 technologies in real-life LCs. The future research should also include a larger number of experts from several stakeholders (e.g. operators and owners of the centers, users of services, and society). In addition, one of the directions of future studies can be manifested through a detailed analysis of the limitations and challenges that may appear during the application of various technologies in certain business segments of logistics centers.

Data Availability

The data supporting the conclusions of the study are presented within the paper.

Disclosure

This research was performed as part of the employment of the authors in the following institutions: University of East Sarajevo, Faculty of Transport and Traffic Engineering;

University of Belgrade, Department of Technology Management and Economics; and Chalmers University of Technology.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

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