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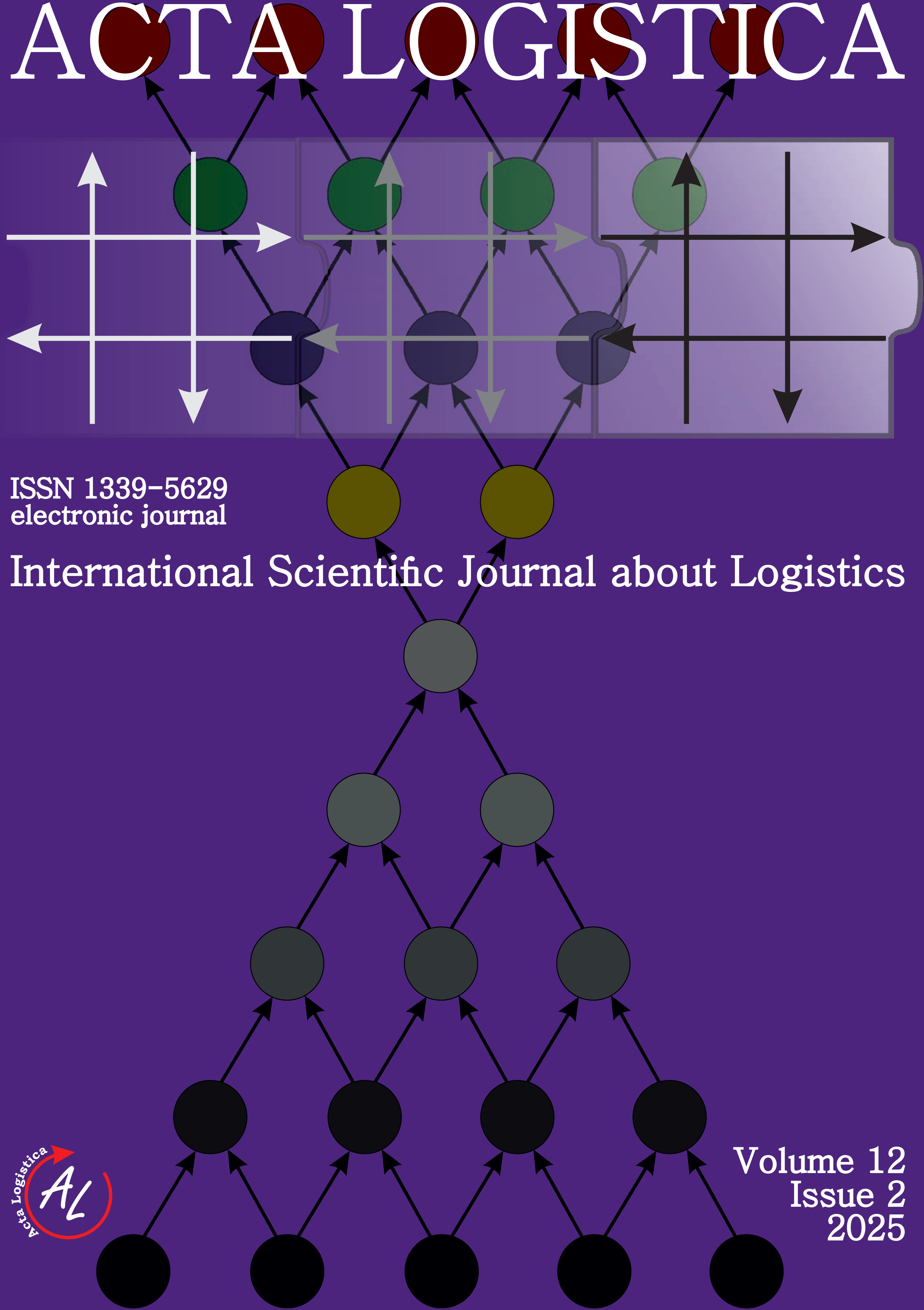

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Key performance indicators as a tool for evaluating efficiency of production processes

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Keywords: key performance indicator (KPI), non-conforming product, diagnostics, maintenance.
Abstract: This paper deals with the topic of Key Performance Indicators as a tool for evaluating the efficiency of production processes. In the current competitive market environment, manufacturing enterprises face increasing demands for maximizing efficiency and performance. Traditional financial indicators often fail to capture the complexity of process improvement, necessitating a shift towards more comprehensive evaluation methods. Key Performance Indicators (KPIs) have become essential tools for assessing production efficiency, providing a framework for monitoring, measuring, and optimizing various production activities. This paper examines the implementation and benefits of KPIs in an engineering company specializing in CNC machining of metallic and non-metallic components. The research outlines a step-by-step algorithm for KPI integration, including process mapping, identification of process owners, data collection, and performance evaluation. The study specifically focuses on the KPI "number of non-conformities" to assess production stability over a 16-month period, using internal parts per million (ppm) metrics. The results demonstrate the role of KPIs in improving transparency, enhancing decision-making quality, and supporting continuous improvement initiatives. Furthermore, the paper discusses the importance of adapting to market trends, such as technological innovations and legislative changes, to maintain a competitive advantage. The findings indicate that the strategic use of KPIs allows companies not only to track operational performance but also to proactively respond to industry changes, thus fostering sustainable growth.

1 Introduction

The current competitive market environment imposes high demands on the maximum performance of manufacturing enterprises. With increasing competition and a high level of competitiveness, the pressure on the performance and efficiency of companies is growing. Enterprise management recognizes that achieving and gaining a competitive advantage leads through efficiency and process performance. Therefore, it is important to monitor individual activities within the company to operate efficiently and strengthen market position.

Current basic financial indicators, which mostly focus on the past and inadequately reflect the need for improvement in specific areas to achieve the company's priority goals, are no longer sufficient for performance evaluation. Companies aiming to enhance their competitiveness must also pay attention to other decisive factors for the sustained success of the enterprise. These may include implementing sustainability practices, which not only reduce costs but also improve the company's reputation. Assessing a wide range of relevant indicators that express the overall performance of processes plays a significant role in today's context. These indicators are referred to as key performance indicators.

For a better understanding of the current market situation, it is necessary to consider other aspects that influence the performance and competitiveness of the enterprise. These factors may include innovation, investment in human resources, development of new products and services, as well as improvement of management processes and communication within the company. The role of employee engagement has also emerged as a critical factor, directly affecting productivity and process outcomes. Effectively utilizing these aspects can have a crucial impact on the long-term success and sustainable growth of the enterprise.

Additionally, it is important to pay attention to rapid changes and trends in the industry that may affect the company's competitive position. This includes technological innovations, legislative changes, changes in consumer preferences, and other factors that can have a significant impact on the company's performance. Companies that actively monitor these changes and incorporate predictive analytics into their strategy are better equipped to stay ahead. Therefore, it is necessary for enterprise management to be able to react flexibly to these changes and adjust their strategy according to the current market situation. In conclusion, it is crucial for companies to maintain flexibility and adaptability in order to successfully compete in a dynamic and constantly changing market environment.

2 Literature review

Key Performance Indicators (KPIs) are among the most common indicators of process efficiency in today's context. This term refers to indicators, i.e., performance metrics and measures assigned to a process, service, organizational unit, or the entire organization. KPIs express the desired performance by assessing the quality, efficiency, or economy of the evaluated entity. They are used at all levels of organizational management, primarily in strategic management, goal-oriented management, and service management [1].

In the standard STN EN ISO 9004:2010 [2], in chapter 8.3.2, key performance indicators are defined as factors that an organization controls and are critical to its sustained success. These must undergo performance measurement and be identified as key performance indicators (STN EN ISO 9004:2010). KPIs are undoubtedly essential tools for measuring and controlling all processes within an organization. These indicators allow for the identification of whether activities are being carried out effectively and help optimize all involved resources. KPIs must reflect the organization's corporate strategy and competitive factors and should focus on how results are achieved [3,4]. KPIs must also be meaningful, coherent, goal-driven, and standardized for objective comparison across different organizations [5]. Many published research papers have dealt with defining and identifying the benefits associated with implementing KPIs into business processes [6,7]. We can state that all authors agree that the most significant contribution of KPIs lies in increasing the efficiency of business processes and improving product quality by introducing measurable production indicators [8,9].

After reviewing numerous literary sources, it is evident that the implementation of key performance indicators brings many advantages to businesses that decide to adopt them. The following benefits are prioritized: providing transparent goals for employees, enhancing productivity, improving the quality of managerial decision-making processes, making performance evaluations more objective and purposeful, strengthening organizational efficiency, enhancing the quality of services provided, and establishing clear safety metrics [10-13].

3 Methodology for implementing key performance indicators in a manufacturing company

The research was conducted in an engineering company specializing in the machining of both metallic and non-metallic components using cutting processes [14]. The products of the analysed company (Figure 1) are utilized in window system mechanisms, the furniture industry, hydraulic units, and primarily in products manufactured by renowned automobile producers, as well as manufacturers of heavy-duty vehicles.

The production involves a wide range of components manufactured mainly through cutting processes, ranging from simple turned parts to intricately machined pieces finished through grinding, threading, rolling, or milling. The primary manufacturing process is CNC machining of both metallic and non-metallic parts. The essence of the production technology is represented by machining centres, CNC lathes predominantly working with bar material, and compact horizontal centres. The products consist of turned and milled components, which can subsequently undergo finishing processes such as grinding, thread rolling, or drilling. The company primarily monitors order-based financial indicators, but it considers it important and necessary to begin tracking indicators that express the overall performance of processes.

The implementation process of KPIs in the analysed company was divided into steps, the fulfilment of which is crucial for the success of the KPI implementation itself. The sequence of carrying out these steps is vital both in the planning phase and during the actual implementation of KPIs into the company's processes.

Figure 1 Example of manufactured components

For the planning of individual steps of KPI implementation into production processes, an algorithm was developed. This algorithm defines the specific steps of introducing KPIs, as well as the assessment of process performance and subsequent actions in case of not achieving the goals:

Step 1. Creation of processes maps.

Step 2. Identification and determination of processes and process owners to be measured.

Step 3. Definition of key performance indicators for the process.

Step 4. Data sources, input measurements for selected KPIs.

Step 5. Analysis and reporting of current process performance.

Step 6. Evaluation of the achievement of process performance goals.

Step 7. Identification of actions for improving process performance.

Step 8. Verification of action implementation, and ongoing data collection and subsequent data analysis.

Based on Step 3, KPIs relevant to the evaluated production were subsequently designed. The identified indicators characterizing product quality include: the number of complaints, plan fulfilment, the number of non-conformities, overall productivity, and production time per unit.

4 Results and discussion

For the purposes of our research, we selected the KPI "number of non-conformities" [14]. Specifically, the performance of orders for part A was assessed based on the number of non-conforming pieces over the total duration of the orders during the 16 months of 2022 and 2023. The result is an expression of internal ppm (parts per million) for part A for each individual order (Table 1). The evaluation is always conducted for the production period of a specific order after its completion. The inputs are the number of produced products per order and the number of non-conforming products generated during that specific order. The indicator INTppm (1) represents the overall production stability for the duration of a particular order during the evaluated period:

$$INT_{ppm} = \frac{Q_n}{Q_t} \cdot 1000000 \qquad (1)$$

Where:
Qn – quantity of non-conforming products in the order,
Qt – total quantity of products manufactured in the given order.

In the graph (Figure 2), the values from the table (Table 1) are visually represented. The graph illustrates a comparative analysis between the quantities of produced pieces per order and the internal ppm per order.

Table 1 Evaluation of order performance for part a using INTppm for the evaluated period

Order Number	Order Completion Date	Total Quantity of Produced Part A in the Order (*Qt*)	Quantity of Non-Conforming Part A in the Order (*Qn*)	Internal ppm (*INTppm*)
1	3.1.2022	1536	5	3255
2	27.1. 2022	1536	0	0
3	24.2. 2022	1536	1	651
4	9.3. 2022	2304	2	868
5	21.4.2022	2304	29	12587
6	28.6.2022	2000	3	1500
7	21.7. 2022	2304	22	9549
8	1.8. 2022	2022	14	6076
9	9.9. 2022	2152	12	5576
10	10.10. 2022	2304	5	2170
11	7.11. 2022	890	8	8989
12	19.12. 2022	1536	16	10417
13	13.1. 2023	1152	5	4340
14	15.2. 2023	1920	5	2604
15	22.3. 2023	2304	0	0
16	15.4. 2023	2000	5	2500

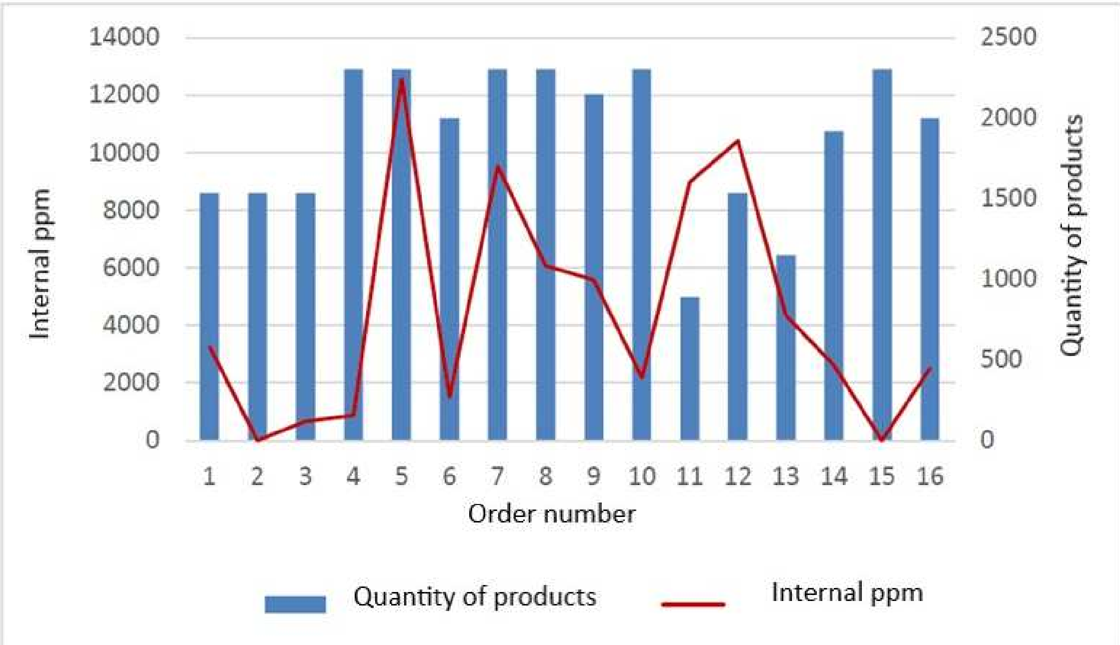

Figure 2 Graphical evaluation of order performance for part a using internal ppm INTppm

When evaluating the results displayed in the graph in Figure 2, it can be observed that the INTppm values exhibit a highly fluctuating tendency, reflecting the instability of the assessed process. The target value for the evaluated KPI is the value of the overall internal ppm, which was set as a quality target for the company in 2022 and 2023, with a maximum value of 2000 ppm. Therefore, the target INTppm value is to achieve a maximum of 2000 ppm for each evaluated order for part A. The achieved average value for individual part A orders during the monitored period, encompassing 16 initiated and completed orders, was 4443 ppm. This indicates that the company's goals in terms of quality and process performance were not met for the specific part A orders. In the analysed company, each non-conforming part is recorded in the company-wide information system called Dialog. Besides the count of non-conforming products, the system allows for entering a description of the non-conformity and its root cause. Following an analysis of the records in collaboration with production operators, production managers, technologists, and quality department personnel, the following descriptions and causes of non-conforming products were identified:

1. Short piece after turning operation, with the cause stated as "clamping error" in the turning operation.

2. Damaged piece, with the cause indicated as "worn cutting insert, need for replacement of the cutting insert."

To eliminate the occurrence of non-conforming pieces, it was necessary to address the identified causes of non-conformities. Based on an analysis of the causes of non-conformities in the analysed process and feedback from stakeholders regarding the issue, the following actions were agreed upon:

1. Elimination of the cause of improper clamping during turning - The technologist will consider the possibility of modifying the clamping process, adjusting the stop, and re-turning the soft jaws of the chuck. The stop against which the part rests during clamping needs to be adjusted so that the part is supported at multiple points, thereby eliminating the possibility of skewed clamping of the part in the chuck.
2. Removal of the cause of worn cutting inserts and timely replacement of cutting inserts during the turning operation involves appropriate diagnosis of the problem and machine maintenance. Preventing the wear of cutting inserts and the resulting non-conforming parts involves specifying an appropriate replacement interval for the cutting insert. The frequency of cutting insert replacement can be determined based on the guidelines provided by the cutting insert suppliers and verified during subsequent production orders. The process of changing the cutting insert is also critical, and it can prevent the occurrence of the first non-conforming piece by focusing on critical dimensions. In this case, the critical dimension is the overall length of the product, which can be adjusted with a suitable excess and subsequent correction.

