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UNCERTAINTY IN IT SYSTEMS FOR MANAGING LOGISTICS PROCESSES AT LOGISTICS CENTERS

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Purpose: The purpose of this article is to assess IT-related uncertainties in the management of logistics processes at logistics centers (LC). The research question is formulated as follows: To what extent does uncertainty affect the IT system used in the management of logistics processes at logistics centers?
Design/methodology/approach: This study employed a literature review, uncertainty analysis methodologies based on the use of an IT system registry, and mathematical methods. The analysis covered the IT system used in the logistics process by LC logistics operators.
Findings: The results of the calculations show that, of the five information events in the logistics processes of the analyzed CL, two are characterized by a moderate level of significance, two are highly significant, and one is critical. In this case, there are no insignificant events.
Research limitations/implications: The study focused exclusively on the IT system within the logistics process at LC. It is suggested that the method under consideration be refined by assessing the impact of logistics process uncertainty on various aspects and outcomes at LC. Future research should cover other areas such as collaboration with partners, deliveries to LC, and customer relations (CRM).
Practical implications: Uncertainty analysis of logistics systems can be used as an ongoing analysis of events throughout the supply chain, followed by a comparison of the results with management decisions.
Social implications: It is recommended that the method proposed in this paper be used to identify and mathematically assess the uncertainty of information systems in LC, in combination with other methods, such as decision trees or scenario analysis.
Originality/value: A research gap has been identified: there is a lack of research on uncertainty and unforeseeable events in the flow of information and their impact on logistics processes at operators' logistics centers.
Keywords: uncertainty, IT system, logistics process, logistics operator.
Category of the paper: research paper.

1. Introduction

Modern logistics companies operate in an environment characterized by increased uncertainty and dynamism, which is why they must adapt flexibly to changing external conditions (Kirzner, 2024). In the era of globalization, communication and transportation form a strong foundation for properly functioning international supply chains (Yang et al., 2025). Today, logistics operators should take into account trends indicating a marked increase in the use of intermodal transport, where logistics centers play a crucial role (Vlachos, Polichronidou, 2022).

In an era of economic development based primarily on knowledge and information, the ability to anticipate specific events and adapt a logistics operator's policies accordingly is particularly important. Modern companies operating within supply chains or supply networks face a clear management paradox (Kocabasoglu-Hillmer et al., 2023). On the one hand, the goal is to ensure the greatest possible operational stability in conditions of uncertainty and unpredictability, but on the other hand, to strive for flexibility and constant change manifested through innovation. The key challenge for logistics operators is to achieve the most effective adaptation to the changing environment in order to eliminate the level of unpredictable events that is unacceptable to customers, which then becomes a real problem for the company (Cichosz et al., 2025).

Logistics processes encompass not only the flow of goods, but also the flow of information and financial resources. The ever-expanding scope of logistics increases the number of processes and risk situations that may arise in a company's logistics operations (Lagorio et al., 2023). Uncertainty refers to the probability of an event occurring that could negatively impact a logistics operator's ability to achieve its objectives. In the current economic climate, the systematic identification and analysis of uncertainties affecting business processes and their productivity appears essential to ensuring a company's survival and competitiveness. The efficiency of logistics systems is inextricably linked to uncertainty, which necessitates the continuous development of methods and tools for managing uncertainty. However, in every logistics process, random events occur. This stems primarily from the fact that the economic instability faced by companies does not follow a simple cause-and-effect relationship and cannot be directly equated with the phenomenon of variability. Uncertainty management involves the process of decision-making and implementing actions, including the analysis of unpredictable events and the development of strategies to minimize them in order to achieve planned financial results and create operational conditions for the flow of goods in the supply chain through proper analysis of information within the system. The drive to ensure an adequate level of competitiveness for logistics systems in the challenging conditions of the modern economy has become the driving force behind the development of various concepts for resource conservation and loss minimization, the implementation of which may be hindered by certain barriers, including the high sensitivity of individual logistics processes.

The aim of this article is to assess uncertainty in the IT system used for managing logistics processes in logistics centers and to develop recommendations for improving the methodology of uncertainty analysis based on the use of an IT system registry and a mathematical method. The research problem is formulated as follows: to what extent does uncertainty affect the IT system in the management of logistics processes at logistics centers? The research gap lies in the lack of studies on the state of uncertainty and unpredictable events in the flow of information and their impact on logistics processes at operators' logistics centers.

