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Source / Izvornik: **Sustainability, 2022, 14, 6514 - 6533**

Journal article, Published version
Rad u časopisu, Objavljena verzija rada (izdavačev PDF)

https://doi.org/10.3390/su14116514

sustainability

Article

Logistics 5.0 Implementation Model Based on Decision Support Systems

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Abstract: With the introduction of Society 5.0 for the sustainable future, special caution is given to humans' role within the general system. Similarly, Industry 5.0 as a concept has been presented, followed by Logistics 5.0 in its theoretical framework. The transition towards the new concept of Logistics 5.0 requires an accurate and optimal strategic plan definition for which, in this paper, an implementation model based on decision support systems will be developed. The output data from this model are the priority of Logistics 5.0 elements (from five groups—green warehousing, green transport, green packaging, infrastructure and organization, and human resources) for the optimal implementation, based on three goals (initial investment, return of investment time, implementation and exploitation complexity) that companies aim to achieve in the future. The model is based on the analytic hierarchy process, and data were collected from an expert group and analyzed with several statistical methods. The result is a model that provides an optimal strategy for the implementation of elements of Logistics 5.0. The implementation priority list of elements is very beneficial for the management of many companies from various types of industries.

Keywords: Logistics 5.0; Industry 4.0; readiness; decision support systems; analytic hierarchy process; strategy

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Citation: Trstenjak, M.; Opetuk, T.; Đukić, G.; Cajner, H. Logistics 5.0 Implementation Model Based on Decision Support Systems. *Sustainability* **2022**, *14*, 6514. https://doi.org/10.3390/su14116514

Academic Editors: João Carlos de Oliveira Matias and Paolo Renna

Received: 14 April 2022
Accepted: 24 May 2022
Published: 26 May 2022

1. Introduction

Logistics processes are one of the key parts of manufacturing, along with technology and organizational processes. In the very beginning, the term sustainability was closely related to production as derived from industrial ecology and green production [1]. With market expansion, globalization, and the higher influence of competitors, there is a need for merging the various production processes (so as the companies) with help of supply chains. This is how the company relates to its suppliers, logistics service providers, and customers. By adding the environmental and economic component of sustainability to the supply chain, as well as the digital component in terms of Industry 4.0, the digital Logistics 5.0 systems are formed, which is a key focus of this research [2].

Digitization is a needed perspective of every manufacturing company on every level. Industry 4.0 as a concept represents a digital solution for automated work with the possibility of predictive activities enabled by big data analytics [3]. The human role within this system changes. Manual work is relocated to artificial intelligence, while the human takes the place of a system and process controller and developer.

Industry 5.0 (often presented as part of the Society 5.0 concept) goes a step further and deals with the human role within the production system, its interaction with technology, as well as other humans within the system [4]. The implementation of Industry 4.0 demands an optimal personalized strategy definition to increase future benefits and minimize the cost of the transformation [5]. Similar is the path to the implementation of Industry 5.0, which can be also observed for its components, such as Logistics 5.0. Logistics 5.0 must provide a sustainable and eco-friendly system on many levels, but also with special caution to human roles and their communication and interaction with the machines or other humans in the system [6]. That is why, in this paper, the model for the transformational strategy definition of Logistics 5.0 will be presented.

Therefore, this paper aims to provide answers to the following research questions:

RQ1: How does one define the priority of Logistics 5.0 elements for its implementation as the optimal digital transformation strategy?

RQ2: Can the transitional strategy plan be defined with the help of decision support systems?

2. Theoretical Background

The application of concepts, models, and methods of sustainability in the management of production and business systems (the adoption of related new knowledge and technologies) reduces the total costs by reducing the waste of resources, reducing waste, and reducing unnecessary activities [7]. This leads to better business results and greater competitiveness, for which there are numerous examples in practice. It follows from the above that companies themselves define trends, concepts, and models of sustainable development.

Along with the terms *sustainable* and *green*, there is an uprising of a digital production and logistics environment in terms of the Logistics 4.0 concept. The unification of green, sustainable, and digital logistics (Logistics 4.0) with the human component can be defined as a step further in technological development, precisely termed Logistics 5.0 [6]. Therefore, in the following chapters, the theoretical background of green logistics and Logistics 4.0 will be given, followed by an extensive literature review based on the state-of-the-art solution to the topic of the implementation of Logistics 5.0 in companies. Based on that, the model for the transitional strategy definition for the implementation of Logistics 5.0 will be developed and described.

2.1. Green Logistics

The idea of green logistics is to eliminate or minimize waste (energy, emissions, and chemical and solid waste) throughout the supply chain and achieve sustainability of all its components [8].

For this reason, green logistics for the purpose of this work will be observed as a system divided into:

- Green transport.
- Green warehousing.
- Green packaging.
- Green transport.

The impact of transport on the environment is likely visible to everyone. Transport is the main source of particulate emissions and NOx and SO_2 emissions.

From research in the previous work of the authors, and in the literature on green transport, the following green elements are most frequently mentioned [9]:

- Reduction of paper consumption.
- Toner and ink recycling.
- Shutting down computers when not in use.
- Use of reusable containers and transport equipment.
- Use of reusable pallets.
- Reduction of unused space in the vehicle.
- Reducing the time the vehicle is at rest.
- Increasing the usability of space in height within the means of transport.
- Use of a means of transport with alternative (renewable) fuel sources (energy).
- Introduction of alternative energy sources in refrigerated vehicles.
- Route optimization.

Looking at green elements, there is a tendency to reduce greenhouse gases (GHG), and this is achieved by the above-mentioned green elements. It should be noted here that the reduction of GHG emissions can be achieved directly by reducing emissions during transport, or indirectly, within the administration, by reducing paper consumption and electricity consumption. The above green elements will be used in the development of models for the introduction of green transport in companies.

2.2. Green Warehousing

Here, as in other green logistics parts, the idea is to introduce green elements that will reduce the consumption of paper, electricity, and energy. The following 'green' elements are used for 'green' warehousing [9]:

- Reduction of paper consumption.
- Toner and ink recycling.
- Shutting down computers when not in use.
- Use of more efficient lighting devices.
- Using light sensors inside the aisle to turn on the light only where someone is.
- Use of more efficient heating devices.
- Use of more efficient air conditioning devices.
- Optimization of transport flows within the warehouse.
- Introduction of fans for hot and cold air circulation.
- Use of doors with sensors for automatic closing.
- Increasing the energy efficiency of the warehouse.
- Use of materials that are better insulators (walls and roofs of the warehouse).
- Use of renewable energy sources.
- Introduction of new storage technologies.
- Use of automated transport systems.

It can be seen here that all the above green elements have a return on investment; the only question is in which period this will be realized. The payback period can vary from a few months (e.g., shutting down computers when not in use) to a couple of years (e.g., using renewable energy sources). The introduction of new warehouse technologies implies the use of picking technologies (pick-up light picking), automated storage systems, innovative warehouse layouts, etc. Green elements will be used to develop a model for introducing green warehousing into the process.

2.3. Green Packaging

Green packaging is often identified with the terms 'ecological package' or 'environmentally friendly package' [10].

The following 'green elements' are mentioned for 'green' packaging [9]:

- Requiring the supplier to take over packaging in which they deliver the goods.
- Existence of a pallet management (return) system.
- Use of packaging materials that have a lower weight.
- Use of materials that are biodegradable.
- Use of recycled packaging materials.
- Use of recyclable packaging materials.
- Packaging design for easier separation and sorting of different types of materials.
- Optimization of packaging for packaging (for secondary and tertiary packaging).
- Use of environmentally friendly colors on the packaging.

The above green elements will be used in the development of models for the introduction of green packaging within the company.

3. Literature Review

Similarly, to Industry 4.0, Logistics 4.0 has all the elements of a digital work environment with the most common characteristics, such as the Internet of Things, smart and flexible processes, cyber physical systems, or big data analytics [11], which, in the specific field of logistics, can relate to driverless transportation, smart containers, smart warehousing, smart shelves, etc. However, by adding the right level of autonomy and intelligence, logistics processes become more efficient, effective, connected to other parts of the value chain, but also more agile and flexible in their ability to respond to the demands of a dynamic market.