5 Conclusion

The integration of key performance indicators (KPIs) within the manufacturing company setting is a complex and lengthy endeavor. To effectively manage this process, the support of upper management, supervisors, and employees in positions related to the implemented KPIs is essential. By monitoring KPIs, organizations establish a systematic approach to identify and establish operational objectives aimed at improving process efficiency. The objective of the study outlined in the paper was to propose a methodology for integrating key performance indicators into production processes and determining the metrics' values.

The identified KPIs were precisely defined to ensure clarity and accuracy for all stakeholders, facilitating transparent monitoring. These indicators are measurable and evaluable even during ongoing processes, with corresponding units assigned for assessment. The primary benefit of KPI implementation for a company lies in its capacity to analyze individual processes holistically, beyond mere financial metrics. Through the introduction of KPIs, companies acquire an analytical tool to quantify process performance relative to predefined goals, thereby enhancing stability and reliability while meeting regulatory standards [15].

The research focused on evaluating the performance of production processes with regard to product quality. The target performance value for part A production processes, based on non-conforming product counts, was defined as the INTppm value. The target INTppm value, aligned with the company's quality objectives, aimed to achieve a maximum value of 2000 ppm for each assessed part A order. However, the average value attained for individual part A orders over the observed period, encompassing 16 initiated and completed orders, was 4443 ppm. Consequently, the company's quality and process performance targets for specific part A orders were not met, indicating a highly unstable process. In response, actions were proposed to address the identified quality issue by modifying the lathe chuck design and implementing timely diagnosis and maintenance of problematic cutting inserts, with the goal of rectifying the quality concerns [16,17].

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Design of handling equipment for logistics operations

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Keywords: flow of material, logistics, lifting mechanisms, stress analysis, optimization.
Abstract: The article deals with the design of a lifting mechanism for trailer trucks used in various logistics operations, e.g. forestry, farms and other areas. The study also includes a demonstration of lifting mechanisms for various logistics operations and their technical description. The lifting mechanisms are used to load loads onto a trolley or to unload loads from a trolley. Lifting mechanisms are usually driven by a separate motor unit. The transmission of forces is provided by hydraulic cylinders. The lifting arm and its parts are modelled in SolidWorks. Material characteristics are assigned to the designed mechanism and the links between the individual structural elements are defined. By meshing the model and modifying the mesh at certain critical points, the lifting mechanism is ready for stress analysis calculation. The results are von Mises stresses, displacements at individual points of the system and total deformations. The critical stresses are removed by optimization, which means designing the best possible dimensions or adjusting the geometry of the arm so that the mechanism is functional and safe. The final section deals with the various accessories that can be easily mounted on the lifting mechanism.

1 Introduction

The subject of work is the design of lifting mechanism for trailer trucks. The lifting mechanism is to be used for loading and unloading of loads from the aforementioned trolleys. The advantage of the arm is its light weight and general use, since different types of accessories can be installed on the end part of the arm for different logistic operations. Different types of lifting mechanisms can be found on the market. However, the advantage of the proposed mechanism is its simple construction, which represents a low cost of its production. The practical part enumerates the products found on the market with their descriptions and their technical parameters are also tabulated. The design of the arm itself, its stress analysis and optimization is solved using SolidWorks software. Voltage concentrators in critical sections are removed. The result of the work is the dependence of the load capacity on the load. It indicates the weight that can be loaded on the lifting mechanism in a given position.

1.1 Hydraulic arms for forestry

Hydraulic arms are used in forestry in the primary timber processing cycle (Figure 1). They are most often used in the logging sector and also in the subsequent transport of timber. Currently, there are a variety of hydraulic arms ranging from small to gigantic [1-6]. Forestry is a global industry where high productivity is required every day. Forestry machinery operators need versatile equipment to ensure smooth logging and logistics of timber transportation. Forestry cranes are used right at the start of the tree felling and transport process.

The weight and reliability of trailers with hydraulic arms are very important factors. Due to their low weight, small trailers can move faster and do not leave such a noticeable trace in the countryside as large machines. Trailers can be pulled by ATVs, UTVs, small tractors and the like. Thanks to their versatility, trailers together with hydraulic arms can be used for various purposes not only in forestry, but also in agriculture, construction, road maintenance and so on.

Figure 1 Trailer with forestry crane behind the ATV

1.2 The current range of products on the market

VahvaJussi 2000+

It is the latest type in the range of professional small balancers (Table 1, Figure 2), which in combination with an ATV, UTV or small tractor makes a very manoeuvrable balancing rig. A new feature is the Knott ramp brake. Also improved and more protected is the all-wheel drive of the balancer, which is additionally available in two variants (200 or 400 cc). Of course, there are swivel tandem axles, heavy-duty 8-ply tyres and a swivel hitch. A wide range of accessories can be purchased for the balancer to make this machine more useful, e.g. hydraulically folding bucket, remote-controlled hydraulic winch, swivel hook, hay bale loader, telescopic hydraulic arm extension, bulk loader, soil drills, splitter head, etc. [7].

Table 1 Technical parameters VAHVA JUSSI 2000+

Weight	**440 kg**
Carrying capacity	**2000 kg**
Low pressure off-road tyres	**STARCOSG 300/65-12-8**
Hydraulic arm reach	**3,2 m**
Lifting force of the hydraulic arm	**410 kg/2 m; 260 kg/3,2 m**
Hydraulic system drive	**Honda GX 200**
Maximum lifting force of the hydraulic arm	**530 kg**

Figure 2 VahvaJussi 2000+

Avesta 4.2

The trolley is equipped with its own petrol unit providing movement of the hydraulic arm, hydraulic winch and wheel drive. When attached behind an ATV, UTV or small tractor, you get an 8×8 powered balancing rig. Up to 2m^3 of timber with a length of 5.5m can be loaded on this Swedish balancer behind an ATV (Table 2, Figure 3). The construction of the balancer is galvanised and it has a practical, swivelling hitch. It includes swing axles and low-pressure, high-load tyres [8]. Various accessories can be purchased for the balancer.

Table 2 Technical parameters AVESTA 4.2

Weight	**400 kg**
Carrying capacity	**1800 kg**
Low pressure off-road tyres	**22×11×8**
Hydraulic arm reach	**4,2 m**
Lifting force of the hydraulic arm	**340 kg/1,7 m; 170 kg/3 m**
Hydraulic system drive	**Honda 6,5 hp**
Dimensions	**3200 (4100) × 1350 mm**

Figure 3 Avesta 4.2

2 Handling equipment model design

The handling equipment designed for the outboard trucks (Figure 4), or timber trucks, is to be used for loading, unloading timber, bulk materials and other loads depending on the situation where the lifting mechanism is to be used.

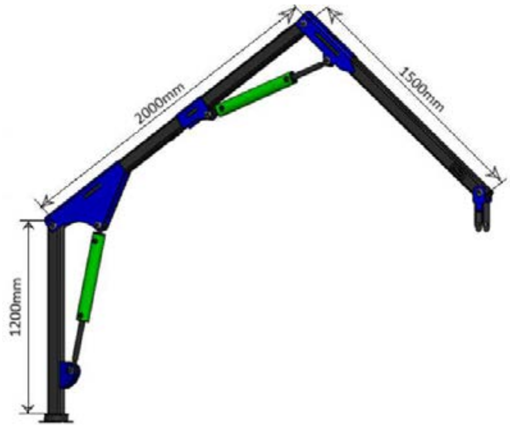
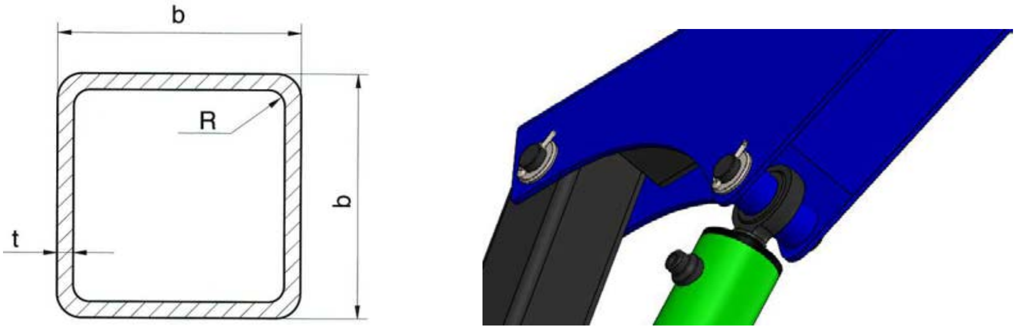


Figure 4 Proposed hydraulic arm

2.1 *Design of handling equipment*

The lifting arm is attached to the trailer with bolts and nuts. At the bottom of the arm there is a swivel device which is driven by a motor. The basic parts are standardised profiles 80×80×5 mm. They are closed profiles with a square cross-section of grade 11, hot rolled (Figure 5a) marked STN 426937 [9]. The theoretical weight of the profile is 11.3 kg per metre of length. Depending on the location of the hydraulic hoses, oval holes are designed in the profiles to hide the hoses and also to protect them against external damage and wear. There is a pin fit between the profiles (Figure 5b).



a ***b***

Figure 5 a,b Closed profile with square cross-section and fit detail

The diameter of the pin is 30 mm. A 25 mm diameter pin is designed at the end link where the last part of the proposed lifting mechanism connects to the rotator. This is due to the assumption that a BALTROTORS GR10 rotator will be used for the arm in question, where the entry hole for the pin is just 25 mm, on which various accessories can be mounted. The rotator in question has unlimited rotation for both directions. The maximum static axial load is 1000kg, with dynamic load (rotation), it is possible to move a load of 500kg. The transition parts between the profiles as well as the attachment of the hydrovalves is solved by welding of 5 mm thick bent plates (Figure 6).

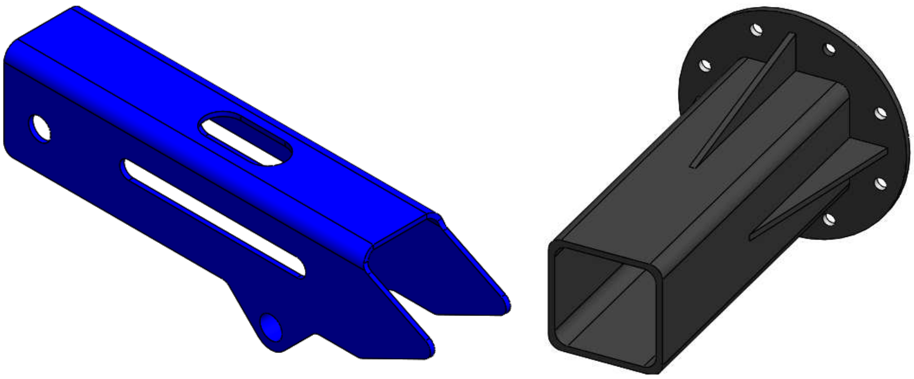


Figure 6 Transition between profiles

Straight-acting double-acting hydraulic cylinders are used to transfer the forces, converting the pressure energy into mechanical energy. Hydraulics are basically divided into stationary (presses, lifts ...) and mobile (agricultural, construction machinery, lifting arms). Mobile hydraulics move mostly on wheels, where control elements such as valves and distributors are operated directly by hand. On the other hand, in stationary hydraulic mechanisms, they are mostly operated electromagnetically. Hydraulic-based mechanisms use fluid to transfer energy. The energy is manifested in the resulting axial force acting on the piston rod. For the lifting arm, the PH-1 63×32/500 111 111 straight-acting double-acting hydraulic cylinders are the most suitable choice (Figure 7). The cylinder pressure rating is 16 MPa and with a maximum working pressure of 20 MPa. The piston speed is 0.5 m/s (Table 3). Two identical hydraulic motors are used for the proposed arm. The advantages of hydraulics are the possibility of transferring large forces using relatively small components, starting from rest can occur even at maximum load, self-lubrication, adjustability, controllability, easy overload protection. Disadvantages are the threat of contamination by the flowing fluid, sensitivity to temperature changes of the fluid under pressure. Hydraulic systems are sensitive to contaminants [10].

Figure 7 Hydraulic cylinder PH-1

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Table 3 Technical parameters of double-acting hydraulic cylinder

Rated pressure	**16 MPa**
Maximum working pressure	**20 MPa**
Static test pressure	**24 MPa**
Working speed of piston	**0.5 m/s**
Working fluid temperature	**-20 to +80 °C**
Working environment temperature	**-20 to + 55 °C**

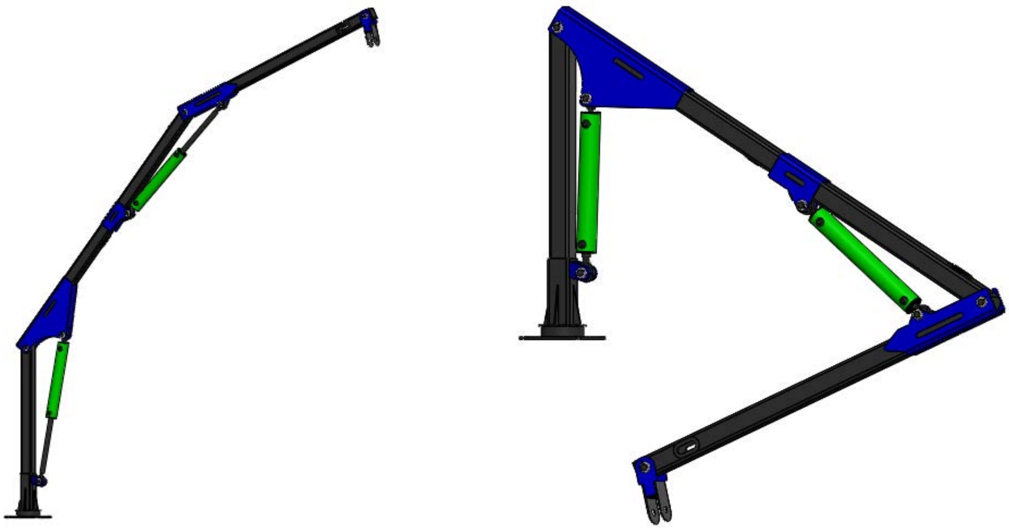
The hydraulic system is driven by a 4-stroke single-cylinder HONDA GX 200 (Figure 8, Table 4) with an output of 4.1 kW at 3,600 rpm, which has an efficient combustion, high power to displacement ratio. The engine is easy to start, consumes little fuel and engine oil. The engine is relatively quiet [10].

Figure 8 Honda GX 200 engine

Table 4 Honda GX 200 engine specifications

Engine category	**GX**
Engine type	**4-stroke single cylinder OHV**
Stroke volume	**196 cm^3**
Maximum performance	**4.1 kW at 3600 rpm**
Cooling	**by air**
Ignition	**transistor**
Weight	**16 kg**
Shaft type	**horizontal**

The arm of model is a simple welded construction. In the open position, when both hydraulic cylinders are extended to their maximum (Figure 9 a), it is possible to lift the load to a height of 3400 mm from the trailer floor. The handling device can move about its axis and within 280°, but this is dependent on the type of trailer where the arm will be positioned. If both hydraulic cylinders are at minimum (Figure 9 b), the height of the arm is 1255 mm. The advantage of using a hydraulic motor is that even at maximum load the motors can operate reliably. The designed arm is analyzed in SolidWorks in all critical positions in the next part of the work.