2. Logistics Centers in Supply Chains: A Literature Review

2.1. Logistics centers as supply chain hubs

A logistics center initiates or supports economic activity, particularly in the field of logistics. The presence of LC leads to the elimination of excessive road transport by increasing the importance and presence of multimodal transport in the region and by gradually centralizing the region's logistics infrastructure around the LC (Kryś, Izdebski, 2019). A LC is a spatially functional facility, complete with infrastructure and organization, where logistics services are provided-related to the receipt, storage, distribution, and release of goods-as well as ancillary services, provided by economic entities independent of the shipper or consignee (Maganawa et al., 2024). A LC is a key hub in the logistics network and constitutes an independent economic entity with a designated area where, on the basis of free competition, several (at least two) companies operate independently of one another, providing logistics services to internal and external customers on an open-service basis, not limited to specific entities (Rai et al., 2022). They should be treated as independent economic entities bringing together all participants in the supply system in one place. Such facilities should be located in close proximity to the areas they serve, which primarily include cities (Ferreira, Esperança, 2025). Systematic joint planning and cooperation among the center's entities should lead to synergistic effects. To achieve this, the logistics center should be managed by an independent and neutral organization responsible for the development and efficient operation of the center as a whole (Novotná et al., 2022). The core activities of a logistics center consist of comprehensive logistics services (including, among others, transportation, warehousing, distribution, freight forwarding, and information management) or their coordination, as well as ancillary services, including, among others, financial or management services.

A LC must have the appropriate infrastructure and superstructure (including roads, yards, parking lots, civil engineering structures, and buildings) to enable it to provide the required services (Raimbekov et al., 2024). Due to the significant growth of intermodal transport, a LC should have access to two or more modes of transport, as well as a transshipment terminal

for combined transport (Talibov et al., 2023). When planning a national network of logistics centers, it should be taken into account that the national intermodal logistics network should consist of intermodal transport hubs in the form of LC as the main nodes of transport corridors, seaports, and independent container terminals cooperating with nearby warehousing centers (Dyczkowska, Reshetnikova, 2022). The primary purpose of a LC is to provide a wide range of logistics services, while competitiveness and entrepreneurship form the basis for improving customer service standards at LC. The tasks of a LC are highly diverse. The primary tasks undertaken by LC are transport and warehousing management. In addition to the tasks that are outsourced by companies, namely transportation and warehousing (Abbasi et al., 2024). From an economic perspective, LC create the conditions for the effective execution of logistics processes by bringing together within their framework many independent companies providing a variety of logistics services; their potential, strengthened by factors of competition and synergy, enables these services to be provided in the most efficient manner (Zabakhshnia et al., 2023). LC located near urban areas coordinate and consolidate the activities of all entities involved in urban logistics services. Logistics operators also expand the scope of their own service offerings by complementing their capabilities with the services of other operators and create a service market that brings together all suppliers and customers (Kramarz, Kmiecik, 2024). These, in turn, benefit from a wide range of logistics services, service prices determined by free market rules, and a high level of service provided by LC. It is very important to take into account the environmental protection requirements formulated and demanded by society (Kmiecik, Wolny, 2022). LCs allow their shippers to focus on production, avoid unnecessary costs associated with building new warehouses, reduce inventory levels, avoid the costs of purchasing transportation vehicles, improve the quality and timeliness of deliveries, lower the costs of physical material flow, and, above all, provide an information system regarding the flow of goods (Cano et al., 2022). Through the IT systems with which they should be equipped, LCs ensure the handling of supply chain information flows; information technologies facilitate cooperation among all entities located within the logistics center and those outside it. LCs represent the most comprehensive solution for optimizing the flow of goods thanks to their appropriately qualified staff and IT systems (Dyczkowska, 2011).

A Logistics Information System (LIS) is an integrated system that combines information from order processing, inventory control, production planning, warehousing, and accounting. LIS offers logistics operators and the LCs they manage improved value chain management through operational processes, automation, and decision support-ranging from strategic to operational-as well as facilitating business transactions (Wu, Sun, 2023). It enables logistics companies to search for, store, and transform data into useful information for the right people at the right time. LIS is essentially a key enabler for the successful delivery of logistics services by increasing information availability and reducing uncertainty for logistics companies in their daily operational processes (Amine, Boujelben, 2024). Value-added activities in the logistics process should therefore be integrated into the system to maximize business value. A thorough

understanding of the differences between logistics companies and the structure of business processes within a given type of company is important for properly designing the LIS project and architecture under conditions of uncertainty in LC logistics areas.