Logistics 4.0, with its theoretical and practical development, is currently one of the key trending topics in the field of industrial engineering; therefore, for the purpose of this paper and the development of this model, a literature review has been provided. The most relevant scientific database, Web of Science, was searched using the keywords 'Logistics 4.0' and 'Smart Logistics' to gather results of the most frequently mentioned elements, in addition to the keywords 'readiness' and 'maturity' to examine the developed models for the optimal transformational strategy definition. As a transition to Logistics 5.0, the research was enhanced with the keywords 'human-centered logistics' and 'logistics 5.0'. The most beneficial and latest results for this work and model development will be presented next.

3.1. From Logistics 4.0 to the Logistics 5.0

As for Logistics 4.0, there are several specific characteristics of this field within the Industry 4.0 system. The first is mass personalization of service, sustainability, the importance of humans in development, optimizing service quality, and reducing errors in complex environments, according to Winkelhaus and Grosse, 2019 [11].

Frederico (2021) [12] presented the Industry 5.0 concept in terms of the supply chain via an extensive literature review. He noted a gap in works regarding Logistics 5.0 and presented a framework based on the technology scope of Industry 4.0 but enhanced with mass personalization, revolutionary technology, and a super smart and sustainable society.

Bhargava et al. (2022) [13] discussed the influence of the internet on the demand and supply of materials, as well as the demand for the fast supply of logistics at the cheapest cost, which has led to the development of smart Internet of Things systems to support logistics processes. They mention that this technology is essential for Industry 5.0 to minimize logistic time and cost while maximizing customer satisfaction and company profits.

Figueiras et al. (2021) [14] studied the impact and importance of big data and digital twin technologies for Logistics 4.0. They placed emphasis on a digital twin as support for the planning and optimization of logistics processes and the reduction of risks and losses. A similar result was shown by Domanski (2019) [15], who examined digital warehouse intralogistics 4.0 and showed significant advances in the implementation of complex technologies in warehouse systems.

Another aspect of Logistics 5.0 is environmental awareness. Demir et al. (2019) described green intermodal freight transportation by principles of green logistics by understanding the multi-objective planning in intermodal freight transportation. In their research, they have also shown the importance and benefits of carbon-related emission reduction in this field [16].

Cimini et al. (2020) [17] noted that logistics activities will be affected on operational and managerial levels as the market demands flexibility and mass customization, which will subsequently influence the work of operators in internal and external logistics. That is why they discussed the 'Logistics Operator 4.0' paradigm. They acknowledge the need for exploration in the field of human–computer and human–machine interfaces to achieve the control of fully automated systems developed with ergonomic standards. They have also suggested that future scenarios will include hybrid human–machine decision-making processes.

Vijayakumar et al. (2021) [18] claim that ignoring the human factors in digital logistics systems may lead to operator fatigue, discomfort, subsequent injuries, and negative consequences for operator performance and the entire logistics systems, which, as there are few literature sources available on this topic, should be developed further to improve performance, quality, and well-being.

Cai et al. (2022) [19] examined a real-time scheduling method in the Logistics 4.0 environment and mentioned the possible problems of future predictions by this method. By using advanced predictive methods, customer satisfaction, equipment utilization, and the energy consumption is increased.

Sgarbossa et al. (2020) [6] discussed the human factors in logistics systems, where they noted that, although there may be a high level of automatization within the company, humans still play a very important role in the logistics system. They also claim that most transformational strategies do not include human factors, which leads to inaccurate planning and decisions, as well as underperforming systems and increased safety risks for human workers. They suggest diversity among human workers and the in-depth integration of digital technologies in operation processes for the development of smart and sustainable human-centered systems, which leads to Logistics 5.0.

Maniah and Milwandhari (2020) [20] studied the risks of one of the main components of Industry 4.0—cloud computing in logistics systems. With a qualitative approach, they explored the companies with logistics services incorporated, and the results showed that procurement and customer service activities have the highest risk values.

Loper de Sousa Jabbour et al. (2020) [21] proposed the adoption of low-carbon operation in logistics systems. The results showed that stakeholder pressures influence both barriers and motivators for decarbonizing operation management practices; a variety of barriers and motivators significantly affect the adoption of low-carbon operation management practices. Developing positive relationships with stakeholders is also important to overcome barriers from the external environment and enhance organizational competitiveness, and low-carbon operation management has an overall effect on firms' carbon performance. Zekhini et al. (2021) [22] discussed the integration of lean and green practices for the sustainable digital supply chain, similarly to Kim et al. (2021) [23], who examined the green supply chain management practices in a multi-tier supply chain with multiple regression analysis, with results that indicated that supplier capabilities mediate the direct effect of customer pressure on the adoption of GSCM practices for local firms. As for the evidence of the implementation of Industry 5.0 technologies in logistics systems, Choi and Siqin (2022) reflected on the use of blockchain technologies in logistics and emphasized the importance of both internal and external organizational considerations for the successful adoption of blockchain technologies in production and logistics systems [24]. Blockchain technologies are one of the crucial parts of digital manufacturing systems, and therefore one of the most important components of Logistics 5.0. IoT and AI have partially been implemented in many logistics activities, while Bhargava et al. (2022) discussed the implementation in vehicular logistics and supply chain management. They enable vehicle-mediated transportation systems to minimize logistic time and cost and maximize customer satisfaction, with improvements from 77 to 98% in overall performance, and can be used in various types of industries [13]. Blockchain technology is widely used in the agriculture-food supply chain in combination with other Industry 5.0 technologies (IoT, big data, RIFD, etc.) and was proven to be very beneficial by Bhat et al. (2022) [25]. Ivanov et al. (2022) discussed the digitization of the supply chain as a service-oriented business model based on cloud technologies in the context of Industry 5.0 [26].

3.2. Readiness for Logistics 4.0

Sternad, Lehrer, and Gajšek (2018) [27] studied the transformation of logistics processes and their readiness for industry 4.0. Their research is based on an *nrw* Industry 4.0 maturity model. They mention that the logistics systems are complex and therefore not many have dealt with its digital transformation, but that it is very important to determine its maturity level, which results in the qualitative distance between the ideal state of the logistics in the company and the current state.

Yavas and Ozkan-Ozen (2020) [28] focused on the transformation of logistics centers by presenting a framework with elements of industry 4.0 and setting their priorities via a fuzzy multi-criteria decision-making methodology. This resulted in 12 critical criteria, which were 'smart handling (C1), zero emission (C2), smart mobility (C3), freight exchange platforms (C4), digital information platforms (C5), intelligent transportation systems (C6), information security (C7), real time locating system (C8), autonomous vehicles (C9), smart warehouses (C10), logistics center alliances (C11) and digital connectivity (C12)'. Digital information platforms (C5), intelligent transportation systems (C6), and smart mobility (C3) were shown to be the most important criteria for Logistics Center 4.0.

Oleśków-Szłapka and Stachowiak (2019) [29] presented a framework of the Logistics 4.0 maturity model, which can be useful to companies when creating a roadmap towards Logistics 4.0 concept implementation. The presented model is based on literature research and previously presented maturity models, but the results of this pilot research were only meant to raise awareness of Logistics 4.0 within the company. The first stage of maturity definition was to create a survey and provide information about the knowledge of the digital concept in companies, which would later be used to calculate the correlation between the maturity level of the company, its competitive position, size, and development dynamics.

Facchini et al. (2019) [30] noted that the difficulties in strategic transitional plan development interrupt the optimal digital transformation of the companies towards the achievement of the Logistics 4.0 system. Their model is based on a survey and built around three macro-aspects: The propensity of the company towards Industry 4.0 and Logistics 4.0, the current use of technologies in the logistics process, and the investment level towards Industry 4.0 technologies for a Logistics 4.0 transition. Results of the survey served as the result of the companies' current maturity level.

Gökalp and Martinez (2021) [31] noted that none of the currently existing maturity models of digital transformation fully satisfy the criteria of sustainability, and therefore presented a holistic maturity model in which the companies are characterized by maturity across five levels. They claim that there are many limitations of the available maturity models, such as simplicity and the lack of an empirical foundation.

3.3. Scientific Gap

The theoretical background of Logistics 4.0 is already presented on various levels, although there are few specific readiness calculation methods available. Moreover, Logistics 5.0 is a relatively new field, towards which every company with logistics activities should aim to. Since it requires changes on many levels with high investments into physical and organizational upgrades, an accurate and optimal strategic plan should be defined. The authors have noted a research gap in this field, because of which the development of a model for the implementation of Logistics 5.0 will be presented next, which will combine the elements of green logistics, human resources and organization, and digital technologies. Most of the presented readiness or maturity calculation methods are mostly based on surveys with a high level of human subjectivity involved, which is why the novel model will use decision support as a tool, as well as an expert group to minimize human subjectivity in the decision-making process to obtain an accurate result and a strategic transformational plan for the company towards Logistics 5.0.