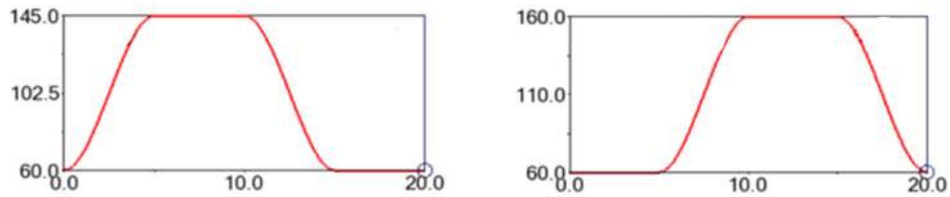


a **b**

Figure 9 Maximum (a) and minimum (b) arm range

2.2 Kinematic analysis

A simplified model of the arm is created in the Adams computer program and subjected to kinematic analysis. The length of the first vertical beam is equal to 1200 mm. Together with a second beam of length 2000 mm, they form an angle of 60° at the lowest position. With the hydraulic cylinder extended, this value is equal to 145° (Figure 10 a). The third beam, 1500 mm long, makes an angle of 60° with beam number two when the hydraulic cylinder is retracted. When the piston rod is maximally extended from the cylinder, the angle is equal to 160° (Figure 10 b).



a) **b)**

Figure 10a,b Angles between beams versus time t

The simulation is run when both piston rods are inside the hydrovalves. Within a time period of five seconds, the first of the hydromotors is extended to the maximum position. The second hydraulic motor then starts its operation until it reaches the peak position. The next step is to lower the first thruster to the zero position within a time period of 5 seconds. The last part is the pulling in of the second hydrovalve. The whole cycle takes 20 seconds (Figure 11) The result is the workspace of the proposed arm (Figure 12). The analysis does not consider the rotation about the proper axis of the arm.

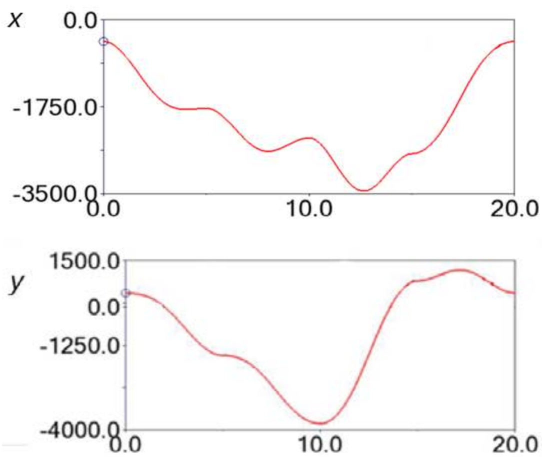


Figure 11 Extension of the arm in the x and y axis direction as a function of time t

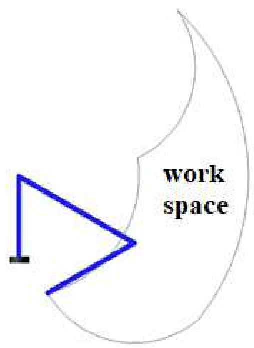


Figure 12 Working space of the proposed mechanism in the plane

2.3 Stress analysis

Stress analysis allows to verify the quality and safety of the product during the design process. The proposed model of the lifting arm for the outboard trucks needs to have initial conditions defined before the actual stress analysis can be run. The analysis is also performed in SolidWorks. Using the stress analysis, the total stresses and strains at different points of the structural system can be calculated in the program [11-15]. The assembly deforms under load with small rotations and also displacements. In the analysis, the effects always remain static, neglecting or ignoring any inertia. The effects remain constant over time [16,17].

The SolidWorks simulation uses the finite element analysis method. The goal of the method is to decode structural elements into solid components or beams using linear stress analysis when the elements or assemblies are subjected to the effects of: force, pressure, acceleration, temperature, and contacts between components. Forces can be imported from a variety of studies including thermal, flow and motion. This is in order to be able to perform multiphase analysis. When defining the conditions, one of the most important parts is the input of material properties, e.g. from the SolidWorks library [18].

For the proposed mechanism, the material from the SolidWorks library was used, namely AISI 1020 steel (Figure 13), which represents the material according to the Slovak technical standard - STN426937 [9]. The ultimate strength of the material is 351.57 MPa, which means that the maximum value of the conventional stress under maximum load must not exceed the given value.

Property	Value	Units
Elastic Modulus	2e+011	N/m^2
Poisson's Ratio	0.29	N/A
Shear Modulus	7.7e+010	N/m^2
Mass Density	7900	kg/m^3
Tensile Strength	420507000	N/m^2
Compressive Strength		N/m^2
Yield Strength	351571000	N/m^2
Thermal Expansion Coefficient	1.5e-005	/K
Thermal Conductivity	47	W/(m·K)

Figure 13 Material characteristic of AISI 1020 steel from SolidWorks software

The connection between the components of the system is a "bonded" bond, which interprets a welded joint. In places where square section profiles are connected by means of pins together with the connecting parts, a so-called "no penetration" bond is used. Since hydraulic cylinders are not included in the stress analysis, the "rigid" bond has been used as a substitute. The lowermost part of the assembly, where the lifting mechanism is fixed using bolts and nuts against the trailer trolley, is the fixed part. The load is applied to the end pin in the assembly. Depending on the distance of the end part relative to the base beam, the loads are applied progressively [19,20]. Once all the conditions are satisfied, the designed model can be meshed. The elements that do not satisfy the first meshing stage are meshed separately (Figure 14).

Figure 14 Solidworks mesh modeling of lifting mechanism

The simulation is then run. In the most ideal case, which represents the smallest distance between the end point of the arm and the axis of the base beam, the assembly can be loaded with 5500 N, which is approximately 550 kg. The stress according to von Mises will be equal to approximately 340 MPa at the critical point, which is still lower than the specified ultimate strength (Figure 15) [16].

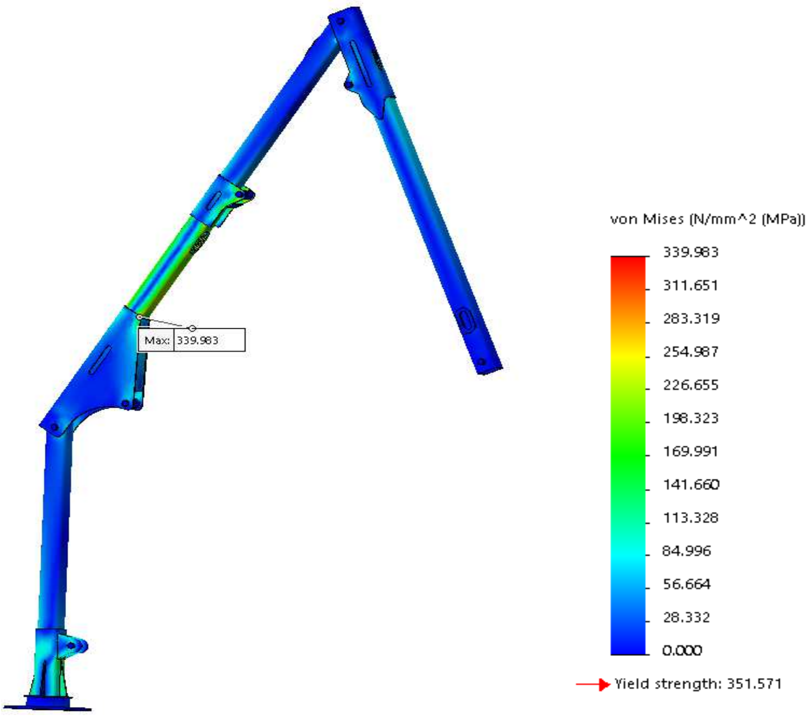


Figure 15 The von-Mises field of principal stresses

When the arm is at the position of greatest reach (Figure 16), i.e. the 3370 mm value of the end of the lifting mechanism from the axis of the base vertical beam, the proposed assembly is loaded with a force of 2500 Newtons, which is approximately 250 kg. The maximum stress in this case is 305 MPa.

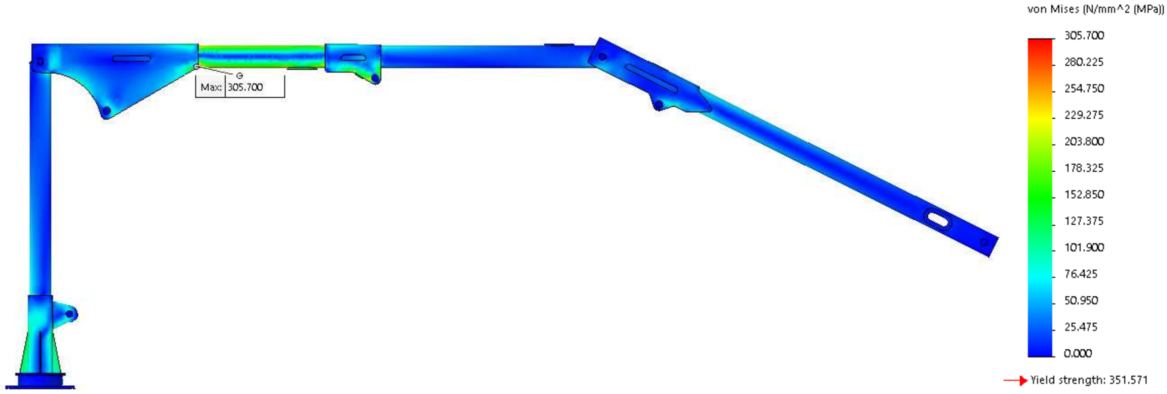


Figure 16 Main stress field at maximum arm reach

By successively loading the proposed model at minimum and maximum range, I have arrived at the results as shown below (Table 5, Table 6).

Table 5 Stresses according to von Mises at minimum arm reach

Load	Stress according to von Mises
5500 N	340 MPa
4500 N	278 MPa
3500 N	216 MPa
2500 N	154 MPa
1500 N	92 MPa

Table 6 Stresses according to von Mises at maximum arm reach

Load	Stress according to von Mises
2500 N	305 MPa
1500 N	183 MPa
500 N	61 MPa

The weight of the system is approximately 82 kg. However, this weight does not include the weights of the accessories and the fluid medium in the hydraulic cylinders.

2.4 Optimisation of the arm model

Optimization in short means that we are looking for the optimal solution so that the product meets the initial requirements, so that the production costs are as low as possible, so that the product meets the safety regulations and many others. There are several ways to achieve improved values. It is possible to change the part design, shape or dimensions. Design changes are represented by parameters that change during optimization - topological optimization - represented by material density in the design domain. Element removal is represented by assigning a weight and stiffness small enough to not contribute to the response. Shape optimization is represented by displacements of nodes on the surface of the component. Optimal design is achieved by shifting the nodes on the surface of the component to local concentrators. In dimensional optimization, the dimensions of the component are changed to increase the stiffness of the whole system. It is possible to vary sheet thickness, length, cross section, etc. In the case of the proposed mechanism, these are mostly subtle adjustments, namely rounding at critical locations where stress concentrators occur (if possible), or minor adjustments to the geometry of the model to avoid high stresses. After running the first simulation, the maximum stress was at 704 MPa, which is almost twice the allowable limit. The stress concentrator was created at the edge of the bracket, where the first of the two hydraulic cylinders is located (Figure 18).

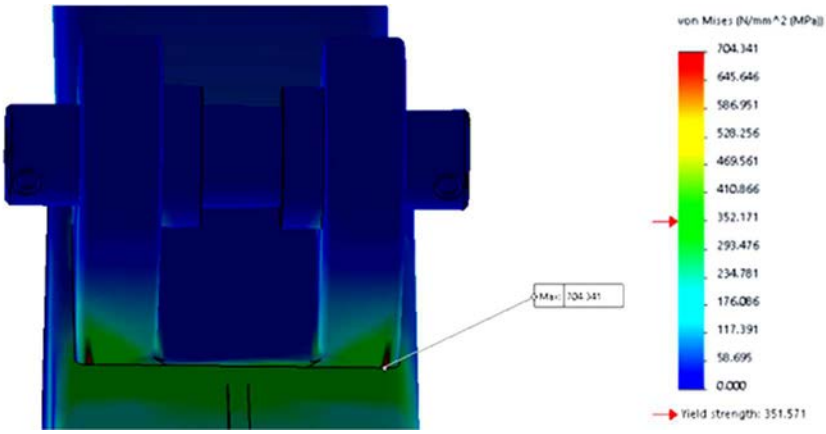


Figure 17 Critical point of the model assembly

After optimizing the bracket, the voltages have dropped significantly and no longer represent a critical point in the assembly. On the contrary, there were other places where the component shapes needed to be adjusted. Mostly, however, these were curvatures. After the optimization of the lifting mechanism was carried out, there were no critical places with high stresses on the model. These are evenly distributed over the entire arm, so further optimization would be in changing the smaller cross-section profiles to larger ones, as well as the other parts. However, this is not necessary for our model as the initial conditions are satisfied (Table 7).

Table 7 Technical parameters of the proposed lifting mechanism

Maximum range (length)	3.3 m
Maximum range (height)	3.4 m
Maximum lifting force to 3.3 m	180 kg
Maximum lifting force to 2 m	350 kg
Maximum lifting force	5500 N

3 Accessories for various logistics operations

The model of the lifting mechanism is designed so that a range of different accessories from catalogues can be applied to it for different logistics operations. For the proposed lifting mechanism model, it is necessary to mount a rotator, which is an essential part of almost all lifting mechanisms due to its features and capabilities.

3.1 Rotators

They are used in industrial machines that require unrestricted rotation of working mechanical cranes (hydraulic arms). Thanks to their design, rotators allow a continuous supply of hydraulic oil to the necessary components without restricting rotation. They allow 360 degree rotation around their axis. They make the work easier and faster and thus reduce costs [21].

For the proposed lifting arm, the Baltrotors GR10 hydraulic rotator (Figure 19, Table 8) is the most suitable choice.

Figure 18 Rotator Baltrotors GR10

Table 8 Technical parameters of the Baltrons GR 10 rotator

Rotations	Unlimited for both directions
Maximum axial load - static	10 kN (1000 kg)
Maximum axial load - dynamic	5 kN (500 kg)
Torque at 25 MPa	350 Nm
Recommended oil flow	10 l/min
Weight	10 kg

3.2 Grapple pliers for wood VahvaJussi

Wood tongs (Figure 20, Table 9) are characterized by their minimal size and minimal weight. Their maximum spread is 75 cm. The tongs will be an accessory mainly for timber extractors [21].

Figure 19 Wood tongs VahvaJusii

Table 9 Technical parameters of pliers VahvaJussi

Maximum opening	750 mm
Weight	22 kg
Carrying capacity	1000 kg
Pressure force	8 kN
Hole for rotator	39,5 mm
Working pressure	175 bar

3.3 Loader for bulk materials FARMA 0,12

The Loader for bulk materials (Figure 21, Table 10) is a suitable complement for lifting equipment with already installed grapple tongs due to its quick installation and low weight. They can be mounted on the Baltrotors GR10 rotator [21].

Figure 20 Loader for bulk materials FARMA 0,12

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Table 10 Technical parameters of loader for bulk materials FARMA 0,12

Spoon volume	58 l
Weight	36 kg
Pressure force	6.3 kN
Carrying capacity	500 kg
Working pressure	17.5 MPa

3.4 Swivel hook VahvaJussi

The hanging swivel hook (Figure 22) is the ideal complement to the hydraulic arms. The hook can easily be mounted directly on the hydraulic rotator instead of pliers or a grab.

Figure 21 Swivel hook

3.5 Soil drill

Soil drills (Figure 23) find use in many activities. They can be used effectively in the construction of protective fencing in forestry, in the construction of fences and corrals on farms, in tree planting and in agriculture. The advantage is their quick assembly and disassembly.