2.2. Logistics processes in supply chains

The fundamental concept in process management is the process. It is a set of interrelated activities (actions, tasks) that transform inputs (I) into outputs (O). Process inputs come from process suppliers (S), and outputs go to process customers (C). Within an organization, the suppliers of inputs and the recipients of outputs are usually other processes. This model is known as the SIPOC model (from: supplier-input-process-output-client) (Min, Sawaya, 2026). Today, logistics processes are understood as integrated material and information flows, and economic processes are viewed through the lens of these flows, the efficiency of their movement, and the costs they entail. This approach to logistics processes also encompasses customer service, its level, quality, and customer satisfaction; in the broadest sense, a "customer" can be a consumer, a manufacturer, a wholesaler, or a retailer-that is, any recipient of products and services (Jahani et al., 2026). The logistics processes carried out within a company are primarily aimed at ensuring the optimal flow of raw materials, materials, finished goods, and related information. Efficient sales are not possible without effective logistics processes, which consist of the individual components of these processes. It appears that the logistical effectiveness of sales process support is primarily influenced by the following elements: transportation processes, warehousing, inventory levels and structure, and the speed of response to customer needs-all of which are ensured by modern information systems (Ferreira, Reis, 2023). Logistics companies strive to deliver shipments at the lowest possible cost for the appropriate quantity of cargo that meets customer expectations regarding quality, delivery time, and delivery location. An important aspect of logistics management is the continuous improvement of processes by the logistics operator in light of the set goal. The pursuit of excellence results in the continuous improvement of the process, taking into account factors critical to quality, delivery costs, safety, and environmental protection (Onukwulu et al., 2023). The reasons why a logistics operator undertakes initiatives to streamline processes can be divided into several groups. The first source of the need for process improvement is growing customer demands. A situation arises in which the recipient of a shipment increases their expectations regarding process outcomes, such as changes in delivery times, as a result of which a process that previously met requirements may become inadequate. The second source of the need for improvements is instability, uncertainty, and excessive process variability, which result in the failure to fulfill the processes required by customers. The third reason for process improvement is the results of benchmarking, the findings of an audit, or the implementation of a new strategy (Cherchata et al., 2022). In all these cases, it is necessary to streamline processes so that they fully meet the set requirements at the lowest possible cost. Supply chain management processes and activities include (Abdullahi, Mohamud, 2023):

- joint planning, forecasting, replenishment, and the monitoring and control of related processes in the supply chain,
- product and network configuration, which involves making key decisions regarding the products and services offered, the organizational structure, and the relationships between the links in the chain,
- product design utilizing the knowledge potential of suppliers,
- forming a production network aimed at selecting and defining production tasks, production locations, and inventory management, which, in line with the concept of deferral, may apply not only to industrial enterprises but also to commercial or logistics companies,
- optimization of supply chain processes related to the physical flow of products and the accompanying flows of information and financial resources,
- unambiguous identification of a product, shipment, or partner's location domestically or globally,
- continuous analysis and tracking of performance indicators and metrics for logistics operators.

The smooth operation of real-world logistics processes depends to a large extent on information. The efficient flow of information, as well as its appropriate scope, structure, completeness, and timeliness, are key factors in ensuring the efficiency and effectiveness of logistics as a whole, both within a company and across supply chains. The dynamic development of information technology in recent years has laid the groundwork for the development and practical application of effective information systems (Samad et al., 2023). The widespread use of information technology has brought a new level of quality to the management of real-world logistics processes. In the field of logistics, given the massive volume of information flows, the scope of information functions performed is particularly broad. Logistics information services generate and utilize data on goods transported within the logistics system. This data includes information about the shipper, consignee, type of goods, order number, quantity, weight, and volume. Logistics information is key to planning, monitoring, and oversight in the provision of actual logistics services. Data-driven logistics activity, closely linked to the core warehousing service, is inventory management.

Additional logistics services include, for example, order picking, palletizing goods for cost-effective shipping (easier loading and transport), additional packaging for protection, identification, and easier handling of goods and products, and repackaging goods from bulk packaging into smaller units.

Complementary information services and additional services can usually be integrated into the core logistics process without requiring increased organizational resources (Lagario et al., 2022). In this way, significant added value can sometimes be created for the logistics service provider. Additional information services may, for example, relate to supplementary

information about goods, such as prices, promotions, and returns. Additional services can be provided at any location, such as a logistics center, during the transport of goods between the point of origin and the destination.