4. Logistics 5.0 Implementation Model

The proposed model has the goal of providing a result in the form of an optimal strategic transformational plan towards Logistics 5.0. This means that, with certain inputs, the output will be a priority list of elements to be implemented in a logistics system.

4.1. Methodology

The input is defined by the company itself and includes their judgement on certain goals that they would like to achieve via the implementation of a novel digital system. Since the main structure of this model is to decide the order of the Logistics 5.0 elements for their implementation, decision support systems will be used. In this case, this will be provided by the analytics hierarchy process (AHP method) [32], implemented in Expert Choice software (ver. 11.5.; Expert Choice; Arlington, VA, USA).

The decision tree is shown in Figure 1.

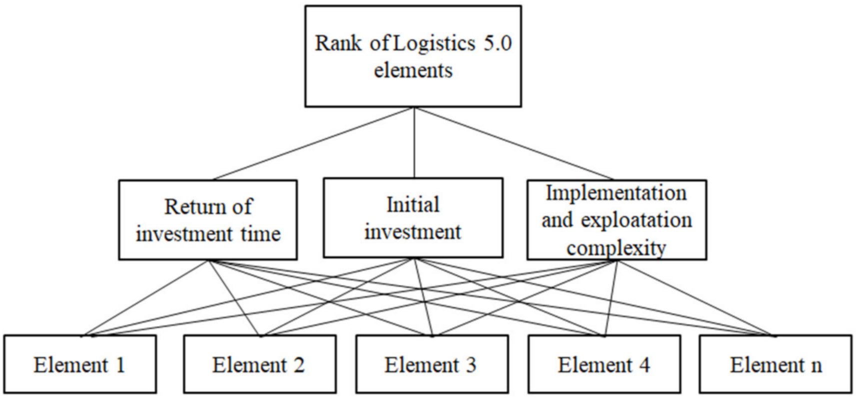


Figure 1. Logistics 5.0 implementation model decision tree.

To define the criteria tree, based on the literature review and previous works [9,33], the authors have defined three goals (for the AHP decision tree) that companies decide to achieve with Logistics 5.0 implementation:

1. Return of investment time.
2. Initial investment.
3. Implementation and exploitation complexity.

The first factor assigns higher priority to the elements that have a shorter return of investment time, the second with lower initial investment, and the third with lower implementation and exploitation complexity. The importance of each goal (criteria) is defined by the company in pairwise comparisons via the AHP method.

The output is a ranking of the Logistics 5.0 elements (AHP alternatives), which are divided into five groups:

1. Green transport.
2. Green warehousing.
3. Green packaging.
4. Infrastructure.
5. Organization and human resources.

Green transport, warehousing, and packaging are related to the 'green' and 'sustainable' components of Logistics 5.0 and the transformation of 'traditional' logistics elements in this direction. Infrastructure is related to digital enablers for the Logistics 4.0 concept, and organization and human resources deal with the human component, which is a progression from Logistics 4.0 to 5.0. The elements are also based on the previous work of the authors [9,33] and are shown in Table 1.

Table 1. Detailed overview of Logistics 5.0 by group.

Green Transport	Green Warehousing	Green Packaging	Infrastructure	Organization and Human Resources
Reduce paper consumption Toner and ink recycling Shutting down computers when not in use Use of reusable containers and transport equipment Use of reusable pallets Reduction of unused space in the vehicle Reducing downtime Increasing the usability of space in height within the vehicle Use of a vehicle with alternative (renewable) fuel sources (energy) Introduction of alternative energy sources in refrigerated vehicles Route optimization	Reduce paper consumption Toner and ink recycling Shutting down computers when not in use Use of more efficient lighting devices Using light sensors inside the aisle to turn the light on only where someone is Use of more efficient heating devices Use of more efficient air conditioning devices Optimization of transport flows within the warehouse Introduction of fans for circulation of hot and cold air Using a door with automatic closing sensors Increasing the energy efficiency of warehouses Using materials that are better insulators (warehouse walls and roofs) Use of renewable energy sources Introduction of new storage technologies Use of automated transport systems	Requiring the supplier to take over his packaging in which he delivers the goods Existence of pallet management (return) system Using packaging materials that have less weight Use of biodegradable materials Use of recycled packaging materials Use of recyclable packaging materials Packaging design to facilitate separation and sorting of different types of materials Packaging optimization (for secondary and tertiary packaging) Use of environmentally friendly paints on the packaging	Collection of data into databases in real-time Data archive Use of data from the database when defining a new work warrant Use of predictive analytics methods Connectivity to external databases Big Data Manipulation State-of-the-art computer infrastructure Flexible and modular hardware solutions Flexible and modular software solutions State-of-the-art internet infrastructure available to everyone Cloud Computing—online data processing ERP systems High network and data security Predictive hardware and software maintenance	Top connectivity with everyone in the value chain Special and high-performance communication channels (social networks) Decentralization within the company High motivation of each employee Willingness of workers to change High innovation of workers Adoption of the principles of lifelong learning Adoption of the principle of continuous improvement (lean, kaizen) Horizontal and vertical integration

Based on these objectives, the survey for the expert group was formed, and they evaluated each element from all five groups by three mentioned goals, ordered according to priority, on a scale from 1 to 9 in which 1 is the lowest priority and 9 is the highest. The expert group consists of 60 professionals from the field of manufacturing engineering and logistics, from which 30 were from academia and 30 were from the industry, with a minimum of 5 years of experience.

All weights were calculated by the normalized vector calculation procedure. This is performed by obtaining the sum of the mean values of the ranks of all Logistics 5.0 elements. After that, the weight of each element is calculated by dividing its mean value by the sum of the mean values of the ranks of all elements. Weights will be rounded according to the mathematical rule to 4 decimal places, and the sum of all weights must be 1.00.

The obtained priority vector of the company will be multiplied by the matrix of the priority vector, which consists of the weight of the elements obtained by the above surveys. In this way, using the rules of the AHP method, a ranked list of applicable Logistics 5.0 elements is obtained for each of the groups.

Apart from the standard AHP, there are several widely used variations of this method. One of them is the Fuzzy Analytic Hierarchy Process (F-AHP), which embeds the fuzzy theory into the basic Analytic Hierarchy Process (AHP) [34]. The standard AHP does not include vagueness for personal judgments, and it has been improved using the fuzzy logic approach. In F-AHP, the pairwise comparisons of both criteria and the alternatives are performed through linguistic variables, which are represented by triangular numbers. The Fuzzy AHP method systematically solves the selection problem using the concepts of fuzzy set theory and hierarchical structure analysis. Basically, the Fuzzy AHP method represents the elaboration of the standard AHP method into the fuzzy domain by using fuzzy numbers for calculation instead of real numbers.

Systems that do not include any information are represented in black and systems that include all information are represented in white. Systems between these two situations, which refer to systems that include partial information, are represented in grey. Grey systems explain the degree of information and relations between black and white systems. In grey system theory, numbers whose exact value is not known are shown with grey numbers.

Grey AHP (G-AHP) is another variation of the standard AHP. In G-AHP, grey numbers are used instead of crisp sets and crisp numbers. Pairwise comparisons are applied with linguistic scales and grey numbers in the G-AHP method. Grey numbers are used for pairwise comparisons and calculations [35].

Both G-AHP and F-AHP are widely used to quantify human judgments that are not precise (0 or 1, black or white). In this model, the standard AHP will be used, but the data will be structured to minimize the influence of imprecise human judgment. The data will be collected by an expert group in a questionnaire with a scale of 1–9, which can increase the precision of their judgments, which will later be processed by the normalized vector method and ranked by the Friedman test ranking method to quantify the final input data for the AHP.

The mathematical procedure of AHP, where the input data are the goal and element weights and the output data are the ranking of elements, is shown in Equation (1)

$$\begin{bmatrix} a_{11} & b_{12} & c_{13} \\ a_{21} & b_{22} & c_{23} \\ \cdots & \cdots & \cdots \\ a_{i1} & b_{i2} & c_{i3} \end{bmatrix} \times \begin{bmatrix} d_{11} \\ d_{21} \\ d_{23} \end{bmatrix} = \begin{bmatrix} e_{11} \\ e_{21} \\ \cdots \\ e_{i3} \end{bmatrix} \quad (1)$$

where:

a_{ij}—weights of return of investment time.