Figure 22 Soil drill

4 Conclusions

The task of this article was the structural design and stress analysis of a lifting mechanism for trailer trolleys, taking into account the various logistic operations performed by this equipment. The mechanism was to be of the simplest possible design with the possibility of quick disassembly. The nominal load capacity should be 400 kg. The total weight of the proposed part is 83 kg.

In the introductory part of the thesis there is a description of similar mechanisms already offered on the market. It describes their mechanical properties and their advantages. The practical part is the actual design of the lifting mechanism. In the design, closed profiles with a square cross-section are used as the main parts. The other elements are the connecting parts, which are bent. Hydraulic cylinders, pins and various other parts are incorporated into the assembly as required. The arm is designed in SolidWorks environment where stress analysis has been carried out. As a result of the work, a lifting arm with a nominal lifting capacity of 400 kg has been designed. The maximum reach of the mechanism is 3370 mm. The lifting capacity depends on the extension of the arm. At the largest extension, the aforementioned 3370 mm, loads weighing 200 kg can be lifted.

The lifting mechanism designed in this way is suitable due to the wide use of various accessories for different logistic flows used in cargo handling.

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Implementation of blockchain technologies in logistics: modern challenges, problems and prospects

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Keywords: blockchain, logistics, supply chain, efficiency.
Abstract: The main goal of the study is to substantiate the conceptual aspects of the implementation of blockchain technologies in logistics with argumentation of the main problems and development prospects. A critical and scientific-methodological analysis of existing learning in the field of introduction of blockchain technologies allowed us to argue the relevance and relevance of this learning. A critical and scientific-methodological analysis of existing learning in the field of evolution of blockchain technologies allowed us to argue the relevance and relevance of this research. Current trends in the introduction of blockchain technologies and their application in all areas and types of activities of modern companies at the global level are stated. The key advantages and disadvantages of blockchain technologies are structured. The main directions and types of blockchain technologies with their subsequent introduction in the logistics activities of companies are argued. To argue the specifics of implementing blockchain technologies in logistics and identifying the main problems and evolution prospects, multidimensional cluster analysis tools were used. The trends in the evolution of logistics activities in countries around the world based on blockchain technologies are assessed. Formalized main prospects for the development of blockchain technologies in the logistics activities of companies. The main business cases for the use and integration of blockchain technologies in logistics by world-class companies are classified. The obtained learning results have their practical value and recommendations for company managers regarding the effective assessment and organization of processes for the application of blockchain technologies in the logistics activities of current companies.

1 Introduction

The digital transformation of modern business and its transition to online formats of interaction with clients and counterparties leads to a rethinking of the essence of logistics as a basic tool for managing supply chains and creating value and justifying the directions of changes that must certainly be carried out in logistics under the influence of technology. The intensive evolution of technologies, their scaling into all directions and business segments, leads to their detailed study, determining the main features, advantages and disadvantages for companies. Blockchain technologies are relevant, in demand in modern realities, which provide maximum acceleration, and optimization of complex business processes in supply chain management, ensuring the reliability and openness of information for making management decisions. Blockchain technologies, in addition to optimizing business processes reduce costs by mitigating potential risks and eliminating unprofitable transactions for clients. Based on what has been presented, it should be noted that technology in the current world acts as a driving mechanism for the introduction of the business environment of any company, which confirms the relevance and relevance of this study. Current trends in the evolution of technologies and their key tools confirm the fact that the application of blockchain technologies in the logistics activities and supply chains of companies is relevant and in demand.

The logistics industry is constantly looking for new ways to optimize work, and one of the innovative solutions is blockchain technology. It allows you to effectively solve problems with documentation, which complicates and slows down processes and leads to costs. Many international companies successfully use blockchain technologies in logistics and the establishment of commodity flows and supply chains, optimizing budgets. Ensuring the efficiency of logistics with the help of blockchain technologies is ensured by the use of a distributed registry, which provides visibility and information security, automation of processes. It should be noted that there is a need to consider the features of the use of blockchain technologies in the logistics activities of companies, which in turn will help to identify the main pain points, problems and development prospects.

Global trends towards fundamental changes and transformations lead to a flexible management system and adaptation to new challenges and application of technologies that are directly related to current processes. Along with this, the application of blockchain technologies in the activities of modern companies, which have a number of advantages for strategical management and evolution, is quite relevant and in demand in the current world. Taking into account what has been provided, it is important to state that logistics activities in modern times are a key link in the mechanism of the global economy, the efficiency and optimality of business processes of which directly affect the results and stability of the global economy as a whole. Technological aspects in optimizing logistics business processes based on the implementation of blockchain technology are relevant in the modern world and require the development of conceptual approaches to assessing the impact of these technologies on logistics, determining their key advantages, disadvantages, and development trends. It is also important to study existing scientific approaches to the implementation of blockchain in the logistics activities of companies to argue for a unified view and methodology for determining basic aspects and recommendations. Increasing attention and demand for the implementation of blockchain technologies in the field of logistics activities determines the need and relevance of this study.

1.1 Theory of development and formation of blockchain technologies

Constant modernization and optimization based on technology and its implementation with innovation have led to the emergence of a new era of technology - blockchain technology. The first fundamental description and implementation of blockchain technology was prepared in 1991 by researchers Stuart Haber and W. Scott Stornetta, who implemented a computationally practical solution for time-stamped digital documents to ensure that date and time cannot be tampered with. The proposed system was based on the use of a cryptographic secured chain of blocks, which were needed to store documents with a time and date stamp. Subsequently, this development was expanded to include Merkle trees, which improved its efficiency, which was ensured by collecting several documents into one block [1]. However, the proposed technology was not used in practice and the patent was lost in 2004, which was due to the emergence of Reusable Proof of Work. Scientist Harold Thomas Finney II in 2004 introduced a system called RPoW, Reusable Proof of Work, which operated by obtaining a non-fungible or non-fungible Hash cash token based on proof of work and signed in RSA, which could then be transferred from person to person. person. It is important to state that RPoW solved the problem of double spending by maintaining ownership of tokens registered on a trusted server that was designed to allow users around the world to verify its correctness and integrity in real time. The RPoW system was the very first and earliest incarnation in the history of crypto currency development [2].

The next step in the evolution of the blockchain was the initiation of a white paper in late 2008 that introduced a decentralized peer-to-peer (P2P) electronic cash system - Bitcoin, in which cryptography was sent by mail using the pseudonym Satoshi Nakamoto. Based on the Hash Cash proof-of-work algorithm, but instead of using a hardware trusted computing function like RPoW, Bitcoin's double-spend protection was provided by a decentralized peer-to-peer (P2P) protocol for tracking and verifying transactions [3].

The next stage in development was the emergence of Bitcoin in 2009, the first Bitcoin block was created by Satoshi Nakamoto. The first recipient of Bitcoin was Hal Finney, who received 10 Bitcoin’s from Satoshi Nakamoto, in the world's first Bitcoin transaction. In 2013, Vitalik Buterin, a programmer and one of the founders of Bitcoin magazine, stated that Bitcoin needed a scripting language to create decentralized applications. So, without receiving consent from the community, he began developing a new, distributed, blockchain-based computing platform, Ethereum, which featured scripted functionality called smart contracts. Smart contracts are programs or scripts that are applied and executed on the Ethereum blockchain and can be used, for example, to complete a transaction if certain conditions are met. Smart contracts are written in specific programming languages, compiled into a byte code, which can then be read and executed by a decentralized virtual Turing machine called the Ethereum Virtual Machine (EVM) [4]. In 2019, the intensity of technology implementation and innovation gave rise to the massive emergence of DeFi (financial services and instruments that are based on blockchain technologies) and after that blockchain became a competitor to the traditional financial system around the world. It is important to note that in modern conditions, the use of blockchain technologies is not limited to crypto currencies; with the help of many advantages, they find their application in all areas of the global economy [5]. Therefore, it should be noted that the use of blockchain is not limited to the sphere of administrative and financial management. The use of blockchain is most effective in all areas where the reliability and immutability of already recorded information is required, for example: medicine, education, real estate, legal system, property rights management, data management, trade, logistics and much more. Based on this, it should be noted that blockchain in today's business is a technology that facilitates and increases the efficiency of company resources. These issues require more detailed definitions and determination of the role, influence and prospects for application in the logistics activities of companies.

1.2 Theory of development and implementation of blockchain technologies in logistics

The demand for improvements and the search for new approaches to effectively manage the logistics of modern companies is inextricably linked with the application of new technologies and tools such as blockchain. Today, blockchain is a complex mathematical algorithm that ensures security and confidentiality in data exchange through peer-to-peer networks. The main idea of introduction blockchain technologies is a chain of blocks with information about each transaction, which is stored in each unit of the computer network. The demand for improvements and the search for new approaches to effectively manage the logistics of current companies is inextricably linked with the introduction of new technologies and tools such as blockchain. Today, blockchain is a complex mathematical algorithm that ensures security and confidentiality in data exchange through peer-to-peer networks. The main idea of application blockchain technologies is a chain of blocks with information about each transaction, which is stored in each unit of the computer network. Blockchain as a technology provides effective and reliable data protection from hacking and third-party interference in the information exchange process. Blockchain is the most important and effective method for the exchange of information between several parties. Taking into account what has been presented, it is necessary to conduct a thorough analysis and learn of existing scientific approaches to the study and formalization of the features of the application of blockchain technologies in the logistics activities of companies. It is important to note that in scientific literature there are many approaches and scientific views regarding the study of the evolution n of blockchain technologies, their introduction and the main aspects in a particular environment. The study took into account only those that relate to the general principles of the evolution and formation of blockchain technologies and the features of their application in logistics. To substantiate scientific and practical recommendations and formalize the basic approach to implementing blockchain in logistics, attention should be given to the following studies:

[6] Reveals the possibility of using and implementing blockchain technologies in logistics companies as a basis for making management decisions using a quantitative approach. This approach allowed us to determine that the most important criteria in logistics are security, openness and audit, the most feasible logistics operations were transportation, loading and unloading, warehousing, order processing and fleet management in a possible blockchain application. The developed methodology allows us to assess the feasibility of blockchain in logistics operations but does not reveal the essence of their application with the argumentation of the main trends in their evolution, advantages and disadvantages, which requires improvement of this approach and further research.

[7] The features of the dependence of the financial results of Islamic banks on the application of financial technologies are revealed. The role of FINTECH tools in generating income for the financial system is revealed, and a separate block of blockchain technology is highlighted, which simplifies business processes and improves the quality and security of transactions. This approach is relevant and fundamental in terms of organizing the financial activities of companies based on new technologies - blockchain technologies but does not reveal the main aspects of logistics activities and features of blockchain application, which requires detailed study and expansion of the research area.

[8] Is based on identifying key aspects of the impact of digitalization and innovation on marketing and logistics of companies. This approach is unique in that it structures technologies depending on their impact on aspects of companies' activities, combining them into a single marketing and logistics system. The features of innovation and digital technologies in the marketing and logistics strategies of current companies are revealed, but the specifics of the implementation of blockchain technologies are not highlighted, which requires further improvement and research in this area.

[9] Based on determining the specifics of the functioning of marketing and logistics in the world during a pandemic. This approach is unique in that it analyzes trends in the evolution of marketing and logistics under conditions of restrictions and substantiates that these restrictions have led to the intensive growth of the technology market, including blockchain. The operational need to optimize and increase the efficiency of processes has led to the rapid introduction of blockchain in all areas of activity. It is important to note that this approach is general and determines only development trends but does not reveal the specifics of using blockchain in logistics, which requires a more detailed study.

[10-11] The study is aimed at identifying trends in the evolution of logistics, its transformation and adaptation to the changes that are taking place in the global economy. The integration of logistics systems of developing countries into international logistics channels based on innovative technologies, including blockchain, is justified. This approach defines the basic aspects of scaling logistics activities based on the technological aspects of the introduction of innovative technologies. However, the

features of blockchain technologies in logistics are not fully disclosed, the specifics and main problems and advantages of their application are not determined, which requires further research.

[12] The focus is on blockchain technologies as a key catalyst for reverse logistics in the automotive industry. The need to reduce disruptions and improve operational efficiency in the automotive industry has been identified, which requires the application of innovative technologies to improve the flow of information and safety. This approach substantiates the role of blockchain technologies and their impact on the main processes of companies, but does not reveal their impact on logistics activities, which requires further research.

[13] Research focused on the Block Supply project, which is a groundbreaking initiative that aims to reimagine supply chain management by using blockchain technology to provide real-time monitoring of product movements and improve transparency, security and traceability. This approach is relevant in modern conditions and can be used as a basis for the application of blockchain in logistics. However, the features of logistics activities based on the application of blockchain technologies and the main problematic and promising points in evolution have not been disclosed, which requires improvement and further research.

[14] Focuses on the features of using smart contracts based on blockchain in logistics and supply chains. Features of application, deployment, audit and operational aspects of smart contracts on the blockchain applied to land, sea and air logistics networks. This approach conceptualizes aspects of blockchain application in supply chains, while improving interactions and transactions with counterparties, which is relevant and valuable in modern conditions. It is important to note that the proposed approach can be applied in practice as recommendations in organizing a flexible supply chain based on blockchain technologies but does not reveal the specifics of their application, taking into account all the problems, advantages and disadvantages in their development, which requires improvement and in-depth research.

[15] This research aims to use blockchain technologies to expand the supply chain capabilities of modern companies. Importantly, from a practical and theoretical perspective, this study shows the development of blockchain technologies to shed light on challenges, opportunities, and prospects, contributing to the evolution of new interdisciplinary supply chain research and practice. However, this approach does not reveal the main trends in the development of blockchain and its implementation in the logistics of companies, which requires a more detailed and in-depth study.

Conceptualizing the presented results of scientific and methodological analysis of research in the field of the theory of blockchain evolution in logistics, it should be noted that in modern conditions this area is relevant, in demand, which does the number of scientific approaches, and views confirm. However, despite this in scientific literature. There is no single approach and methodology for determining the role, specifics and features of the implementation of blockchain technologies in the logistics activities of modern companies, which requires detailed research and elaboration of this area.

2 Methodology

Peer review process

The modern stage of functioning of companies' business strategies leads to the mandatory application of technological innovations, which are caused by new technologies and their tools. Technological innovations play an important role in the global economy, and logistics and supply chain management cannot remain aloof from this process. To argue the conceptual aspects of the application of blockchain technologies in logistics with the substantiation of the basic problems and prospects for evolution, a number of tools were used in the study:

- to argue the relevance and necessity of the study, a scientific and methodological analysis of scientific approaches and views in the field of research into the theory of blockchain development and its implementation in logistics was carried out. The main most important and leading studies that served as the theoretical basis for this study are highlighted. The lack of a methodology for determining the humidity of blockchain technologies in logistics was noted.
- Structuring modern trends in the development of blockchain technologies and their implementation in all areas and types of activities of current companies at the global layer. For the first time, focus groups have been formed on the areas of development of blockchain technologies and their application.
- Scientific generalizations and analysis made it possible to identify and formulate the key advantages and disadvantages of blockchain technologies in current conditions.
- Critical analysis and argumentation of the features of blockchain technologies provided justification for the main types of blockchain technologies with their subsequent evolution in the logistics activities of companies.
- Multidimensional cluster analysis made it possible to substantiate the features of the application of blockchain technologies in logistics and identify the main problems and development prospects.

Multidimensional cluster analysis tools are a multidimensional statistical procedure that collects data containing information about a sample of objects (Logistics Performance Index (LPI) for countries of the world), and then organizes objects into relatively homogeneous groups (structuring countries of the world into homogeneous clusters according to the layer of logistics efficiency. Cluster analysis is not a single algorithm, but a general problem for the solution of which various approaches are used. In particular, clustering algorithms can differ significantly in terms of understanding what to include in one cluster and how to effectively search for them. Among the popular concepts of clusters are groups with elements that are developed on the basis of measuring the distance and the payment areas between them, taking into account the periodicity and statistical distributions. Therefore, clustering can be formulated as a multi-criteria optimization problem. Let X be the set of objects (countries classified according to the global logistics efficiency index, Y be the set of numbers (the name of the structural indicators of logistics: infrastructure, customs, international deliveries, logistics competence, tracking and tracing and timeliness). Additionally, the evolution trend of blockchain technologies and their introduction is considered and affects logistics systems in the world. The function is set to interpose between objects (1):

$$p\ (x, \grave{x}) \tag{1}$$

end selection of objects (2):

$$\mathrm{X}_m = \{x_1, \ldots, x_m\} \subset X \tag{2}$$

Taking into account what has been presented, a selection was then carried out on non-intersecting subsets, which are called clusters (countries according to the layer of the global logistics efficiency index), so that each cluster consists of objects that are close in the metric ρ. and the objects of different clusters were significantly different. For any skin object $\mathrm{x}_i \in X_m$ a number is assigned to the cluster y_i.