2.3. Uncertainty in the logistics sector

The causes of unforeseen events and changes essentially identify and clearly define the very concept of unpredictability. Unpredictability should therefore be understood as: an endo or exogenous event, or a resulting change in the planned course of a logistics process, which occurred as a result of the above causes, for which it is impossible to predict its occurrence or indicate the possibility of a specific set of consequences, and for which it is generally impossible to determine the direction and magnitude of the impact on the planned logistics process (Liu, 2024). Many organizations strive to reduce uncertainty in their operations by improving their ability to obtain, filter, and analyze relevant information to facilitate decision-making within the company or to share it with other supply chain participants in order to maximize mutual business benefits (Barmuta et al., 2022). Uncertainty in the supply chain refers to a situation where decisions cannot be made within the framework of supply chain operations. One of the main causes of such failure is a lack of information (Jedliński, Marzantowicz, 2016).

In fact, the lower the uncertainty, the less buffer a company needs to build into its internal structure, thereby reducing operating costs. Hence, there is a significant incentive to reduce uncertainty. Uncertainty within a company can be caused internally by business processes or externally by suppliers or customers (Towill et al., 2000). identified four types of uncertainty sources that can cause disruptions in the supply chain. These are: supply-side uncertainty, demand-side uncertainty, process-side uncertainty, and control-side uncertainty.

Time, quality, and costs are, in general terms, the key indicators of the proper execution of logistics processes. The degree of uncertainty depends on the speed at which factors to be included in the predictive analysis are identified. If time is an indicator of the efficiency of a logistics process, then the degree of uncertainty and unpredictability affect that process through (Kalkha et al., 2023):

- extending the lead time in the process schedule,
- prolonging the decision-making process,
- extending the time horizon for resource utilization,
- extending the duration of logistics operations,
- extending the time required for delivery, ordering, production, and distribution.

In logistics, quality means that a company meets the requirements and expectations agreed upon with the customer regarding the following service characteristics: ease of obtaining necessary information and of placing and transmitting orders; timely and reliable delivery of ordered goods; and communication, accurate, complete, and damage-free order fulfillment, error-free documentation, timely and customer-responsive after-sales service, and the accurate and timely exchange of information between functional departments within the company and between the company and its external partners to support planning.

In terms of quality, as a factor influencing the efficiency of the logistics process, the degree of uncertainty and unpredictability are significant because they lead to (Ercan, Çelik, 2022):

- an increase in the number of consequences resulting from uncertainty and unforeseen events due to the inability to respond appropriately,
- an increase in the process's complexity, and consequently, an increase in its intricacy,
- opening the process to excessive and uncontrolled access by external factors, which causes problems with maintaining process discipline,
- disruptions in the flow of materials and information, resulting in, for example, limited availability.

From the very beginning of the implementation of the logistics approach, supply chain optimization has focused on reducing costs, particularly those associated with logistics processes. With regard to costs, uncertainty and unpredictability affect the logistics process in the following ways (Ivanov, Dolguj, 2025):

- profit margins decrease, leading to excessive resource consumption,
- the cost intensity of procurement, production, and distribution processes increases, as well as that of return and reverse logistics,
- it generates additional, unpredictable costs associated with mitigating these effects,
- it contributes to supply uncertainty,
- uncertainty regarding the pace of consumption (production) increases,
- additional unforeseen costs of logistics operations are generated.

Uncertainty regarding value creation by individual functional areas of logistics is, in essence, a risk determined by the degree to which these areas are exposed to uncertainty (to varying degrees) and unpredictability; it depends on the optimal (balanced) interplay of time, quality, and cost in logistics (Wang et al., 2015; Wang, 2024). The goal of logistics and logistics management by a logistics operator is to influence the physical and informational transactions of logistics processes in a manner that meets specific requirements and effectively combines elements and methods, using as few resources as possible and at the lowest cost. Such effective logistics processes can provide a significant competitive advantage for the companies involved.

3. Methodology

Given the management pressure to identify and mitigate so-called bottlenecks in the LC logistics process and to prevent unacceptable deviations from the plan at the planning stage, we must first examine the occurrence of undesirable events themselves. Here, randomness and incidentality play an obvious role, which means that it is not enough to simply make the

logistics process more flexible, but also to anticipate where irregularities will occur by identifying the flow of information through the supply chain via the logistics center. There is therefore a legitimate need to recognize uncertainty as an element of the logistics strategy. Under this assumption, this implies a readiness to make changes in the area of the resulting constraints. The aim of this study is to assess uncertainty in the IT system for managing logistics processes in logistics centers and to develop recommendations for improving the methodology of uncertainty analysis based on the use of an IT systems registry and a mathematical method.