B_{ij}—weights of initial investment.

c_{ij}—weights of implementation and exploitation complexity.

d_{ij}—values of company priority vector calculated by the AHP method.

e_{ij}—ranks.
i—number of Logistics 5.0 elements.
$j = 3$—number of criteria.

The performance of the model was verified by providing the what-if analysis and simulation in which the predicted input generates the predicted output data, and minor changes of up to 5% do not cause a difference in the element ranks, which validates the robustness of the model.

AHP can identify and analyze the inconsistencies of a decision maker in the process of judging and evaluating the elements. Humans are rarely consistent in assessing the value or relationship of qualitative elements in the hierarchy. AHP mitigates this problem by measuring the degree of inconsistency and informing the decision maker.

If there was a possibility of precisely determining the values of the weight coefficients of all elements compared with each other at a given level of the hierarchy, the eigenvalues of the matrix (1) would be completely consistent.

However, if it is claimed, for example, that A is much more important than B, B is slightly more important than C, and C is slightly more important than A, inconsistency in problem-solving arises, and the reliability of the results decreases. The judgement errors can be calculated by a consistency index for the obtained comparison matrix, and then the degree of consistency can be calculated.

To calculate the degree of consistency (*CR*), the consistency index (*CI*) should first be calculated according to Equation (2):

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (2)$$

where λ_{max} is the maximum value of the comparison matrix. The closer λ_{max} is to n, the lower the inconsistency is. Saaty [32,36] proposed that we use this index by comparing it with the appropriate one. The appropriate Consistency index is called the Random Consistency Index (*RI*). He randomly generated a reciprocal matrix using this scale and obtained the random consistency index to determine whether it is approximately 10% or less. Then, he proposed what is called the Consistency Ratio, which is a comparison between the Consistency Index and the Random Consistency Index (3).

$$CR = \frac{CI}{RI} \quad (3)$$

If the value of the Consistency Ratio is smaller or equal to 10%, the inconsistency is acceptable. If the Consistency Ratio is greater than 10%, we need to revise the subjective judgment.

The consistency in the criteria (goal) evaluation should always be checked because of the influence of human subjectivity. That is why a company must always set the priorities of each goal with the help of an expert in the decision-making process, to minimize the inconsistency level, which is, by AHP standards, a maximum of 10% (0, 1).

4.2. Results

The ranking of the elements of Logistics 5.0 is performed according to the following principles:

- Implementation of elements with a shorter return of investment time, which means that the elements with a shorter ROI time have a higher weight.
- Implementation of elements where the company is more willing to invest financially, which means that the elements in which the companies are more willing to invest have a higher weight.
- Implementation of elements with less complexity of implementation and exploitation, which means that the elements that are simpler in terms of implementation and exploitation have a higher weight.

The ranking of the elements of groups of criteria according to a certain goal is shown in Tables 2–6.

Table 2. Ranks and weights of green transport elements.

Element	Return of Investment Time		Initial Investment		Implementation and Exploitation Strategy	
	Rank	Weight	Rank	Weight	Rank	Weight
Reduce paper consumption (E1)	5.5278	0.0838	6.8571	0.1039	6.8214	0.1034
Toner and ink recycling (E2)	4.8889	0.0741	8	0.1212	9.0357	0.1369
Shutting down computers when not in use (E3)	3.5556	0.0842	8.6429	0.131	8.4643	0.1282
Use of reusable containers and transport equipment (E4)	6.5	0.0985	4	0.0606	5.4643	0.0828
Use of reusable pallets (E5)	6.9722	0.1056	5.3571	0.0812	6.7857	0.1028
Reduction of unused space in the vehicle (E6)	6.8611	0.104	6.8214	0.1034	5.2143	0.079
Reducing downtime (E7)	7.1944	0.109	6.8571	0.1039	4.8571	0.0736
Increasing the usability of space in height within the vehicle (E8)	6.1667	0.0934	7.0357	0.1066	5.3929	0.0817
Use of a vehicle with alternative (renewable) fuel sources (energy) (E9)	4.5278	0.0686	3.3929	0.0514	5.4643	0.0828
Introduction of alternative energy sources in refrigerated vehicles (E10)	4.1944	0.0636	3.5	0.053	4.1429	0.0628
Route optimization (E11)	7.6111	0.1153	5.5357	0.0839	4.3571	0.066
∑	66	1	66	1	66	1

Table 3. Ranks and weights of green warehousing elements.

Element	Return of Investment Time		Initial Investment		Implementation and Exploitation Strategy	
	Rank	Weight	Rank	Weight	Rank	Weight
Reduce paper consumption (E1)	8.6579	0.0721	11.1071	0.0926	9.8929	0.0824
Toner and ink recycling (E2)	8.4211	0.0702	13.25	0.1104	13.1071	0.1092
Shutting down computers when not in use (E3)	9.25	0.0771	13.6786	0.114	11.8929	0.0991
Use of more efficient lighting devices (E4)	9.7632	0.0814	8.8571	0.0738	9.4286	0.0786
Using light sensors inside the aisle to turn the light on only where someone is (E5)	8.5263	0.0711	10.6429	0.0887	11.0714	0.0923
Use of more efficient heating devices (E6)	8.7763	0.0731	4.9286	0.0411	4.5357	0.0378
Use of more efficient air conditioning devices (E7)	8.3158	0.0693	4.2857	0.0357	4.9643	0.0414
Optimization of transport flows within the warehouse (E8)	8.1711	0.0681	9.8571	0.0821	6.6429	0.0554
Introduction of fans for circulation of hot and cold air (E9)	6.9605	0.058	8.6071	0.0717	7.5357	0.0628
Using a door with automatic closing sensors (E10)	7.6579	0.0638	9.8214	0.0818	11.1429	0.0929
Increasing the energy efficiency of warehouses (E11)	6.7368	0.0561	5.5714	0.0464	5.7143	0.0476
Using materials that are better insulators (warehouse walls and roofs) (E12)	7.6447	0.0637	4.3929	0.0366	7.6071	0.0634
Use of renewable energy sources (E13)	7.8421	0.0654	4.7143	0.0393	6.1071	0.0509
Introduction of new storage technologies (E14)	6.9079	0.0576	6.1071	0.0509	5.1786	0.0432
Use of automated transport systems (E15)	6.3684	0.0531	4.1786	0.0348	5.1786	0.0432
∑	120	1	120	1	120	1

Table 4. Ranks and weights of green packaging elements.

Element	Return of Investment Time		Initial Investment		Implementation and Exploitation Strategy	
	Rank	Weight	Rank	Weight	Rank	Weight
Requiring the supplier to take over his packaging in which he delivers the goods (E1)	5.1458	0.1144	6.8214	0.1516	4.6071	0.1024
Existence of pallet management (return) system (E2)	5.7083	0.1269	6.25	0.1389	5.6071	0.1246
Using packaging materials that have less weight (E3)	5.7083	0.1269	5.6071	0.1246	5.75	0.1278
Use of biodegradable materials (E4)	4.7917	0.1065	3.25	0.0722	4.9286	0.1095
Use of recycled packaging materials (E5)	4.7917	0.1065	5.4286	0.1206	5.3214	0.1183
Use of recyclable packaging materials (E6)	5.0625	0.1125	5.4286	0.1206	5.2143	0.1159
Packaging design to facilitate separation and sorting of different types of materials (E7)	4.8333	0.1074	3.0357	0.0675	3.5	0.0778
Packaging optimization (for secondary and tertiary packaging) (E8)	4.5	0.1	4.5714	0.1016	3.4643	0.077
Use of environmentally friendly paints on the packaging (E9)	4.4583	0.0991	4.6071	0.1024	6.6071	0.1468
∑	45	1	45	1	45	1

Table 5. Ranks and weights of infrastructure elements.