The stagnant clustering algorithm is an approach function (3):

$$a: X \to Y \tag{3}$$

For any object of investigation $x \in X$ set the alert to the cluster number $y \in Y$.

The multiplicity Y in some cases is obvious from behind, so the task is more often to determine the optimal number of clusters, depending on the criterion of clustering efficiency. An important aspect in conducting a multi-world cluster analysis is those that are similar to the data, and themselves: objects are not guilty of correlating with each other; objects loom but are dimensionless; the distribution of objects is close to normal; the objects of guilt exhibit significant stability, which means the presence of influx on their values of temporary officials; The selection of data must be uniform [16-17]. The result of multi-world clustering is a group of objects, united by the same characteristics and characteristics in this category of clusters of regions according to the efficiency of logistics and the trend of influx of blockchain technology on them. The verification of the stability of the isolated clustering is limited to verification of its reliability. Here the basic rule of thumb is that there is a constant typology when defining clustering methods. The results of cluster analysis should be checked using iterative cluster analysis and the k-means method. When aligning the group, more than 70% (more than 2/3 of the runs) are retained, then the cluster decides to accept what remains.

3 Results and discussion

The modern global logistics industry is a key link in organizing the mechanism for moving goods and services around the world. Traditional supply chain management systems often face challenges related to transportation, efficiency, and business process tracking. All of these challenges will fundamentally change the logistics process and lead to increased operating costs, delays, and a lack of trust between various stakeholders involved in the supply chain. The emergence of blockchain technologies has opened up many opportunities to solve these problems and open up new possibilities for managing logistics in an integrated and efficient manner. Blockchain technologies act as a decentralized accounting system, ensuring transparency, security and stability of processes and transactions between parties without the need for intermediaries. The relevance and demand for blockchain technologies is confirmed by the constant growth of interest in the world as an innovative technology that is used for storing and transmitting digital data. Considering the above, it should be noted that the blockchain (from the English “block” - “block”, “chain” - “chain”) — a classification of a global database of data from all over the world, which is stored as a chain of blocks. Each block contains information about the volumes of transactions and data from the previous block, and thus they are all interconnected. Global digitalization and the introduction of blockchain technologies have significantly transformed supply chains, driven by the advent of tools such as GPS tracking, radio frequency identification (RFID), barcodes, smart labels, location-based data and wireless sensor networks. Implementation of the presented tools and their further integration with web services that have the potential for unification of information and business processes, ensuring openness and traceability of logistics activities of companies in current conditions. It is important to state that from a supply chain management perspective, blockchain technologies provide security and trust in the process of information exchange between stakeholders [18]. The functioning of a modern business is inextricably linked with long-term evoluyion, planning and an effective logistics management system, which ensures the life cycle of goods and services. It is important and relevant in the modern world to ensure the optimality, transparency and ease of business processes of companies, including logistics. It is impossible to imagine achieving the strategic goals and business objectives of modern logistics companies without the application of blockchain technology. Considering what has been presented, it should be noted that the application and intensity of scaling up of blockchain technologies in the world is because these technologies, in addition to the global optimization of business processes and increasing operational efficiency, have a number of advantages that provide this. The conceptual advantages of blockchain technologies in modern conditions are presented in Figure 1.

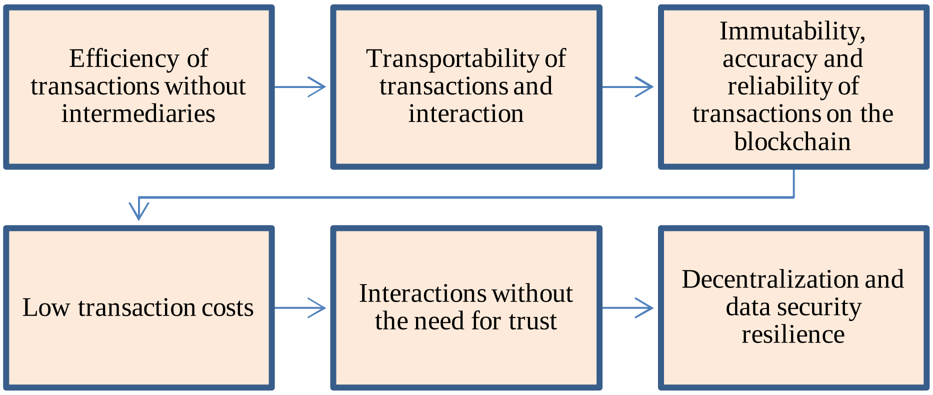

Figure 1 The conceptual advantages of blockchain technologies in modern conditions

It is important to note that the world economy directly depends on international logistics; this global business process is quite complex technically and financially [19]. In modern realities, the technological sphere does not allow us to fully comprehend the emerging problems and difficulties in the delivery process, which leads to the fact that most participants increase the final price of goods and services. There are also problems with tracking and moving goods, where information is not always current and updated. Considering what has been presented, a solution is possible in blockchain technologies, since they are a consolidated tool that optimizes and improves all key stages of logistics. Processing time and requests are significantly optimized, while the quality of logistics services, their transportability, and accessibility are improved, which increases their profitability. Based on what has been presented, the authors structured the key principles of blockchain operation in the company's logistics services using the example of transport transportation, which are present in Figure 2.

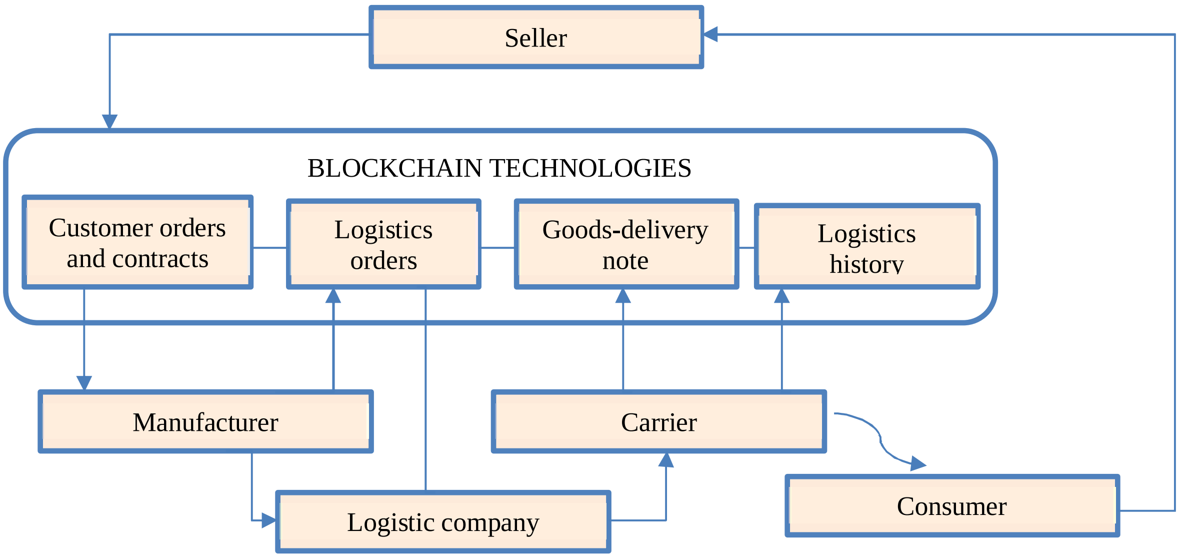

Figure 2 Structuring the key principles of blockchain operation in logistics services of companies (using the example of transport transportation)

Based on what has been presented, it should be argued that the arrows show the process of interaction between transport structures and the main participants in the logistics process. It can be seen that at any given time, any link can view information about a particular process and track its parameters. All transactions are safe, transparent, the possibility of fraud is eliminated the efficiency and rationality of resource use increases, which confirms the peculiarity of blockchain as a transfer technology without which effective optimization of the work of modern companies is impossible. Blockchain technology and its application in the logistics business processes of companies simplifies cargo tracking, concluding long-term contracts, processing transactions, and conducting any audits and observations by auditors. Consumers can independently track at any time the location and the entire logistics path taken by the product. In current conditions, company strategies should be based on blockchain technologies, which allow for real-time accounting and tracking, what is still relevant and necessary today. However, like all existing technologies that have their application in the business segment of the modern level, blockchain also has its drawbacks, which are stated and presented by the author in Figure 3.

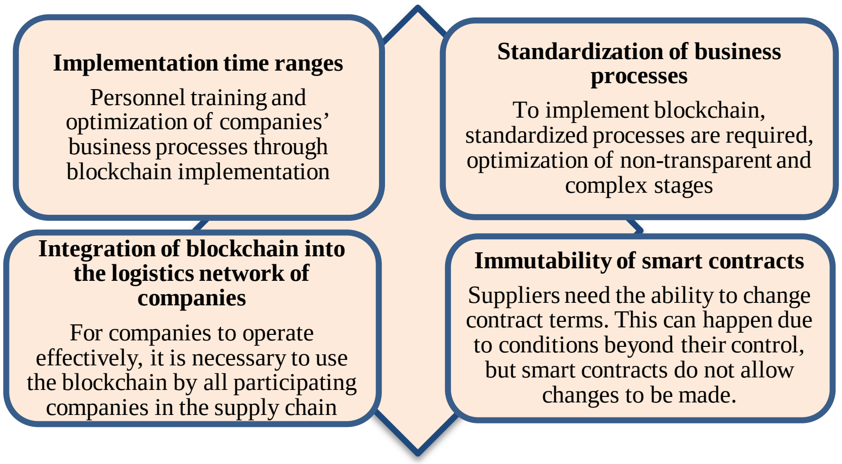

Figure 3 Classification of key disadvantages of blockchain technologies in the logistics activities of companies

It is important to state that blockchain in the supply chain performs a number of important functions due to its transparency, traceability and speed. These technologies are characterized by transparency, which is an important criterion when collaborating with partners and clients, since data protection is guaranteed. Based on what has been presented, it is necessary to consider the main trends in the evolution and application of blockchain technologies in the world, which are structured and presented by the authors in Figure 4.

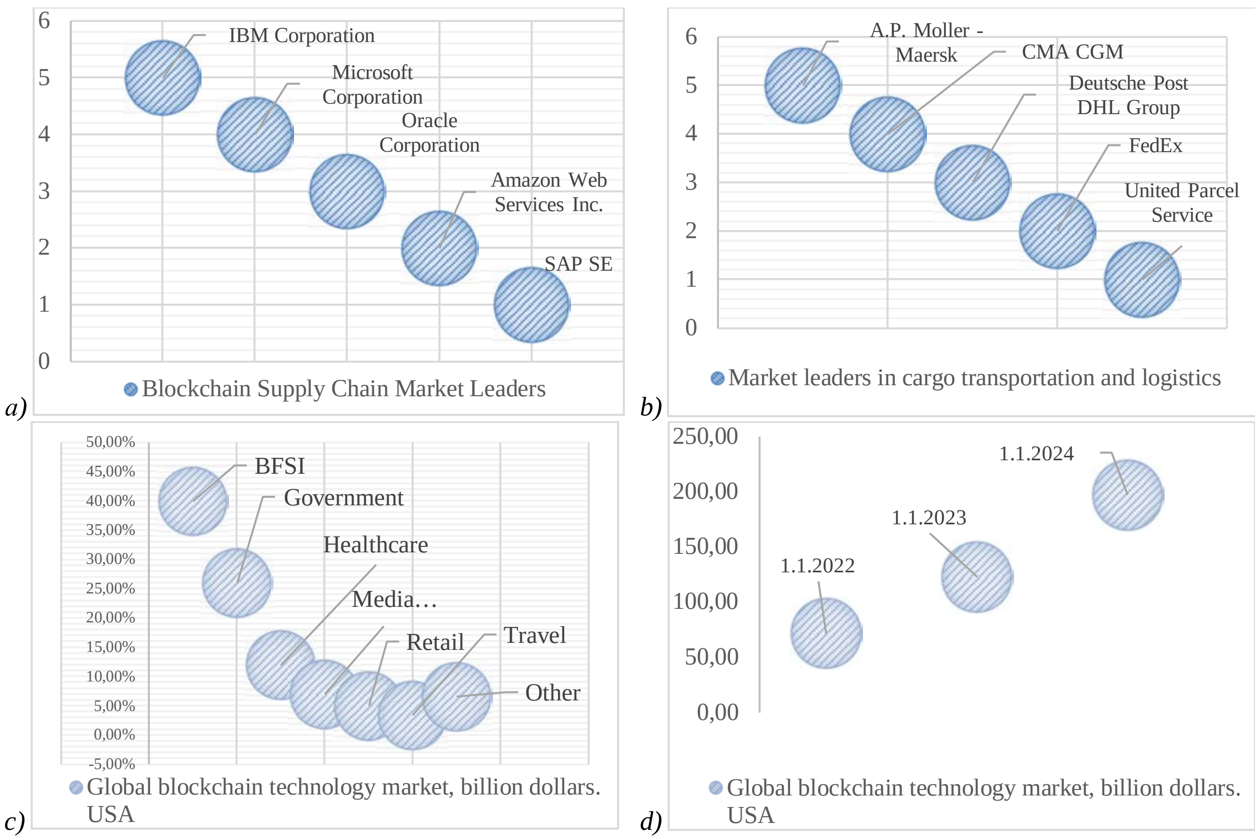

Figure 4 Structuring of conceptual trends in the evolution and introduction of blockchain technologies in the world (a - Leaders of the blockchain supply chain market; b - Leaders of the cargo transportation and logistics market; c - Global blockchain technology market, billion dollars. USA; d - Global blockchain technology market, billion dollars USA)

Conceptualizing what has been presented, it should be noted that the global size of the blockchain technology market is estimated at 197 billion US dollars in 2024. It is important to state that from the previous trends, it is observed that the average annual growth rate of these technologies and their use in the global economy is 17.5%. The high interest and demand for these technologies leads to a rapid increase in the number of blockchain users. Blockchain are often referred to as trust technology because they do not have a single point of failure and cannot be changed from a single computer. In addition, blockchain enables the use of tools such as smart contracts, which can potentially automate manual processes, from processing claims and grievances to distributing the contents of a will. These are some of the desirable features that are driving the BFSI industry to embrace blockchain [20].

It should be noted that blockchain technology requires huge investments to create the appropriate infrastructure and its maintenance. The important fact is that Blockchain-as-a-service offerings are transforming the BFSI industry, with banking institutions and financial services companies among the key investment companies. This is because with a plethora of high-value decentralized applications, it is giving rise to new business models in various areas such as cross-border payments, remittances, exchanges, online banking, and trade finance. However, it is still at a nascent stage in the market due to which banks and financial institutions are exploring the viable opportunities of this technology and investing in it, which is likely to drive the growth of the market. Although global freight volumes grew 3.6% year-on-year in 2022, supply chain bottlenecks continue to impact road freight transport. Logistics is one of the priority areas of the global economy, which is actively implementing blockchain technologies into its efficient organization [21]. Supply chains undergo changes and transformations every year, which are caused by a number of global factors: pandemics, uncertainty, wars, instability. The implementation of blockchain technologies requires a radical approach and global restructuring and standardization of business processes, which in turn leads to increased profitability, reduced operating costs and business scaling.