The process-oriented approach adopted in this article sets the direction for considerations regarding the identification of the impact of uncertainty and unpredictability in logistics and their potential consequences. The research problem formulated is to what extent uncertainty affects the IT system in the management of logistics processes in logistics centers (Choy et al., 2007). The following research hypothesis was formulated:

H1: Uncertainty in logistics processes significantly affects the functioning of information systems used in logistics process management at LCs, reducing the efficiency of information flow, the quality of decisions made, and the level of process coordination.

Additionally, the following specific hypotheses were formulated:

H2: The use of an IT system registry and mathematical methods for uncertainty analysis enables more effective identification and mitigation of the effects of uncertainty in the management of logistics processes in LCs.

H3: The higher the level of uncertainty in the logistics processes of a LC, the greater the impact on reducing the effectiveness of IT systems supporting logistics management.

The research methodology is based on the use of general scientific methods, including analysis, generalization, induction, deduction, synthesis, classification, etc. Furthermore, the improvement to the uncertainty analysis method suggested in the study is based on the use of mathematical methods, expert judgment, and uncertainty assessment tools. The change log is used to generate the necessary information about risks that may arise during the implementation of specific processes, to analyze them, and to develop appropriate preventive measures or measures to minimize the consequences of risky events. This tool can be used to identify and assess the uncertainty of a logistics operator as a whole or a LC, as well as to evaluate its information systems, including procurement management, inventory management, product manufacturing, etc. The change log should be regularly reviewed and updated to ensure continuous monitoring. The methodology used enables a comprehensive assessment of the problem of uncertainty in IT systems in logistics and the formulation of conclusions and recommendations regarding risk mitigation and increasing the reliability of systems supporting logistics processes. The information systems used in logistics centers are responsible for planning, monitoring, and controlling warehousing, transportation, and distribution processes. Every action carried out in the system generates specific events, which are recorded and processed to ensure the continuity of logistics processes and to support decision-making.

To assess uncertainty using the method proposed in this study, it is necessary to determine the impact of identified changes on the processes under consideration and the company's business results, using the expert assessment method and the criteria provided in Table 1.

Table 1.
Criteria for determining the impact of uncertainty on logistics processes at LC

Determining the extent of the event's potential negative impact on the effectiveness of LC's operations	Number of points	Impact assessment
Unforeseeable events cause minor delays or disruptions in logistics processes; their consequences can be easily mitigated or ignored.	1	Minor
An unforeseeable event causes minor delays or disruptions in logistics processes; its consequences can be easily resolved.	2	Low
An unforeseeable event results in a minor loss of resources and negatively impacts operational efficiency; when it occurs, it involves a complex process of dealing with the consequences.	3	Moderate
An unforeseeable event results in a significant loss of resources and has a major impact on LC's operations, and its occurrence involves a complex recovery process.	4	High
An unforeseeable event results in a significant loss of resources and has a critical, negative impact on LC's operations; its occurrence involves a long and complex recovery process.	5	Critical

Source: own elaboration.

The second column specifies the number of points assigned based on the extent of uncertainty, ranging from 1 to 4. The significance of uncertainty can be assessed as follows: below 4 points - insignificant, 4-8 points - low, 8-12 points - moderate, 12-16 points - high, above 16 points - critical. Each category is assigned a weight from 0 to 1.

Table 2 presents the criteria for assessing the probability of occurrence of the considered unpredictable and uncertain events.

Table 2.
Criteria for determining the likelihood of unforeseeable events in LC logistics processes

Probability of an unpredictable event occurring [%]	Number of points	Probability assessment
Less than 10%	1	Very low
10-25%	2	Low
26-50%	3	Moderate
51-75%	4	High
More than 75%	5	Very high

Source: own elaboration.

The number of points awarded depends on the percentage probability of the risk occurring. The following formula is used to calculate the materiality factor for an uncertainty event:

$$UE = IE * PE \tag{1}$$

where:

UE - the significance of an unforeseeable event,

IE - the number of points awarded for assessing the total impact of the event on the company's performance,

PE - the number of points awarded for assessing the probability of the event occurring.