Element	Return of Investment Time		Initial Investment		Implementation and Exploitation Strategy	
	Rank	Weight	Rank	Weight	Rank	Weight
Collection of data into databases in real-time (E1)	7.8	0.0743	8.4333	0.0803	7.9667	0.0759
Data archive (E2)	8.1667	0.0778	8.15	0.0776	8.6833	0.0827
Use of data from the database when defining a new work warrant (E3)	7.4	0.0705	8.2667	0.0787	7.6667	0.073
Use of predictive analytics methods (E4)	7.6833	0.0732	6.9167	0.0659	7.05	0.0671
Connectivity to external databases (E5)	6.3333	0.0603	6.9	0.0657	7.5167	0.0716
Big Data Manipulation (E6)	7.65	0.0729	6.1167	0.0583	5.9	0.0562
State-of-the-art computer infrastructure (E7)	6.25	0.0595	7.7167	0.0735	6.85	0.0652
Flexible and modular hardware solutions (E8)	7.3667	0.0702	7.4833	0.0713	7.0167	0.0668
Flexible and modular software solutions (E9)	7.25	0.069	8.2667	0.0787	7.7833	0.0741
State-of-the-art internet infrastructure available to everyone (E10)	7.4333	0.0708	8.2	0.0781	8.4	0.08
Cloud Computing—online data processing (E11)	7.3833	0.0703	8.0333	0.0765	7.8333	0.0746
ERP systems (E12)	8.35	0.0795	6.1167	0.0583	7.3167	0.0697
High network and data security (E13)	8.35	0.0795	6.3833	0.0608	7.4833	0.0713
Predictive hardware and software maintenance (E14)	7.5833	0.0722	8.0167	0.0763	7.5333	0.0717
∑	105	1	105	1	105	1

Table 6. Ranks and weights of organization and human resources elements.

Element	Return of Investment Time		Initial Investment		Implementation and Exploitation Strategy	
	Rank	Weight	Rank	Weight	Rank	Weight
Top connectivity with everyone in the value chain (E1)	4.2167	0.0937	5.1	0.1133	4.5667	0.1015
Special and high-performance communication channels (social networks) (E2)	5.5833	0.1241	4.1667	0.0926	6.6167	0.147
Decentralization within the company (E3)	4.8167	0.107	3.6167	0.0804	5.1167	0.1137
High motivation of each employee (E4)	5.3667	0.1193	5.2	0.1156	5.3	0.1178
Willingness of workers to change (E5)	5.2333	0.1163	6.3667	0.1415	4.0167	0.0893

Table 6. *Cont.*

Element	Return of Investment Time		Initial Investment		Implementation and Exploitation Strategy	
	Rank	Weight	Rank	Weight	Rank	Weight
High innovation of workers (E6)	5.25	0.1167	5.3167	0.1181	4.15	0.0922
Adoption of the principles of lifelong learning (E7)	5.3833	0.1196	5.6167	0.1248	5.0833	0.113
Adoption of the principle of continuous improvement (lean, kaizen) (E8)	4.9667	0.1104	5.35	0.1189	5.25	0.1167
Horizontal and vertical integration (E9)	4.1833	0.093	4.2667	0.0948	4.9	0.1089
∑	45	1	45	1	45	1

Practical Case Simulation

The functionality, useability, and reliability of the Logistics 5.0 implementation model will be shown using an example of a company with the following goal priorities:

The company aims to find the highest importance of the minimum initial investment, but also with the shortest return on investment time.

Therefore, the priority matrix for each of the five groups is formed in Expert Choice software, as shown in Figure 2.

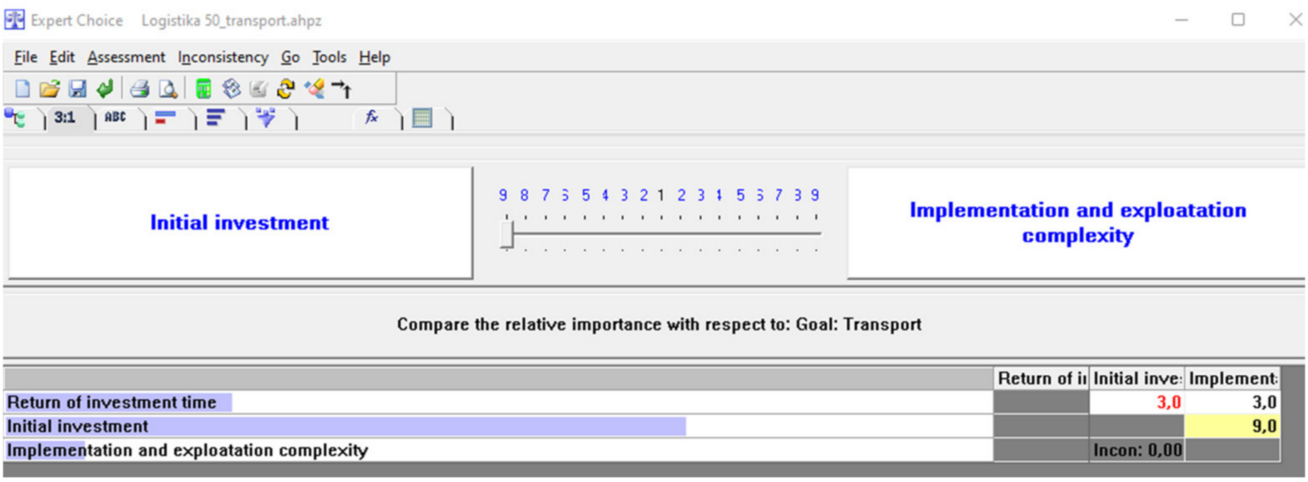


Figure 2. Goal priority matrix.

The weights of each criterion are filled in the software with the option 'Direct ratings' to minimize the influence of human subjectivity in the entire process, as shown in Figure 3.

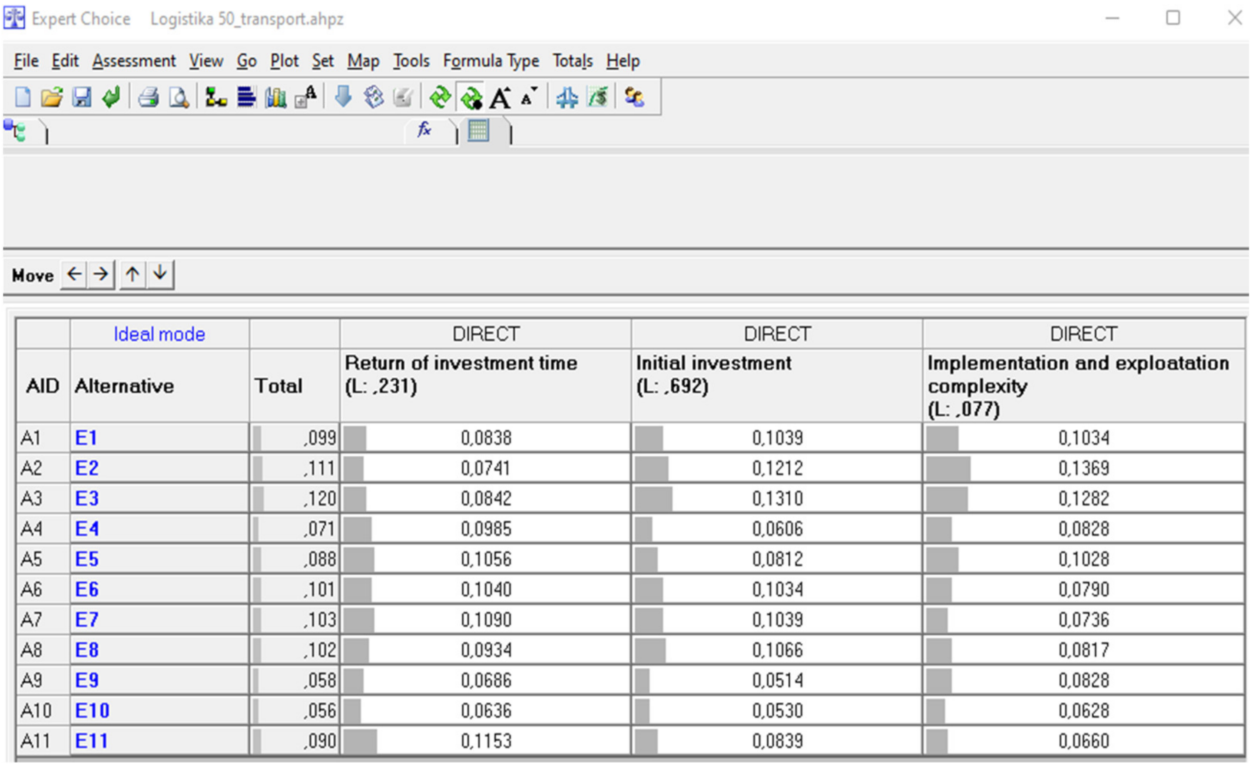
After the calculation, the output is the priority list of elements of each group for the implementation, as shown in the example for the warehousing group in Figure 4.

Therefore, the highest priority for implementation has the E3 element from the Warehousing group, which is 'Shutting down computers when not in use'.