The present results of conceptualization of key trends in the development of blockchain technologies indicate that the blockchain technology market is developing under the influence of such factors as the growing demand for secure and efficient digital transactions, the need for transparent supply chains and the growing interest in decentralized finance (DeFi) applications [22]. Changes in the legislative framework of many countries contribute to the development of this segment of the world market. According to international studies, about 77% of top managers of modern companies believe that blockchain technology will become a new era in the development of the global economy in the coming years. This fact is confirmed by the growing potential of blockchain technologies themselves, which are causing dramatic and revolutionary transformations in many sectors of the global economy. It is important to note that the presented structure of blockchain technology development trends indicates that the payments segment occupies a dominant position in the blockchain technology market, occupying more than 44% of the share. This is due to the fact that blockchain technologies and their advantages that blockchain technology offers for making payments, such as increased security, transparency and reduced transaction costs. Blockchain does not require intermediaries, optimizes business processes and makes payments faster than traditional banking systems. This capability is especially useful in cross-border transactions, where blockchain can significantly reduce processing time and fees. The growth of blockchain implementation in payments is still the growing acceptance of crypto currencies and the growing demand for more efficient payment solutions in various sectors of the global economy.

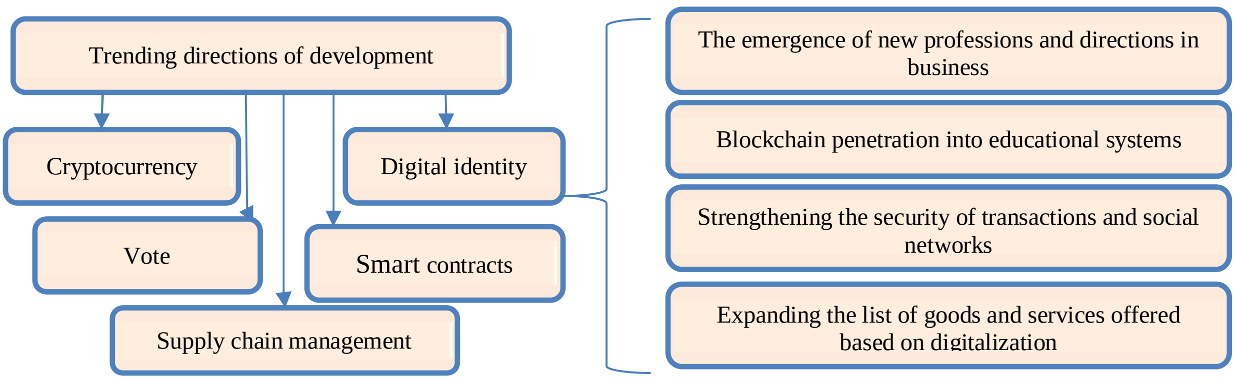

Figure 5 Structuring key development trends and identifying the promising potential of blockchain technologies in the world

As world-class companies and consumers seek alternatives to traditional payment methods, which can be slow, costly and prone to fraud, blockchain represents a viable solution. Its ability to provide immutable transaction records and instant verification has made it an attractive option for increasing the security and transparency of transactions, including in logistics, an industry in which payment plays a significant role in the global economy [23]. Based on what has been presented, it should be emphasized that the process of intensive evolution and scaling of blockchain technologies in the global economy is increasing and growing every day. To argue and structure the key development trends and determine the promising potential of blockchain technologies in the world, the author presents the main ones in Figure 5.

Having stated the above, it should be noted that blockchain technology is a relatively new technology that has potential for volatility in many industries worldwide. In today's environment, crypto cards are a popular payment instrument in terms of currency conversion. Therefore, it is not surprising that payments using crypto currency for goods or services instead of paying with regular cards are gaining popularity and scaling across business segments. Trends in the development of blockchain technologies and their scaling in the world indicate their scaling and increased growth. Considering that logistics activities are rapidly developing and are the main artery of the global economy, the implementation of blockchain technologies is relevant and in demand. Considering the relevance and demand for blockchain technologies and their application in the logistics of current companies as part of the need to optimize business processes and achieve strategic business objectives, the author has structured practical examples of the application of blockchain technologies in the logistics of excellent companies, which are presented in Table 1.

Table 1 Structuring of key cases of implementation of blockchain technologies in the logistics activities of modern world-class companies

COMPANY	WORLD ECONOMY SEGMENT	CHARACTERISTICS OF THE IMPLEMENTATION FEATURES OF BLOCKCHAIN TECHNOLOGIES
VISA	Financial sector	Launching our own payment service - B2B Connect. Thanks to this tool, businesses and companies can directly make cross-border payments for large amounts faster and cheaper without intermediaries and additional commissions, which improves the quality of interactions between counterparties.
MASTERCARD		The Crypto Secure system based on blockchain technologies has been implemented, which is focused on increasing the level of security of transactions, tracking, and blocking transactions on exchanges with an increased risk of fraud, which helps prevent fraud, theft of personal information and other types of financial crimes.
WALMART	Retail and logistics support	The introduction of blockchain technologies has made it possible to implement a tracking platform based on the VeChainThor blockchain with more than 100 product lines and services.
NESTLE		Implementation of the Food Trust platform based on blockchain technology for managing ingredient supply chains, which allows consumers to study the composition of products.
MEDILEDGER		Implementation of a distributed registry to manage the supply of medications in accordance with EPCIS standards.
MAERSK	Logistics and shipping	Implementation based on the TradeLens blockchain ecosystem for tracking transport and the supply chain. The platform consolidates and integrates cargo data into a single secure blockchain network and provides secure access to information.
FedEx		Implementation of blockchain and smart contracts to track and store records for planning purposes and create a consolidated register for participants in supply chains with state control.
DOLE, TYSON, GSF, UNILEVER, MCCORMICK, KROGER, DRISCOLL'S, MCLANE	Logistics and food supply system	IBM, based on the application of the Hyperledger Fabric distribution registry, launched the IBM Food Trust ecosystem, which is aimed at increasing the transparency and traceability of food supply chains by creating end-to-end “stories” of each product. Today, the IBM Food Trust is a neutral platform that can be joined by any manufacturer, supplier, retailer or other market participant who wants to increase consumer brand trust and create a smarter, more sustainable and transparent food supply chain.
KUEHNE, NAGEL	Logistics and Supply Chain	Blockchain technologies have been implemented to optimize the operation of the Verified Gross Mass (VGM) logistics portal, which processes more than 800,000 transactions per month. The new technology is responsible for the safety and immutability of information passing through the portal, as well as for the automation of document flow.
DLA		The US Defense Logistics Agency (DLA) has implemented blockchain technologies in logistics and supply chain management for the entire US military, as well as several federal agencies and international allies.
DHL	Logistics and inventory management	Postal provider DHL and Accenture have implemented a prototype of an open platform for collecting information on production (formulation, ingredients, technologies and equipment), transportation and storage specifics of medicines. Access to the database for manufacturers, warehouses, distributors and other participants, who together with the blockchain will ensure the integrity of the information.

For example, payment options with crypto are offered by such global brands as KFC, Burger King, Subway, Starbucks, Microsoft, PayPal and many others. An important blockchain technology is digital identification, which ensures the creation of secure digital identities protected from unauthorized access. National governments to create a secure and openness electronic voting system can also use Blockchain technologies. It is important to create a register of transactions in the supply chain and logistics of companies. Blockchain technology allows you to safely create and execute programs in a decentralized manner such as smart contracts, which can be used to automate many types of agreements: the purchase and sale of goods and services, financial management and investment. It is important to state that blockchain technologies can be used in any activity to increase the efficiency of business processes, optimize them and increase their level of profitability. Based on what has been presented, it should be noted that the number of areas of application of blockchain technologies and their popularity in the world is constantly growing. From the presented examples of the introduction of blockchain technologies in logistics activities, it should be emphasized that all large world-class companies have introduced these technologies into their business processes, at the same time increasing their efficiency and effectiveness, which in turn leads to an economy of time and financial waste and profitability growth. To implement blockchain technologies in the logistics activities of modern companies, it is not necessary to develop their own solutions; today there are many ready-made solutions from tech giants such as (IBM, Microsoft) and crypto projects (VeChain), which optimize the work of all parts of the supply chain, regardless of the type and specificity of the activity companies [23,24].

Having structured the conceptual features of the introduction of blockchain technologies in the logistics activities of companies with the argumentation of key advantages, disadvantages and problems in scaling, a multidimensional cluster analysis should be carried out. The information base of the study was the structural indicators of the logistics activities of companies and the trends in the evolution of blockchain and its application in logistics. To substantiate the features of the implementation of blockchain technologies in logistics and identify the main problems and development prospects, multidimensional cluster analysis tools were used. The main results of multidimensional cluster analysis of the features of the application of blockchain technologies in the logistics activities of countries around the world are presented in Table 2.

Table 2 The main results of multidimensional cluster analysis of determining development trends and application of blockchain technologies in the logistics activities of countries around the world

STRUCTURAL INDICATORS OF LOGISTICS/ BLOCKCHAIN IMPLEMENTATION	MINIMUM VALUE RANGE	RANGE OF MAXIMUM VALUES	RANGE OF AVERAGE VALUES	CLUSTER NUMBER	LEVEL OF DEVELOPMENT OF LOGISTICS AND BLOCKCHAIN IMPLEMENTATION
BLOCKCHAIN IMPLEMENTATION	3.50	4.5	3.35	1	High level
	2.51	3.0	2.42	2	Average level
	2.50	2.99	2.38	3	Low level
LPI	3.01	4.5	3.20	1	High level
	2.51	3.0	2.42	2	Average level
	2.50	2.0	2.29	3	Low level
CUSTOMS	2.50	5.0	3.55	1	High level
	2.39	3.0	2.44	2	Average level
	2.13	1.8	2.02	3	Low level
INFRASTRUCTURE	2.99	4.5	3.65	1	High level
	2.50	3.0	2.46	2	Average level
	2.44	1.65	2.01	3	Low level
INTERNATIONAL DELIVERIES	2.89	4.0	3.01	1	High level
	2.55	3.16	2.45	2	Average level
	2.38	2.22	2.03	3	Low level
LOGISTICS COMPETENCE	3.10	4.5	3.15	1	High level
	2.45	2.96	2.55	2	Average level
	2.49	2.07	2.31	3	Low level
TRACK AND TRACE	3.10	4.5	3.42	1	High level
	2.35	2.9	2.32	2	Average level
	2.54	1.94	2.03	3	Low level
TIMELINESS	3.47	4.5	3.52	1	High level
	2.86	3.5	2.94	2	Average level
	2.10	3.0	2.45	3	Low level

**High level - Cluster of countries with a high level of efficiency in logistics and implementation of blockchain technologies; Average level - Cluster of countries with an average level of efficiency in logistics and implementation of blockchain technologies; Low level - Cluster of countries with low efficiency in logistics and implementation of blockchain technologies.*

Having stated the presented results of a multidimensional cluster analysis of trends in the introduction of blockchain technologies in the logistics activities of countries around the world, we should consider the structure of each cluster, which is presented by the author in Figure 6.

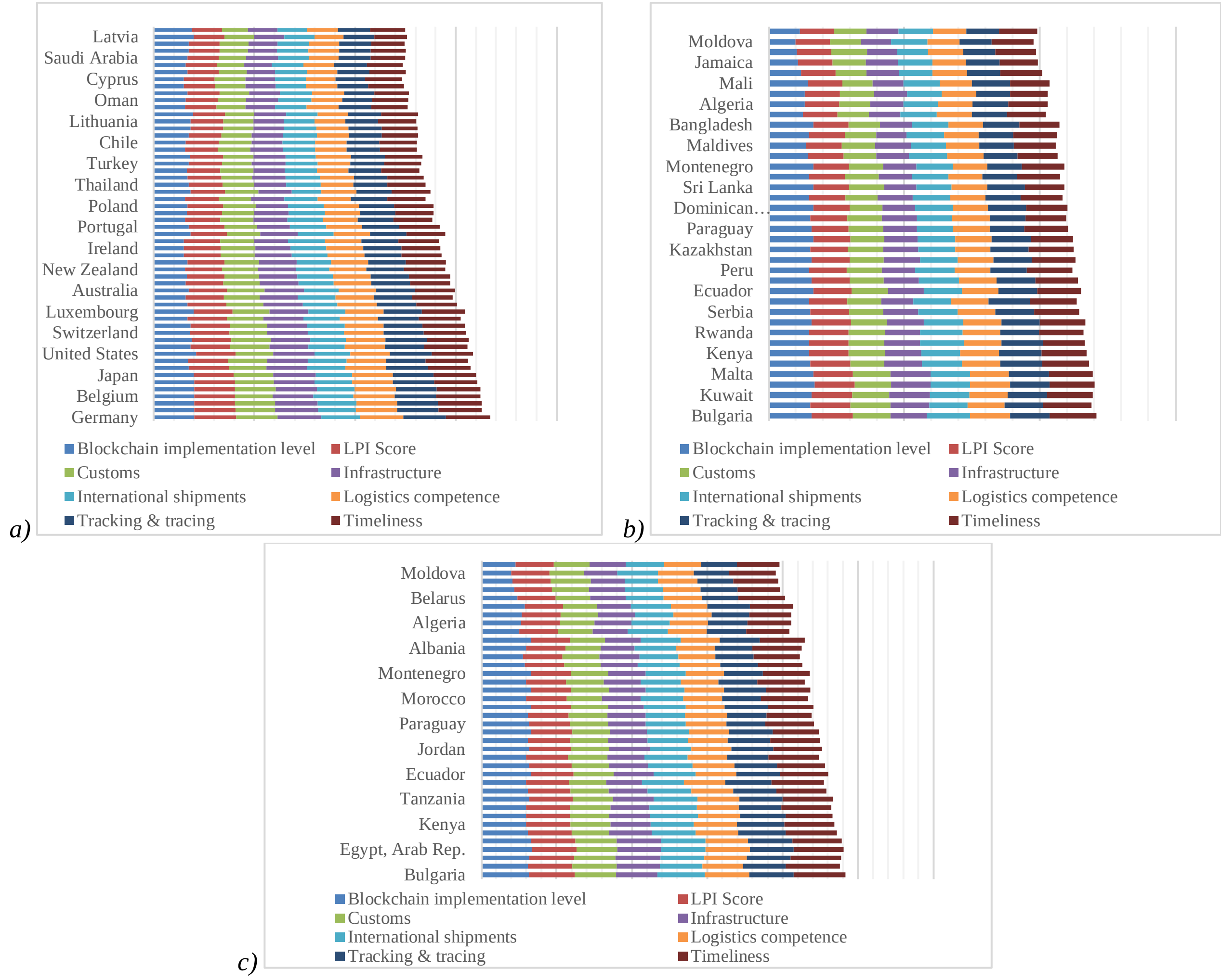

Figure 6 Structure of clusters for multidimensional analysis of trends in the application of blockchain technologies in the logistics of countries around the world (a - Cluster of countries with a high level of efficiency in logistics and implementation of blockchain technologies b - Cluster of countries with an average level of efficiency in logistics and implementation of blockchain technologies; c - Cluster of countries with low efficiency in logistics and application of blockchain technologies)

Having stated the above, it should be summarized that the introduction of blockchain technologies provides increased transparency and security of the supply chain, which, in turn, increases the efficiency of processes. The application of the technology is complex, but the benefits of blockchain outweigh these problems, as evidenced by the results of the resulting clusters.

4 Conclusions

The conceptual results of the survey are that the features and key trends of the need to implement blockchain technologies in the logistics activities of modern companies have been identified. The intensity of evolution and scaling of blockchain technologies in all industries and segments of the global economy is generating demand for these technologies, as they ensure the efficiency of business processes, their transparency, and manageability and improve their revenue side. It has been proven that the modern logistics strategy of companies requires new technologies and approaches to build optimal business processes and supply chains that play a strategic role in the global economy.

The main theories of the evolution of blockchain as a technology are stated with the argumentation of the basic stages and their role in the applications process. It has been proven that blockchain technologies are rapidly gaining momentum and scaling into all spheres of human life. A scientific and methodological analysis of existing scientific approaches and views was carried out as part of the formation of the theory of the development of trends and the introduction of blockchain technologies in the logical activities of companies in current conditions. The lack of a unified approach and the need for further research into trends in the development of blockchain technologies and their applications in logistics are highlighted, which is characterized by increased interest and demand among top managers of companies.