Therefore, it is proposed to use the following formula to determine the total impact of unforeseeable logistics process events on LC's operations:

$$IE = (WC_1 * IEPE_1 + WC_2 * IEPE_2 + \cdots + WC_n * IEPE_n) \quad (2)$$

where:

$WC_{1\ldots n}$ – significance coefficients (category weights) of the categories affected by a given event,

$IP_{1\ldots n}$ – the number of points assigned to the assessment of a given event's impact on the category in question.

The method proposed in this study is examined using the example of an analysis of unforeseeable events in logistics processes at a selected logistics center.

4. Results

Uncertainties associated with the management of the LC logistics information subsystem and the use of information technology:

- leaks of confidential information from LC,
- information security issues (regarding customer data security),
- inappropriate selection of methods for collecting, storing, and transmitting data,
- an improperly designed (inefficient) information exchange process during the execution of logistics operations,
- software failures/malfunctions.

Classifying an unpredictable and uncertain IT event in a logistics system into a specific category makes it possible to identify the processes that require special attention when developing a LC logistics strategy, as well as to pinpoint logistics vulnerabilities and additional costs associated with policies for preventing unforeseen situations. The classification presented earlier also enables a transparent analysis of unforeseen events in logistics processes. Table 3 presents a summary of IT-related events in LC logistics processes, compiled based on this classification for a selected LC involved in the flow of goods in a cross-docking system.

Table 3.
Event log for IT systems at a selected LC

Event reference number	Identified event	Probability assessment
E1	Ineffective internal communication	Creating a unified corporate communication platform. Employee survey
E2	Viruses/cyberattacks	Staff training on network security. Antivirus software, software updates.

Cont. table 3.

E3	Delays in communicating delivery information to the relevant parties	Improving the information exchange system among logistics process participants
E4	Leakage of confidential company information	Implementing data leak prevention software
E5	Leakage of customers' personal data	Using a VPN connection

Source: own elaboration.

Table 4 presents the results of the assessment of unforeseen events conducted using expert judgment and mathematical methods, based on criteria for determining the impact and probability of events occurring, as well as formulas (1) and (2). The following activities were assigned specific weights: OC – operating costs (weight -0.22); DE – delivery efficiency (weight -0.28); CR – customer relations (weight -0.29); FR – company reputation (weight -0.21).

Table 4.
Assessment of unforeseen events in the area of information systems for logistics processes at a selected LC

Event reference number	The impact of the event on selected aspects				The overall impact of the event	Probability of the event occurring	Significance of the event
	OC	DE	CR	FR			
E1	3	3	4	3	3.29	3	9.87
E2	5	4	4	4	4.22	2	8.44
E3	3	5	5	4	4.35	4	17.4
E4	4	3	3	4	3.43	3	10.29
E5	4	4	5	5	4.5	3	13.5

Source: own elaboration.

The results of the calculations presented in Table 4 show that, of the five information events in the logistics processes of the analyzed LC, two are characterized by a moderate degree of significance, two are highly significant, and one is critical. In this case, there are no insignificant events. Among the high-significance events, the following risks are particularly dangerous: E3 (critical), as well as E4 and E5. For the LC, the most critical aspect in logistics systems is the immediate transmission of information regarding shipment deliveries to customers, not only through shipment tracking but also by providing additional updates on the situation. It is recommended to develop additional measures to minimize these risks. In the case of E5, the use of a VPN connection may prove insufficient to protect customers' personal data; therefore, it is necessary to account for the costs of a potential IT systems audit, customer data encryption, and the use of modern data protection algorithms. In the case of E4, an audit and training for LC employees are recommended.

The presented results indicate that the use of a multi-criteria expert assessment—which takes into account the impact of events on operating costs, delivery efficiency, customer relations, and the company's reputation—enables the identification of events of the greatest significance to the functioning of information systems for logistics processes. Event Z3 received the highest significance score and was classified as critical, while events Z4 and Z5 were assessed as high-significance risks. The results confirm that the efficient operation of information systems has a direct impact not only on the continuity of logistics processes but

also on the level of customer service and the company's image. A novel aspect of this research is the comprehensive combination of expert assessment with a weighted mathematical evaluation method, which allows for the simultaneous consideration of multiple impact criteria and the probability of events occurring. The proposed approach allows for the prioritization of risks and the identification of areas requiring the implementation of preventive measures. The results can serve as a practical tool to support risk management in logistics centers and aid in decision-making regarding investments in information system security. At the same time, the limitations of the conducted research should be noted. The analysis was based on a single case study of a selected logistics center, which limits the ability to directly generalize the obtained results to other companies. Furthermore, the risk assessment is based on expert opinions, which, despite the use of a structured assessment method, contain an element of subjectivity. Another limitation is the use of fixed weights for individual criteria, whereas their importance may vary depending on the specific characteristics of the company, the industry, or changing market conditions. The study covered only selected incidents related to information systems supporting logistics processes, omitting other potential sources of risk that may occur in practice.