The priorities for the implementation of the elements from each group are shown in Table 7.

If the company has already implemented certain elements from the list, it can move past them in the list and continue with others.

As shown in Table 6, the highest priority to be implemented by the group 'Green transport' is 'Shutting down computers when not in use', 'Toner and ink recycling', and 'Reduction of unused space in the vehicle'. The last priority for the implementation was 'Introduction of alternative energy sources in refrigerated vehicles', which leads to the conclusion that the results are accurate according to the importance of the goal of low initial financial investment. In the second group of 'Green packaging', the first element to be implemented is 'Requiring the supplier to take over his packaging in which he delivers the goods', while in Green warehousing, it is also 'Shutting down computers when not in use'. Compared to the weights from the development phase, this proves the efficiency of the model because the elements that have the highest weights according to certain goals also have top priority after analytics with the AHP method.



	Ideal mode		DIRECT	DIRECT	DIRECT
AID	Alternative	Total	Return of investment time (L: ,231)	Initial investment (L: ,692)	Implementation and exploatation complexity (L: ,077)
A1	E1	,099	0,0838	0,1039	0,1034
A2	E2	,111	0,0741	0,1212	0,1369
A3	E3	,120	0,0842	0,1310	0,1282
A4	E4	,071	0,0985	0,0606	0,0828
A5	E5	,088	0,1056	0,0812	0,1028
A6	E6	,101	0,1040	0,1034	0,0790
A7	E7	,103	0,1090	0,1039	0,0736
A8	E8	,102	0,0934	0,1066	0,0817
A9	E9	,058	0,0686	0,0514	0,0828
A10	E10	,056	0,0636	0,0530	0,0628
A11	E11	,090	0,1153	0,0839	0,0660

Figure 3. Elements and their weights as alternatives in Expert Choice software.

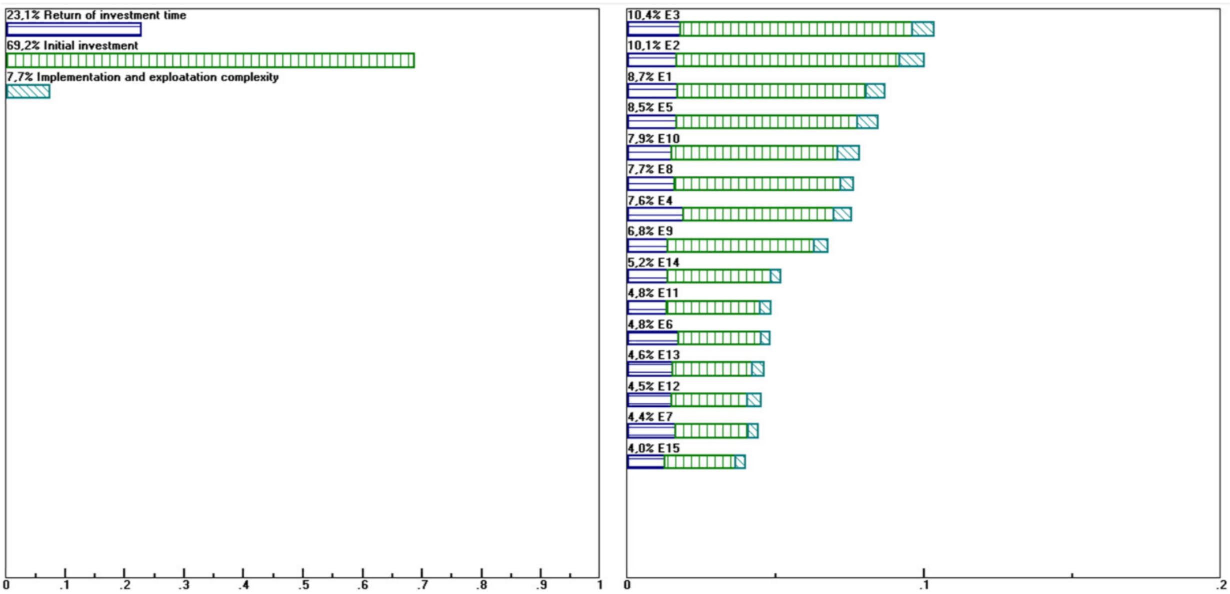


Figure 4. Rank of elements (alternative)—results of a decision-making process.

Table 7. Logistics 5.0 transformation strategy—rank of elements.

Rank	Green Transport	Green Packaging	Green Warehousing	Infrastructure	Organization and Human Resources
1	Shutting down computers when not in use	Requiring the supplier to take over his packaging in which he delivers the goods	Shutting down computers when not in use	Collection of data into databases in real-time	Special and high-performance communication channels (social networks)
2	Toner and ink recycling	Existence of pallet management (return) system	Toner and ink recycling	Data archive	High motivation of each employee
3	Reduction of unused space in the vehicle	Using packaging materials that have less weight	Reduce paper consumption	Use of data from the database when defining a new work warrant	Adoption of the principles of lifelong learning
4	Reducing downtime	Use of recycled packaging materials	Using light sensors inside the aisle to turn the light on only where someone is	Flexible and modular software solutions	Willingness of workers to change
5	Increasing the usability of space in height within the vehicle	Use of recyclable packaging materials	Using a door with automatic closing sensors	State-of-the-art internet infrastructure available to everyone	High innovation of workers
6	Reduce paper consumption	Use of environmentally friendly paints on the packaging	Use of more efficient lighting devices	Cloud Computing—online data processing	Adoption of the principle of continuous improvement (lean, kaizen)
7	Route optimization	Packaging optimization (for secondary and tertiary packaging)	Optimization of transport flows within the warehouse	Predictive hardware and software maintenance	Decentralization within the company
8	Use of reusable pallets	Use of biodegradable materials	Introduction of fans for circulation of hot and cold air	State-of-the-art computer infrastructure	Top connectivity with everyone in the value chain
9	Use of reusable containers and transport equipment	Packaging design to facilitate separation and sorting of different types of materials	Introduction of new storage technologies	Flexible and modular hardware solutions	Horizontal and vertical integration
10	Use of a vehicle with alternative (renewable) fuel sources (energy)		Use of more efficient heating devices	Use of predictive analytics methods	
11	Introduction of alternative energy sources in refrigerated vehicles		Increasing the energy efficiency of warehouses	Connectivity to external databases	
12			Using materials that are better insulators (warehouse walls and roofs)	High network and data security	
13			Use of renewable energy sources	ERP systems	
14			Use of more efficient air conditioning devices	Big Data Manipulation	
15			Use of automated transport systems		

5. Discussion

The results have shown that decision support systems, in this case, the analytic hierarchy process, can be a useful tool when deciding on the transitional strategy towards Logistics 5.0. If the company has not already started the transition process and depends on traditional technologies, not only in the logistics but also in every other aspect, an optimal strategy plan must be set to increase the future beneficial impact of digital technologies and reduce possible additional and unwanted costs. Decision support systems have already been used in calculating the readiness of a single company for Industry 4.0 [37–40], with that used as a starting point for the transitional strategy definition. In this research, the analytic hierarchy process has been proven to be a useful tool with a novel approach towards Logistics 4.0, which combines digital technologies, ecological and sustainable aspects, and human-centered awareness. Using expert groups for model development and the quantification of qualitative criteria via the normalized vector method, the level of human subjectivity has been minimized in the process, as opposed to many other methods previously presented where a single user evaluates the condition of a company by rough methods [5,40–46]. As of Logistics 5.0, there are few research studies published on this topic, mostly as a description of a theoretical framework of this concept [6,12,18,20]. At the same time, there are few published research studies on the topic of Logistics 4.0 readiness as well, which can be related to this paper and the presented implementation model [27–30,47].

These studies do not evaluate the overall area of internal logistics, its partial activities, or even the concept of logistics activities within the company in detail.