Formalization of key tools and directions for the evolution of blockchain technologies with arguments for their key advantages and disadvantages. Structured basic principles of operation of logistics of a road transport company based on blockchain technology. The transparency, controllability and safety of building such logistics processes are highlighted, which is in demand and necessary in modern conditions. The necessity of using tools for multidimensional cluster analysis of trends in the applications of blockchain technologies in the logistics of countries around the world is substantiated. An information base for multidimensional cluster analysis has been defined, which includes structural indicators of logistics and its efficiency and the level of implementation of blockchain technologies by country of the world. The main examples of the applications of blockchain technologies in logistics by world-class companies are conceptualized. The obtained research results are complete and valuable and can be applied in practice when building strategies for logistics companies based on blockchain technologies to achieve strategic goals, improve process control and transparency.

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Postal optimization by three metaheuristics – a case study

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Abstract: The efficiency of postal delivery services impacts various aspects of business operations as well as the daily lives of individuals. With the surge in online shopping, increasing expectations for timely deliveries, and intense competition, postal operators are under pressure to optimize their transportation networks. This poses a significant challenge for traditional postal systems, particularly in such areas as route optimization, resource allocation and network planning. Postal operators recognize that optimizing transportation routes is a critical task to ensure cost-effectiveness and customer satisfaction, which directly influences their business performance and market share. In this paper, we analyze three possible approaches to solving a real-life, practical instance of a postal transportation plan optimization problem. Specifically, we evaluate the performance of three metaheuristic methods: Simulated Annealing, Tabu Search, and a Genetic Algorithm. We analyze which approach performs best in a real-life scenario inspired by the operations of one of the biggest postal operators in Central and Eastern Europe. This scenario mixes elements of multiple standard routing problem specifications, like capacity constraints of vehicles and network nodes, time windows, pickups and deliveries or multiple types of vehicles.

1 Introduction

Optimization of logistics and transportation networks is a key challenge in many industries, particularly in sectors where cost efficiency, timely deliveries, and resource management are critical. Postal service operations, which involve the movement of large volumes of mail and parcels across extensive networks, require advanced optimization techniques to improve performance while keeping costs under control. Given the combinatorial complexity of such problems, traditional optimization methods often struggle to find high-quality solutions for problems that involve practical constraints. As a result, metaheuristic algorithms have gained popularity as effective approaches for tackling large-scale, complex transportation optimization problems [1].

This study examines the application of metaheuristic optimization techniques to a real-world postal service problem, evaluating their ability to enhance transportation planning and cost efficiency. Specifically, we compare the performance of three popular algorithms – Simulated Annealing, Tabu Search, and a Genetic Algorithm, in improving pre-optimized transportation plans within a limited computational budget. These algorithms, known for their effectiveness in combinatorial optimization, are tested under real-world constraints to determine their suitability for postal logistics planning. The case study presented in this paper incorporates multiple elements into a single problem specification, including time windows, vehicle capacities, postal outlets capacities, operating costs of vehicles and postal outlets, multiple vehicle types, multiple network connection types (standard and express), compatibilities between vehicles and postal outlets or varying demand densities (low, expected, and peak loads). Therefore, contribution of this paper is twofold. First, it provides a description of a real-life postal optimization problem faced by one of the largest postal operators in Central and Eastern Europe, with the goal of enriching the understanding of the complexities involved in practical optimization of transportation problems encountered by such companies. Second, it presents a comparative study of three optimization algorithms. These methods are applied to the same postal transportation case study, and their results are reported and compared. As a consequence, the paper seeks to offer insights into the applicability and effectiveness of the tree algorithms. We focus here on an operational level optimization of postal delivery plans, i.e. we assume that the structure of the transportation network is fixed. Scenarios involving problem instances, where technical parameters of the network elements can be adjusted by the algorithm, i.e. a brownfield scenario, and where only the Genetic Algorithm was used, were analyzed in [2], where the aim was to identify network elements that could serve as hubs for satellite locations.

The remainder of this paper is organized as follows. Section 2 provides a brief review of the main types of transportation problems and of the three metaheuristic algorithms we employed for optimization. Section 3 presents the assumptions of the case study that we consider as a reference scenario for testing the algorithms. Section 4 details the methodological aspects of the tested algorithms. This is followed by a discussion of the results, presented in Section 5, where results of numerical experiments are reviewed, and the algorithms are compared in terms of the quality of obtained solutions and the robustness of their performance. Finally, Section 6 concludes.

2 Literature review

Postal transportation systems play a crucial role in facilitating global commerce, trade, and communication, making them essential for the efficient functioning of modern societies [3]. With the rapid growth of e-commerce and the increasing demand for quick and reliable delivery services, optimizing postal transportation plans has become a critical task for postal operators [4]. To ensure timely delivery of mail and packages, postal service providers are increasingly focused on enhancing the efficiency of their networks and of their transportation plans [5]. As a consequence, over the years, researchers and practitioners have focused on developing and testing approaches to enhance the performance of transportation operations [6-8].

Technically, the problem analyzed in this article falls into the category of Vehicle Routing Problems (VRP), which serves as a quintessential model for addressing logistical challenges, including elements such as optimization of delivery routes, vehicle assignments, and resource utilization [9,10]. In essence, VRPs address the question of how to best allocate vehicles – and potentially drivers – to deliver cargo (e.g., mail or packages) or to provide services at specified locations. VRPs come in various forms, each presenting unique challenges and complexities. Among these, several types of VRP can be distinguished [11], for example: Capacitated VRP (CVRP), where vehicles have limited carrying capacities, and the goal is to meet customer demands while adhering to these capacity constraints, Heterogeneous Vehicle Routing Problem (HVRP), involving a fleet of vehicles with diverse characteristics, such as capacity, speed, cost, fuel usage, or the type of cargo they can carry, VRP with Time Windows (VRPTW), where customers must be served within specific time slots, introducing a temporal dimension to route planning, Multi-Depot VRP (MDVRP), where vehicles can be dispatched from multiple depots, adding optimization opportunities, Pickup and Delivery VRP (PDVRP), where vehicles perform both pickup and delivery operations, with each pickup task paired with a corresponding delivery task, and routes requiring adherence to specified sequences of pickups and deliveries, Split Delivery Vehicle Routing Problem (SDVRP), which relaxes the constraint that each customer must be visited exactly once, allowing split deliveries, Vehicle Routing Problem with Backhauls, where all deliveries on a route must be completed before any pickups are made, and Dynamic VRP (DVRP), where problem parameters, such as customer demands or vehicle availability, change over time, requiring real-time adaptation of routes. There are also other variants of VRPs, however, practical scenarios typically are more complex than theoretical models as they mix different variants of VRPs. The version of a VRP considered in this article falls into this category and it can be classified as a Rich VRP [12]. This means that it combines various elements of such variants as CVRP, VRPTW and others.

In this paper we aim to evaluate the suitability for application of metaheuristic optimization algorithms to a practical instance of a Rich VRP experienced by a postal service provider. We use three popular algorithms – Simulated Annealing (SA), Tabu Search (TS), and the Genetic Algorithm (GA). These algorithms were selected for benchmarking and comparison as each of them follows a distinct optimization strategy: SA employs a probabilistic search process that balances exploration and exploitation, TS utilizes a structured, memory-based approach to refine solutions, and GA applies evolutionary principles to iteratively enhance quality of solution. The SA algorithm was introduced by Kirkpatrick et al. in 1983 [13] and has since become a widely used optimization technique for solving complex optimization problems, both continuous and discrete ones. It is inspired by the physical process of annealing used to determine low energy states of physical systems. At the beginning of the search space exploration, it acts more like a random search method, and it gradually shifts towards a greedy search state. This state transition is governed by a parameter called the temperature. The TS method was introduced by Glover in the late 1980s [14] and it can be perceived as an enhancement of SA, where the search space exploration process is more guided, i.e. the neighborhood of the current solution is more intensively explored before a transition to the new solution is performed. To avoid a local minimum trap, the algorithm uses a mechanism called a tabu list, which prevents it from cycling around local minima. GA was first introduced earlier, by Holland, in the 1960s [15], and also has become a widely recognized optimization method across various fields. It is based on the principle, where new solutions are constructed from the existing ones, with elements of randomness involved. By employing numerical procedures called genetic operators – selection, reproduction and mutation, it intends to mimic the process of natural selection and evolution.

3 Problem formulation

The problem considered in this paper falls into the category of so-called rich or practical VRPs. These problems aim to determine optimal routes for a fleet of vehicles while accounting for a variety of practically important constraints. In particular, the postal delivery version of the VRP analyzed in this paper is based on the following assumptions.

- Each node in the network represents a postal operations outlet. The network comprises 14 main nodes that serve as major logistics platforms, 12 local or regional network nodes, 180 distribution and reloading nodes, approximately 8,000 postal service nodes, and about 34,000 post boxes. Postal service nodes and postal outlets are integral to the first- and last-mile optimization sub-problem.
- Outlets operate within specific hours (some 24/7, others not) and have diverse technical characteristics

depending on their size, location, construction, and installed equipment. Each outlet has a defined list of vehicle types it can accommodate, along with its capacity in terms of the number of vehicles it can process per hour. For each cargo type, an outlet is characterized by the volume it can handle per hour, the unit cost of processing, its storage capacity, and the unit storage cost. These volumes, times, and costs primarily depend on the size of the outlet and the types of installed equipment.

- Several types of vehicles with capacitated storage spaces are available, as in the Capacitated Vehicle Routing Problem, ranging from smaller delivery cars to various sizes of vans and larger trucks. Each vehicle type has a defined capacity for different types of standardized cargo (e.g., boxes and pallets) and an average traveling speed, which depends on the time of day and the chosen route. Additionally, there are special-purpose vehicles designed to carry specific types of cargo. Each vehicle type also has unique loading and unloading times. Vehicles incur costs per hour and per kilometer, while drivers have defined hourly rates. These characteristics classify the problem as a variant of the heterogeneous fleet VRP. Since the postal operator outsources its transportation services, the costs are determined by an external fleet service provider responsible for delivering the required number of vehicles of various types to the respective locations. Consequently, we assume the number of vehicles of each type is unlimited.
- Vehicles operate from multiple depot locations, as in the Multi-Depot Vehicle Routing Problem. They can begin and end their routes at any of the locations that function as depots or destination points. All network nodes can serve as both pickup and delivery sites. The first and last miles are pre-optimized and integrated into the problem as parameters that specify the time required to manage pickups and deliveries during the first and last mile.
- When delivering cargo to postal outlets, a vehicle arriving at a network node that is currently busy serving other vehicles must queue and wait according to the first-in, first-out principle.
- Cargo is shipped in standardized forms, such as boxes and pallets. Mail is transported in boxes, while parcels are carried on pallets, both of which must be picked up from and delivered to designated locations – nodes of the transportation network – as in the Pickup and Delivery Vehicle Routing Problem. In practice, cargo shipment demands exist between all pairs of locations.
- Vehicles travel along routes connecting network nodes, with travel times between nodes varying throughout the day. There are two types of network connections: standard and express. In the transportation plan, when a vehicle travels between two locations, the type of network connection must be specified. Typically, optimized solutions assign trucks and vans to standard network connections, while smaller, more flexible vehicles utilize express connections.
- Each postal outlet must be served within defined time windows, as in the Vehicle Routing Problem with Time Windows. Some outlets operate with longer time windows to accept pickups and deliveries, while others have more restrictive time constraints. To ensure cargo is delivered to its final destination on a given day, it must reach the designated outlet before a specified cutoff time, usually during the night.

An important aspect of the problem formulation are business objectives. In these terms, it is assumed that the operator aims to minimize operational costs, including penalties for violating Service Level Agreement (SLA) constraints. SLA constraints vary depending on the type of cargo being shipped. For mail, SLA ranges from next-day delivery for priority shipments to delivery within three days for economy shipments. The same timeframes apply to parcels. However, pallets must be delivered under a next-day regime.

Standard versions of VRP are challenging itself. The number of possible routes grows exponentially with the number of network locations and vehicles, leading to a vast solution space that is computationally expensive to explore. This phenomenon is known as combinatorial explosion. The practical version of the problem that we consider here, involves numerous simultaneous constraints, such as vehicle capacity and time windows, which further complicate the problem and narrow the set of feasible solutions. Optimizing such practical VRPs requires carefully balancing trade-offs between conflicting objectives, such as minimizing travel costs or distances while maximizing vehicle utilization. To tackle such complexities, numerous methods have been explored over the years, including exact algorithms, metaheuristics, and hybrid approaches. Exact techniques, such as dynamic programming and mixed-integer programming, employ methods like branch-and-bound, cutting plane, and column generation to iteratively narrow the search space and explore selected subregions in pursuit of an optimal solution. However, these methods are most effective when the problem formulation does not involve nonlinear interactions between problem elements. They also often struggle with scalability. As a result, exact methods excel when applied to more stylized VRP instances, particularly when the problem can be naturally formulated as a mixed-integer linear program. Metaheuristic algorithms, such as Genetic Algorithms, Tabu Search, Simulated Annealing, Particle Swarm Optimization or Ant Colony Optimization, provide, on the other hand, an efficient way to explore the search space in cases where problem formulations deviate from simplified scenarios. These methods iteratively refine solutions using heuristic guidance, enabling them to find high-quality, often near-optimal, solutions within a reasonable computational time. This makes them well-suited for real-world applications. Hybrid methods combine the strengths of different approaches by integrating exact and metaheuristic techniques to enhance performance and robustness compared to standard metaheuristics. In the following sections, we test three popular metaheuristic approaches. In what follows we consider the metaheuristic approach to solving the case study.

4 Methodology

Although optimizing logistics and transportation processes is essential for improving resource utilization and enhancing overall operational efficiency, the combinatorial nature and complexity of these problems pose significant challenges for traditional optimization methods. Over the years, metaheuristic algorithms have emerged as powerful tools for addressing these challenges, providing effective and efficient solutions to a wide range of optimization problems in logistics and transportation. Metaheuristic algorithms are iterative optimization techniques capable of exploring vast solution spaces. While they do not guarantee finding an optimal solution, their goal is to identify high-quality solutions within a reasonable computational time. These algorithms often draw inspiration from natural processes, social behaviour, and mathematical principles to guide the search process [16]. Some of the most widely used metaheuristic algorithms for optimization in logistics and transportation include:

- Genetic Algorithms (GA) that are inspired by the process of natural selection and evolution. They operate on a population of candidate solutions, iteratively evolving them through selection, reproduction, and mutation, which, as numerical procedures, are referred to as genetic operators.
- Simulated Annealing (SA) is based on the concept of sampling the next solution from the neighborhood of the current one, always accepting moves to better solutions while occasionally accepting moves to worse solutions with a controlled probability. This approach is inspired by the annealing process in metallurgy, where a material is heated and then gradually cooled to reach a low-energy state.
- Tabu Search (TS) is an optimization algorithm that explores the solution space by iteratively transitioning from one solution to a neighboring one while avoiding previously visited regions. It incorporates a memory mechanism to guide the search and prevent cycling back to recently explored search space regions.
- Particle Swarm Optimization (PSO) is inspired by the behavior of bird flocks and fish schools. It maintains a swarm of solutions (particles) that iteratively adjust their positions based on both individual and collective experience of particles, guiding the search toward promising search space regions.
- Ant Colony Optimization (ACO) mimics the foraging behavior of ants, where solutions are constructed iteratively by simulating the pheromone trails that ants lay down to communicate and reinforce optimal paths. This mechanism guides the search process toward more promising solutions over time.

Some other notable examples of metaheuristics include Iterated Local Search and Variable Neighbourhood Search. In general, metaheuristic algorithms are powerful tools for tackling complex optimization problems within a reasonable timeframe. By drawing inspiration from natural and social phenomena, they can generate effective and efficient sub-optimal solutions for a wide range of problems. In the remainder of this chapter, we provide a brief overview of the metaheuristic methods used in this study.