Despite these limitations, the results provide valuable insights for risk management practices. For incident Z5, it is advisable to expand security measures beyond the use of a VPN by conducting regular security audits, encrypting customer data, and implementing modern data protection mechanisms. For incident Z4, systematic process audits and employee training to raise awareness of information security threats are recommended. For incident Z3, however, which is classified as a critical risk, it is necessary to develop comprehensive response procedures and systems for promptly notifying customers of disruptions in delivery.

The effects of supply chain disruptions can also negatively impact logistics processes and the overall operations of a logistics provider; therefore, it is recommended to minimize events related to uncertainty, in this case by developing and regularly updating contingency plans or providing an additional information system. An additional information system in the form of a LIS, designed to reduce events resulting from uncertainty, appears to be a sufficient measure to mitigate the negative impact of this risk. Event logging and analysis enable real-time monitoring of a logistics center's operations, rapid detection of anomalies, and the implementation of corrective actions. Data from ERP, WMS, TMS, and automatic identification systems form the basis for analyzing the efficiency of logistics processes, forecasting risks, and improving work organization. Modern logistics centers are increasingly using solutions based on real-time data analysis, artificial intelligence, and machine learning, which allow them to anticipate potential disruptions and limit the impact of uncertainty on the functioning of the entire supply chain. The analysis also indicates the possibility of cost reduction by the LC, for example by deferring costly mitigation measures for events of low significance in favor of mitigating threats with a high significance factor.

Uncertainty in logistics processes is one of the most significant challenges facing modern logistics centers. It stems from the difficulty in predicting events that affect warehouse, transportation, and distribution processes. Sources of uncertainty can include both internal factors, such as IT system failures, and external factors, including fluctuations in demand, delivery delays, weather conditions, disruptions in supply chains, and changes in legal regulations.

A significant area affected by uncertainty is logistics operating costs. Delivery delays, the need to maintain larger safety stock levels, additional shipments, and the costs of resolving the effects of system failures all lead to increased operating costs. Companies also incur expenses related to securing their IT infrastructure, implementing monitoring systems, and training employees in risk management. Uncertainty also has significant consequences for the functioning of IT systems supporting logistics. Incomplete or outdated data, integration errors between ERP, WMS, and TMS systems, and failures in ICT infrastructure can lead to incorrect operational decisions. The quality of information therefore becomes one of the key elements in reducing uncertainty in logistics management.

5. Discussion

In an environment characterized by increased uncertainty and dynamic external conditions, the importance of assessing uncertainty in information systems within LC logistics processes is growing, as it aims to anticipate potential risks and develop measures to minimize them. Uncertainty management and the analysis of unforeseen situations in logistics are becoming a strategically important subsystem of management in modern organizations (Kubasova, 2018; Cervantes-Cabrera, 2018). It should be emphasized that methods such as sensitivity analysis and uncertainty modeling are often used to analyze unforeseen logistics operations. The application of these methods can be time-consuming for LC. A viable solution for analyzing uncertainty in logistics systems may be the use of continuous event analysis throughout the supply chain, followed by a comparison of the results with management decisions. It is recommended to use the method proposed in this study to identify and mathematically assess the uncertainty of information systems in the supply chain, in combination with other methods, such as decision trees or scenario analysis. It is suggested that the method under consideration be refined by assessing the impact of logistics process uncertainty on various aspects and outcomes of the supply chain.

Certain differences compared to previous studies stem primarily from the scope of the analysis. Most publications focus on risks occurring throughout the entire supply chain or analyze only cybersecurity risks, whereas this study focuses on the uncertainty present in the information systems of a single logistics center and its impact on the execution of logistics

processes. This allowed for a more detailed identification of threats specific to the analyzed company; however, it also limits the ability to fully generalize the obtained results.

The novel contribution of this study is the development of a practical method for assessing the impact of uncertainty on the functioning of information systems supporting logistics processes using a multi-criteria risk assessment. The proposed approach enables logistics companies to prioritize preventive measures and rationally plan investments in IT system security, employee training, and risk management procedures. The results obtained can serve as a basis for developing decision-support models in other logistics centers and as a starting point for further research involving a larger number of companies and utilizing real operational data.