Zoubek and Simon (2021) [47] provided a maturity model for internal Logistics 4.0 and noted that one of the most important segments of the implementation of a digital concept is the implementation of the Internet of Things segment and general connectivity within the system. They evaluated a system according to five levels by five main dimensions, with three subdimensions for each. The model presented in this paper takes a more detailed approach with many more detailed evaluations and an overview of several aspects of the logistics. Cyplik et al. (2019) [48] structured a model in three dimensions (areas): Management, physical processes, and information flow process area. The highest weight is given to a 'Utilization of supply chain management systems' in the 'Management area'; the robotization of processes in the 'Physical process area', and 'Real time data-access', 'Data Analysis technology', and 'Cloud Computer technologies' in the information flow process area. The criteria were evaluated by an expert group, and certain similarities can be found in the 'Information flow process area' in which big data analytics was also recognized as one of the elements with the highest value (weights). Gupta, Singh, and Gupta (2021) [49] used the Fuzzy AHP method for the prioritization of manpower readiness factors in the research, where the highest importance was given to training and functional skills for development followed by top management support and commitment to digitalization and organizational culture for process digitalization. The results of our research in the field of human resources have given only slightly different results in which the top priority was given to the implementation of high-performance communication channels (social networks), but also to high motivation to each employee and willingness of workers to change, which can be related to organizational culture and top management support for change. The Logistics 5.0 implementation model is a useful and simple tool for the management of every company with an aspiration to transition their logistics department towards an advanced state-of-art digital concept. Digitization towards a flexible, sustainable, eco-friendly, and human-centered system can rapidly adapt to any demand from the market and achieve personalized products or services with optimal utilization of human knowledge. The changes occur, not only at the physical level but also at the organizational level, due to which it increases the complexity of the implementation. The risks are high due to high investments, because of which the tool for the optimal strategy definition is very useful to avoid unnecessary loss in various types of resources. The core of this model is based on the knowledge of experts in the field of logistics and production management, which makes it relevant and reliable, and the structure of the model using the analytic hierarchy process implemented in Expert Choice software enables accessibility, with primary results the company can use to test multiple strategy scenarios via what-if analysis.

Limitations

The AHP method has several limitations, and those were minimized by cautious structuring of the Logistics 5.0 implementation model. The possible inconsistency in the decision-making process, which increases with more complex problems that consist of many criteria, was avoided by defining weights of the criteria with the normalized vector method, after the ranking of the Logistics 5.0 elements with a statistical method using the Friedman test. The risk of inconsistency remains in the use of the pairwise comparison of the goals as input data. This can be avoided by the supervision of an expert from the evaluating team. According to R. W. Saaty (1987), the acceptable inconsistency rate is 0.1. Another significant limitation, t influence of human subjectivity in the decision-making process, was minimized by the evaluation of an expert group.

6. Conclusions

The decade of Industry 4.0 is behind us. In the meantime, many theoretical frameworks have been presented, but not many have implemented the complete system in practice. Natural development has led to the implementation of its fragments, but few have had the possibility to enact a full implementation and overall digitization of their work environment. The reasons behind this were the most common barriers, already studied in the literature, such as a fear of change, the lack of needed skills or knowledge, or lack of a transitional strategy to maximize the benefits of a digital system in the future. Lately, the term "Society 5.0" has been presented, which is an upgrade from Industry 4.0 and is related to an entire digital society with high awareness of the human component within. Similarly, the framework of Industry 5.0 has been developed along with all of its components, such as Logistics 5.0. The implementation challenges have remained the same, because of which, in this paper, an implementation model based on decision support systems for Logistics 5.0 has been developed. The preposition was given that one of the key facts is to decide the strategy of optimal implementation of Logistics 5.0 elements. That is why the decision support systems were used as a tool for strategy definition, in this case, it was the analytic hierarchy process. The input data were a decision tree with three goals (initial investment, return of investment time, and implementation and exploitation complexity), which served as an input defined by the company for which the strategy is being formed. The goals in the decision tree serve as the criteria, and the output is a rank of alternatives of Logistics 5.0 elements divided into five groups (green transport, green warehousing, green packaging, infrastructure and organization, and human resources). This provides an answer to RQ2. During the implementation model development phase, the expert group ranked the elements in each group by all three goals. The collected data were processed by statistical methods of ranking using the Friedman test and the normalized vector method to define the weights of each element, which answers RQ1.

From this point, there are several research perspectives possible in the future. One is the development of such a model for other organizational segments of a company such as manufacturing, production planning and control, maintenance, human resources, accounting, etc. Second is the possibility to conduct research on a sample of companies in single or multiple regions to gain insight into the differences in personalized implementation strategies based on chosen goals. Fifth is the development of the same model in other decision support systems to observe how the difference in mathematical methodologies influences the results.

Author Contributions: Conceptualization, T.O., G.Đ., M.T. and H.C.; methodology, H.C.; software, M.T.; validation T.O.; formal analysis, M.T.; investigation, T.O. and M.T.; resources, G.Đ.; data curation, H.C.; writing—original draft preparation, M.T.; writing—review and editing, G.Đ. and H.C.; visualization, T.O.; supervision, T.O. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data available on request from the correspondence author.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Scoones, I. Sustainability. *Dev. Pract.* **2010**, *17*, 589–596. [CrossRef]
2. Burroughs, B.; Burroughs, W.J. Digital Logistics: Enchantment in Distribution Channels. *Technol. Soc.* **2020**, *62*, 101277. [CrossRef] [PubMed]
3. Ghobakhloo, M. Industry 4.0, Digitization, and Opportunities for Sustainability. *J. Clean. Prod.* **2020**, *252*, 119869. [CrossRef]
4. Potočan, V.; Mulej, M.; Nedelko, Z. Society 5.0: Balancing of Industry 4.0, Economic Advancement and Social Problems. *Kybernetes* **2021**, *50*, 794–811. [CrossRef]
5. Castelo-Branco, I.; Cruz-Jesus, F.; Oliveira, T. Assessing Industry 4.0 Readiness in Manufacturing: Evidence for the European Union. *Comput. Ind.* **2019**, *107*, 22–32. [CrossRef]
6. Sgarbossa, F.; Grosse, E.H.; Neumann, W.P.; Battini, D.; Glock, C.H. Human Factors in Production and Logistics Systems of the Future. *Annu. Rev. Control* **2020**, *49*, 295–305. [CrossRef]
7. Ageron, B.; Gunasekaran, A.; Spalanzani, A. Sustainable Supply Management: An Empirical Study. *Int. J. Prod. Econ.* **2012**, *140*, 168–182. [CrossRef]
8. El-Berishy, N.; Rügge, I.; Scholz-Reiter, B. The Interrelation between Sustainability and Green Logistics. *IFAC Proc. Vol.* **2013**, *46*, 527–531. [CrossRef]
9. Opetuk, T. *Model of Green Supply Chain Management Implementation*; Faculty of Mechanical Engineering and Naval Architecture: Zagreb, Croatia, 2016.
10. Zhang, G.; Zhao, Z. Green Packaging Management of Logistics Enterprises. *Phys. Procedia* **2012**, *24*, 900–905. [CrossRef]
11. Winkelhaus, S.; Grosse, E.H. Logistics 4.0: A Systematic Review towards a New Logistics System. *Int. J. Prod. Res.* **2019**, *58*, 18–43. [CrossRef]
12. Frederico, G.F. Logistics Review from Supply Chain 4.0 to Supply Chain 5.0: Findings from a Systematic Literature Review and Research Directions. *Logistics* **2021**, *5*, 49. [CrossRef]
13. Bhargava, A.; Bhargava, D.; Kumar, P.N.; Sajja, G.S.; Ray, S. Industrial IoT and AI Implementation in Vehicular Logistics and Supply Chain Management for Vehicle Mediated Transportation Systems. *Int. J. Syst. Assur. Eng. Manag.* **2022**, *13*, 673–680. [CrossRef]
14. Figueiras, P.; Lourenco, L.; Costa, R.; Graca, D.; Garcia, G.; Jardim-Goncalves, R. Big data provision for digital twins in industry 4.0 logistics processes. In Proceedings of the 2021 IEEE International Workshop on Metrology for Industry 4.0 and IoT, MetroInd 4.0 and IoT 2021, Rome, Italy, 7–9 June 2021; pp. 516–521. [CrossRef]
15. Domańsk, R. Logistics 4.0. In *Warehousing—Current State and Trends: Business Logistics in Modern Management, Proceedings of the 2019 19th International Scientific Conference Business Logistics in Modern Management, Osijek, Croatia, 10–11 October 2019*; EFOS: Osijek, Croatia, 2019.
16. Demir, E.; Hrušovský, M.; Jammernegg, W.; van Woensel, T. Green Intermodal Freight Transportation: Bi-Objective Modelling and Analysis. *Int. J. Prod. Res.* **2019**, *57*, 6162–6180. [CrossRef]
17. Cimini, C.; Lagorio, A.; Romero, D.; Cavalieri, S.; Stahre, J. Smart Logistics and The Logistics Operator 4.0. *IFAC-Pap.* **2020**, *53*, 10615–10620. [CrossRef]
18. Vijayakumar, V.; Sgarbossa, F.; Neumann, W.P.; Sobhani, A. Framework for Incorporating Human Factors into Production and Logistics Systems. *Int. J. Prod. Res.* **2021**, *60*, 402–419. [CrossRef]
19. Cai, L.; Li, W.; Luo, Y.; He, L. Real-Time Scheduling Simulation Optimisation of Job Shop in a Production-Logistics Collaborative Environment. *Int. J. Prod. Res.* **2022**, *60*. [CrossRef]
20. Maniah; Milwandhari, S. Risk Analysis of Cloud Computing in the Logistics Process. In Proceedings of the 2020 3rd International Conference on Vocational Education and Electrical Engineering: Strengthening the Framework of Society 5.0 through Innovations in Education, Electrical, Engineering and Informatics Engineering, ICVEE 2020, Surabaya, Indonesia, 3–4 October 2020. [CrossRef]
21. Lopes de Sousa Jabbour, A.B.; Chiappetta Jabbour, C.J.; Sarkis, J.; Latan, H.; Roubaud, D.; Godinho Filho, M.; Queiroz, M. Fostering Low-Carbon Production and Logistics Systems: Framework and Empirical Evidence. *Int. J. Prod. Res.* **2020**, *59*, 7106–7125. [CrossRef]
22. Zekhnini, K.; Cherrafi, A.; Bouhaddou, I.; Chaouni Benabdellah, A.; Bag, S. A Model Integrating Lean and Green Practices for Viable, Sustainable, and Digital Supply Chain Performance. *Int. J. Prod. Res.* **2021**, *59*. [CrossRef]
23. Kim, S.; Foerstl, K.; Schmidt, C.G.; Wagner, S.M. Adoption of Green Supply Chain Management Practices in Multi-Tier Supply Chains: Examining the Differences between Higher and Lower Tier Firms. *Int. J. Prod. Res.* **2021**, *55*, 6407–6422. [CrossRef]
24. Choi, T.M.; Siqin, T. Blockchain in Logistics and Production from Blockchain 1.0 to Blockchain 5.0: An Intra-Inter-Organizational Framework. *Transp. Res. Part E Logist. Transp. Rev.* **2022**, *160*, 102653. [CrossRef]