Refining the uncertainty analysis methodology aims to identify opportunities to account for the specific characteristics of the logistics processes under study, as well as their impact on company performance, in order to increase the likelihood of making sound management decisions. Future research should cover other areas, such as partnerships, deliveries to CL, and customer relations.

6. Conclusion

The research objective was achieved by assessing uncertainty in the IT system used for managing logistics processes in logistics centers, and recommendations were developed for improving the methodology of uncertainty analysis based on the use of an IT system registry and a mathematical method. The research problem was solved, as uncertainty and unpredictable events affect the IT system in the management of logistics processes in logistics centers. The hypotheses were verified positively, confirming the assumptions in part of the results.

The results obtained provide an answer to the research question concerning the impact of uncertainty on the functioning of information systems supporting logistics process management in logistics centers. The analysis showed that unforeseen events related to information systems can significantly disrupt the flow of information, affect the timeliness of logistics processes, and degrade the quality of customer service. Events Z3, Z4, and Z5 received particularly high significance scores, indicating the need to prioritize them in the risk management process.

The research results allow for a positive verification of hypothesis H1. The assessment showed that uncertainty in logistics processes significantly affects the functioning of the information systems used to manage those processes. The greatest impact was observed in the areas of information flow efficiency, customer relations, and delivery efficiency. This means that an increase in the level of uncertainty can lead to a deterioration in the quality of operational decisions and a reduction in the level of coordination of logistics processes.

Hypothesis H2 was also confirmed. The use of an event log and the combination of expert assessment with the weighted mathematical evaluation method enabled the systematic identification of risks, their classification by level of significance, and the identification of areas requiring the implementation of risk-mitigation measures. The results indicate that the proposed methodology can serve as a practical tool to support the risk management process in logistics centers.

Analysis of the results also confirms hypothesis H3. Events characterized by a higher level of uncertainty and a greater probability of occurrence received the highest significance index values. This applies primarily to event Z3, which was classified as critical, and to events Z4 and Z5, which are classified as high-risk. The results therefore confirm the relationship between an increase in the level of uncertainty and a decline in the effectiveness of IT systems supporting logistics processes.

The results obtained are consistent with those of previous studies on risk management in logistics, which indicate that the efficiency of information systems is one of the key factors ensuring the resilience and continuity of supply chains. As in previous studies, the importance of timely information flow, data security, and effective communication with customers was emphasized as factors that mitigate the negative effects of disruptions. At the same time, this study expands on previous approaches by employing an integrated method that combines expert assessment with a weighted mathematical evaluation, thereby enabling a quantitative assessment of the significance of individual events and their comparative analysis.

Uncertainty and the unpredictability of events in logistics are closely linked to the management of the flow of goods and information, as well as potential failures in the operation of the logistics system resulting from undesirable events occurring in its subsystems or in the external environment. Managing uncertainty in logistics is hampered by a number of barriers, including the centralization of product distribution, changing consumer expectations, a lack of necessary information, difficulties in managing information flows and outsourcing processes, as well as divergent IT system standards used by partners. Under such circumstances, there is a growing need for effective uncertainty management through the analysis of unpredictable events in logistics, based on processes for identifying and analyzing potential risks. This study presents an improved method for the quantitative assessment of uncertainty, which enables the identification of risks to the execution of logistics processes for LC, as well as the analysis of their impact and significance, in order to make decisions regarding their mitigation. To ensure the comprehensiveness of the analysis, it is recommended to apply the suggested method in combination with other effective uncertainty assessment tools, such as decision trees and scenario analysis. An area for further research is the analysis of methods for assessing and managing uncertainty in information systems within logistics processes in the context of the digital transformation of LC. In summary, uncertainty in logistics processes affects all areas of a logistics center’s operations—from operational efficiency and costs, through customer service quality, to the reliability of IT systems. Systematically identifying sources of uncertainty,

measuring their impact using performance metrics, and implementing appropriate risk management methods can increase an organization's resilience and improve its operational and financial performance.

Uncertainty also affects the quality of customer service. Delays in order fulfillment, picking errors, and product unavailability reduce customer satisfaction and can lead to a loss of trust and customers. In a highly competitive environment, maintaining a high level of reliability in logistics processes becomes one of the key factors in competitive advantage. A topic for further research is the analysis of methods for assessing and managing uncertainty in information systems within logistics processes in the context of the digital transformation of CL.

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