25. Bhat, S.A.; Huang, N.F.; Sofi, I.B.; Sultan, M. Agriculture-Food Supply Chain Management Based on Blockchain and IoT: A Narrative on Enterprise Blockchain Interoperability. *Agriculture* **2022**, *12*, 40. [CrossRef]
26. Ivanov, D.; Dolgui, A.; Sokolov, B. Cloud Supply Chain: Integrating Industry 4.0 and Digital Platforms in the Supply Chain-as-a-Service. *Transp. Res. Part E Logist. Transp. Rev.* **2022**, *160*, 102676. [CrossRef]
27. Sternad, M.; Lerher, T.; Gajšek, B. Maturity levels for logistics 4.0 based on Nrw's industry 4.0 maturity model. In Proceedings of the 18th International Scientific Conference Business Logistics in Modern Management, Osijek, Croatia, 11–12 October 2018.
28. Yavas, V.; Ozkan-Ozen, Y.D. Logistics Centers in the New Industrial Era: A Proposed Framework for Logistics Center 4.0. *Transp. Res. Part E Logist. Transp. Rev.* **2020**, *135*, 101864. [CrossRef]
29. Oleśków-Szłapka, J.; Stachowiak, A. The Framework of Logistics 4.0 Maturity Model. *Adv. Intell. Syst. Comput.* **2019**, *835*, 771–781. [CrossRef]
30. Facchini, F.; Olésków-Szłapka, J.; Ranieri, L.; Urbinati, A. A Maturity Model for Logistics 4.0: An Empirical Analysis and a Roadmap for Future Research. *Sustainability* **2020**, *12*, 86. [CrossRef]
31. Gökalp, E.; Martinez, V. Digital Transformation Maturity Assessment: Development of the Digital Transformation Capability Maturity Model. *Int. J. Prod. Res.* **2021**, *59*. [CrossRef]
32. Saaty, T.L. What is the analytic hierarchy process? In *Mathematical Models for Decision Support*; Springer: Berlin/Heidelberg, Germany, 1988; pp. 109–121. [CrossRef]
33. Trstenjak, M. *A Model for Calculating the Process Planning Oriented Industry 4.0 Readiness Factor*; Faculty of Mechanical Engineering and Naval Architecture: Zagreb, Croatia, 2021.
34. Yamashita, T. Fuzzy Ratings and Crisp Feedback in Fuzzy AHP for Supporting Human Decision Making. *J. Adv. Comput. Intell. Intell. Inform.* **2006**, *10*, 219–224. [CrossRef]
35. Huang, G.; Sun, S.; Zhang, D. Safety Evaluation of Construction Based on the Improved AHP-Grey Model. *Wirel. Pers. Commun.* **2018**, *103*, 209–219. [CrossRef]
36. Saaty, R.W. The Analytic Hierarchy Process—What It Is and How It Is Used. *Math. Model.* **1987**, *9*, 161–176. [CrossRef]
37. Schumacher, A.; Erol, S.; Sihn, W. A Maturity Model for Assessing Industry 4.0 Readiness and Maturity of Manufacturing Enterprises. *Procedia CIRP* **2016**, *52*, 161–166. [CrossRef]
38. Basl, J.; Doucek, P. A Metamodel for Evaluating Enterprise Readiness in the Context of Industry 4.0. *Information* **2019**, *10*, 89. [CrossRef]
39. Lucato, W.C.; Pacchini, A.P.T.; Facchini, F.; Mummolo, G. Model to Evaluate the Industry 4.0 Readiness Degree in Industrial Companies. *IFAC-Pap.* **2019**, *52*, 1808–1813. [CrossRef]
40. De Carolis, A.; Macchi, M.; Negri, E.; Terzi, S. A Maturity Model for Assessing the Digital Readiness of Manufacturing Companies. *IFIP Adv. Inf. Commun. Technol.* **2017**, *513*, 13–20. [CrossRef]
41. Brozzi, R.; D'Amico, R.D.; Pasetti Monizza, G.; Marcher, C.; Riedl, M.; Matt, D. Design of Self-Assessment Tools to Measure Industry 4.0 Readiness. A Methodological Approach for Craftsmanship SMEs. *IFIP Adv. Inf. Commun. Technol.* **2018**, *540*, 566–578. [CrossRef]
42. Maisiri, W.; van Dyk, L. Industry 4.0 Readiness Assessment for South African Industries. *S. Afr. J. Ind. Eng.* **2019**, *30*, 134–148. [CrossRef]
43. Tripathi, S.; Gupta, M. Indian Supply Chain Ecosystem Readiness Assessment for Industry 4.0. *Int. J. Emerg. Mark.* **2021**, ahead of print. [CrossRef]
44. Pirola, F.; Cimini, C.; Pinto, R. Digital Readiness Assessment of Italian SMEs: A Case-Study Research. *J. Manuf. Technol. Manag.* **2020**, *31*, 1045–1083. [CrossRef]
45. Machado, C.G.; Winroth, M.; Carlsson, D.; Almström, P.; Centerholt, V.; Hallin, M. Industry 4.0 Readiness in Manufacturing Companies: Challenges and Enablers towards Increased Digitalization. *Procedia CIRP* **2019**, *81*, 1113–1118. [CrossRef]
46. Sriram, R.M.; Vinodh, S. Analysis of Readiness Factors for Industry 4.0 Implementation in SMEs Using COPRAS. *Int. J. Qual. Reliab. Manag.* **2021**, *38*, 1178–1192. [CrossRef]
47. Zoubek, M.; Simon, M. A Framework for a Logistics 4.0 Maturity Model with a Specification for Internal Logistics. *MM Sci. J.* **2021**, *2021*, 4264–4274. [CrossRef]
48. Cyplik, P.; Oleskow-Szlapka, J.; Tobola, A.; Adamczak, M. Building a model for assessing the maturity of Polish enterprises in terms of logistics 4.0 assumptions. In Proceedings of the 19th International Scientific Conference Business Logistics in Modern Management, Osijek, Croatia, 10–11 October 2019.
49. Gupta, A.; Singh, R.K.; Gupta, S. Developing Human Resource for the Digitization of Logistics Operations: Readiness Index Framework. *Int. J. Manpow.* **2021**, *43*, 355–379. [CrossRef]