4.1 Simulated annealing

It is highly versatile and applicable across various practical domains, including the Traveling Salesman Problem, Vehicle Routing Problem, job scheduling, manufacturing, asset allocation problems, and the estimation of meta-parameters in statistical and machine learning models. SA avoids getting trapped in local extrema and seeks to converge toward a global optimum by occasionally accepting steps that temporarily worsen the objective function's value. The algorithm is relatively simple to implement and requires minimal problem-specific parameter tuning. The initialization phase involves generating an initial solution x_0, setting the initial value of the temperature parameter $t_0 > 0$, and setting the annealing schedule parameter α, which governs how temperature drops from one iteration to the other. The initial solution is randomly sampled from the search space and pre-optimized using simple heuristics, such as a push-forward insertion heuristic. The initial temperature t_0 is calibrated through a trial-and-error process, while the temperature update parameter α is set to ensure that the algorithm converges when the computational budget is exhausted. At each iteration, a candidate solution x'_k is drawn uniformly from the neighborhood of the current solution $N(x_k)$. The neighborhood consists of solutions that can be obtained from x_k by applying small random perturbations. These perturbations modify certain elements of the solution x_k, such as the grouping of cargo bundles, the assignment of vehicles to routes, or the order in which network nodes are visited. As the activation function, we use the Metropolis function, given by (1).

$$p = \min\left(1, \exp\left(-\frac{f(x'_k)-f(x_k)}{t_k}\right)\right) \qquad (1)$$

As the temperature update schedule, which gradually decreases the temperature over iterations, we use an exponential decay schedule defined as $t_{k+1} = \alpha \times t_k$. The temperature decay parameter α is calibrated so that after all

K iterations, the final temperature is $t_K = 10^{-2}$. The parameter K is set to fit the available computational time budget.

4.2 Tabu search

In each iteration, it performs an intensive Monte Carlo exploration of the neighborhood $N(x_k)$ of the current solution x_k and selects the move to the next solution x_{k+1} that results in the greatest improvement to the objective function. Solutions within the neighborhood $N(x_k)$ are generated by perturbing the current solution x_k, however, according to the tabu list principle, perturbations applied within the last n iterations cannot be undone, see (2), where the tabu list in the k-the iteration is denoted by TL_k.

$$x_{k+1} = argmin_{x \in N(x_k) \setminus TL_k} f(x) \quad (2)$$

This mechanism prevents the algorithm from revisiting previously explored regions of the search space, allowing TS to effectively escape local extrema and move toward more promising search space regions. Tabu list is updated in each iteration according to the First-In First-Out queue principle. The length of the tabu list, n, which is referred to as memory, is calibrated experimentally. Additionally, once every m_{int} iterations, a local search heuristic is applied to locate the nearest local extremum – this step is known as the intensification phase. Similarly, every m_{div} iterations, diversification is applied, where the algorithm jumps to a random region of the search space to assess whether it is, on average, better than the currently explored region. On top of that, we employ the strategy of aspiration moves, which is an exception that allows a normally forbidden (tabu) move to be accepted, if it results in a solution better than any previously found solution. Compared to SA, TS focuses more on exploitation, guiding the search faster toward promising search space regions, while SA emphasizes exploration, by probabilistically allowing moves that temporarily worsen solution quality. This exploitation-oriented strategy of TS often leads to faster convergence to high-quality solutions. Since TS employs a memory mechanism, through the use of a tabu list, it records recent moves and prohibits undoing them for a certain number of iterations. This prevents the algorithm from getting stuck in repetitive cycles around local extrema. In contrast, SA does not incorporate a memory mechanism, which may result in revisiting suboptimal regions of the search space multiple times.

4.3 Genetic algorithm

In contrast to SA and TS, GA processes in each iteration an n-element population of solutions $P_k = \{x_k^1, x_k^2, \dots, x_k^n\}$ rather than a single solution x_k. Additionally, unlike SA and TS, where a new solution is generated from the neighborhood of the current one $N(x_k)$, GA generates the next iteration's population of solutions P_{k+1} by employing consecutively three genetic operators, called selection, reproduction and mutation. Selection is responsible for choosing pairs of solutions from P_k for reproduction. We employed a tournament selection operator. During reproduction, for each pair of selected solutions (referred to as parents), GA randomly combines their elements, so that a new pair of solutions emerges (referred to as offspring). This process mimics natural selection and evolution. To ensure that each pair of parent solutions produces a new pair of feasible offspring solutions, we apply a set of crossover operations. For example, this involves taking routes from one solution x', removing cargo shipped along these routes from the second solution x'' and inserting these routes into the second solution x''.

After recombination, mutation is applied to introduce random changes to the offspring solutions. This helps maintain diversity in the population and prevents premature convergence to suboptimal search space regions. For mutation we employ operators analogous to perturbation operators used in SA and TS. After each offspring undergoes mutation with probability $p_m = 5\%$, GA produces the next iteration's population P_{k+1}. As a representation scheme to programmatically encode (represent) solutions as object instances, we use a natural representation, where all solution elements (routes, assigned vehicles etc.) are directly (explicitly) written into object instances storing them. In contrast, for example, to an interger programming formulation, where artificial variables are used to represent solutions.

5 Results of numerical simulations

In this section, we present the results of numerical simulations conducted to compare the efficiency of the three algorithms. The problem structure, including the logistic network and available resources, fully reflects the real-life scenario, however, the values of the operational parameters characterizing the problem, like cost related parameters and technical parameters, differ from those in the original case. To account for uncertainty arising from both the stochastic nature of the algorithms and the specific instance of the problem, the experiment was designed as follows:

1. The real-life problem instance was stochastically transformed into 10 variations, where parameter values related to operational costs and the technical characteristics of network nodes were perturbed.
2. Each of the 10 problem instances was solved 30 times by each algorithm, and the mean value trajectory of the objective function was computed across the 30 runs (for GA, this represents the mean trajectory of the best solution in the population).
3. Each algorithm was run on each problem instance for 8 hours (an operational time budget constraint).

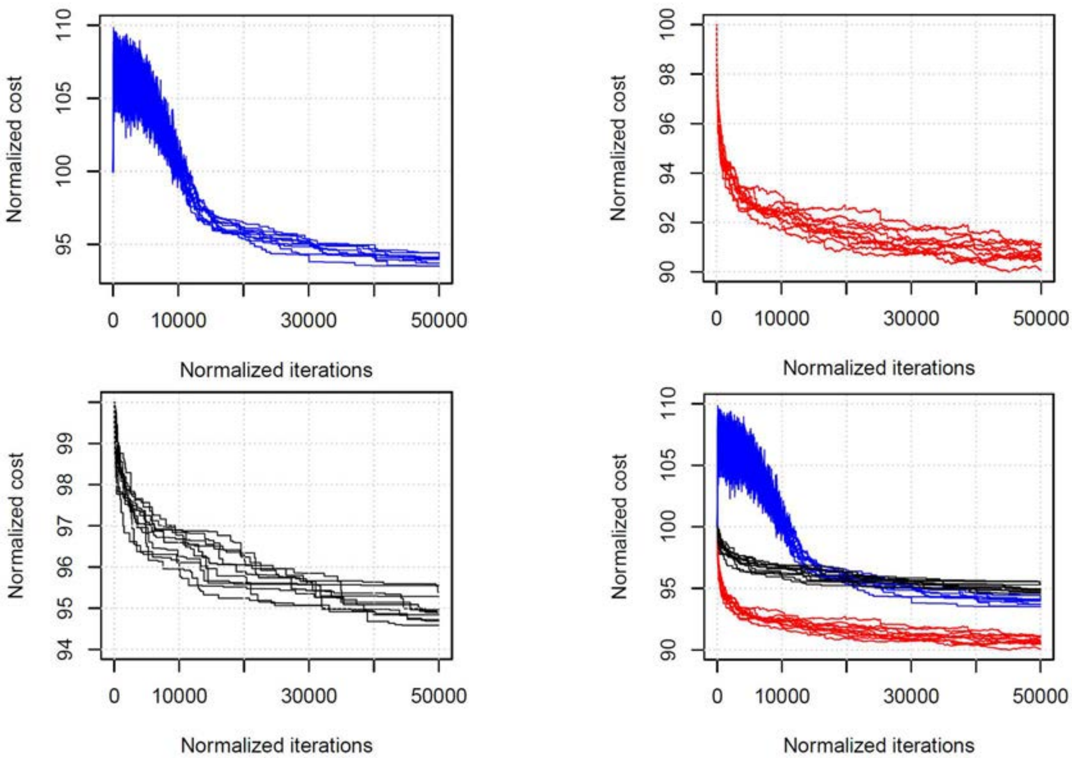

Figure 1 Mean trajectories of SA (upper left), TS (upper right) and GA (lower left). Mean trajectories of SA (blue), TS (red) and GA (black) imposed on a single plot (lower right)

Table 1 Statistics of costs at respective stages of search space exploration for each algorithm (Q1 = first quartile iteration, Q2 = median iteration, Q3 = third quartile iteration, Q4 = final iteration). Mean values are expressed in normalized terms, where the cost of the initial solution equals 100*. Standard deviations are expressed in percentage points. Means and standard deviations are calculated over 30 runs of 10 parametrizations of the considered postal optimization problem*

	Simulated Annealing	Tabu Search	Genetic Algorithm
Mean Q1	98.11	92.11	96.32
Std Q1	0.67	0.36	0.43
Mean Q2	95.30	91.34	95.61
Std Q2	0.42	0.58	0.31
Mean Q3	94.47	90.99	95.20
Std Q3	0.42	0.48	0.26
Mean Q4	93.91	90.68	94.98
Std Q4	0.29	0.32	0.32

The experiment was conducted on a server with 32 cores, enabling parallel computations (parallel runs of the algorithms). For better comparison, mean value trajectories of the objective functions are adjusted in the reported figures, so that the length of each trajectory equals 50,000 iterations (in reality, the computing time is the same across algorithms, while the number of iterations varies). Additionally, the objective function cost was normalized so that the cost of the initial solution equals 100 (for GA, this represents the cost of the best solution in the initial population). This means that if the solution cost decreases to 95, the algorithm has improved the solution by 5%. The initial solution was already pre-optimized, and in case of GA, the initial population consisted of the pre-optimized initial solution, solutions obtained by randomly perturbing the pre-optimized solution, and of purely random solutions.

Figure 1 presents the trajectories of SA, TS, and GA for the 10 variants of the postal optimization problem (see point 1 above). Due to the normalization of the objective function, these variants are directly comparable, both within each algorithm and across different algorithms. For better visualization, Figure 1 also overlays the trajectories onto a single plot (lower right plot).

Table 1 provides the average cost of solutions obtained by each algorithm at different stages of the optimization process, along with their standard deviations. Here, Q1 represents the first-quartile iteration, Q2 the median iteration, Q3 the third-quartile iteration, and Q4 the final iteration. The values in the table correspond to the trajectories shown in Figure 1. Since the cost of the initial pre-optimized solution is normalized to 100, the difference between 100 and the reported values represents the cost savings in percentage points.

The main conclusion drawn from the comparison is that the TS algorithm (presented in Figure 1 in red) produced the best results. It consistently outperformed the other two algorithms across all problem instances and throughout the entire search space exploration process. Regarding the final solutions, the SA algorithm (presented in Figure 1 in blue) ranked second, though the shape of its search trajectory differed significantly from that of the TS and GA (presented in Figure 1 in black). At the initial stages of the optimization process, SA consistently exhibited a tendency to sharply increase the solution cost, which aligns with its inherent mechanism – SA initially performs a highly exploratory search (a random search phase), frequently accepting moves that worsen the objective function value. As the optimization progresses, it becomes increasingly greedy, eventually converging to a fully greedy search state. The sharp cost increase observed in the early stages search space exploration by the SA algorithm can be mitigated by adjusting the initial value of the temperature parameter (t_0). However, experimental results indicate that for the considered postal optimization problem, achieving this would require forcing the algorithm into a highly greedy state early on, causing it to behave similarly to a local greedy descent method. Consequently, this leads to premature convergence and entrapment in a local minimum state, hindering global search space exploration. Despite this reported initial cost increase, SA, over time, demonstrates a significant potential for improving solutions. However, because it starts from an elevated cost level, it ultimately fails to catch up to TS, which does not exhibit such cost fluctuations in its early stages of the optimization process. The GA initially outperforms SA – for approximately 30% of the runtime, but ultimately it yields worse results than both SA and TS. This observation holds across different crossover operators tested in this study, as well as in scenarios where elitism mechanisms were incorporated.

Numerically, TS improved the initial pre-optimized solution by up to nearly 10% (with a standard deviation of 0.32 percentage points), compared to approximately 6% for SA (with standard deviation of 0.29 percentage points) and about 5% for the GA (with standard deviation of about 0.32 percentage points). In terms of cost dispersion in the final iteration, all three algorithms exhibited similar performance. Overall, in the considered case study, TS emerged as the most effective approach, with SA and GA ranking second and third, respectively. However, the difference between SA and GA was noticeably smaller than the difference between either of these two algorithms and TS. Using one-sided t-tests to compare the differences in mean values, both under the assumptions of equal and unequal variances, we find that the mean objective function value in the final iteration of the TS algorithm is statistically lower than that of the other two algorithms, with significance levels of 1%, 0.5%, and even 0.01%. Regarding the difference between the mean objective function values of SA and GA, the hypothesis that SA outperforms GA in the final iteration of the search space optimization process holds at the 1% significance level but must be rejected at the 0.5% significance level.

6 Conclusions

In this paper, we examined an optimization problem inspired by a real-life case study involving one of the largest postal service operators in Central and Eastern Europe. The objective was to determine whether popular metaheuristic optimization algorithms – Simulated Annealing (SA), Tabu Search (TS), and a Genetic Algorithm (GA) – could effectively reduce the cost of initially pre-optimized solutions within a reasonable timeframe of 8 hours, and to identify which algorithm performed best. The results indicate that all three algorithms achieved cost reduction, but to different extents. With fine-tuned parameters, SA initially increased the cost, diverging from the original solution before exhibiting a steep descent trajectory, ultimately producing solutions that were 5%–6% better than the originally pro-optimized one. As expected, due to its exploitative rather than explorative nature, TS produced a more uniformly decreasing trajectory, ultimately yielding solutions 9%–10% better than the initial one. GA ranked below SA and TS, following a uniformly decreasing trajectory similar to that of TS, and achieving cost reductions of 4%–5%.

One limitation of this study is the maximum runtime cap imposed on the algorithms, set at 8 hours. This runtime cap represents the operational requirement of the postal operator. Additional experiments suggest that the algorithms further improve the objective function, given more time, but our focus was on evaluating their performance within operational time constraints. Furthermore, the algorithm parameters were fine-tuned through a series of trial-and-error experiments. While this approach yielded effective configurations, employing external solvers to optimize parameter values could potentially enhance performance, which we leave for future investigations.

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Key drivers of digital transformation in supply chain management: insights from enterprises in Vietnam's southeastern region

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Abstract: This study aims to evaluate the impact of digital transformation on logistics and supply chain management in the Southeastern region of Vietnam, focusing on material flows, information flows, financial flows, and human flows. The research examines key factors influencing the decision to implement digital transformation, including peer influence, organizational capabilities, conversion costs, advantages of digital technology, digital technology experience, adaptation to digital technology, usefulness, and ease of use. Data was analyzed using Cronbach's Alpha to assess reliability, with AVE (Average Variance Extracted) used to validate the model. The study reports high reliability, with Cronbach's Alpha coefficients ranging from 0.864 to 0.930. AVE values for observed variables range from 0.613 to 0.769, all exceeding the 0.5 threshold, indicating that the variables met the AVE analysis requirements. The results emphasize the significant role of digital transformation in optimizing logistics flows and supply chain management, providing enterprises with enhanced efficiency and competitiveness.

1 Introduction

The Southeast region is one of the most developed agricultural production areas in Vietnam, with small and medium-sized enterprises (SMEs) accounting for approximately 97% of the total number of businesses. This region is known for its dynamic economic activities, significantly contributing to national GDP and labor force. SMEs employ around 51% of the labor force and contribute over 40% of the country's GDP. These statistics highlight the critical importance of focusing on and supporting SMEs in their digital transformation journey, as such efforts could have a significant impact on the overall digital transformation process for businesses across Vietnam [1].

However, small and medium-sized enterprises (SMEs) in this region face numerous challenges in applying digital transformation to optimize material flows, information flows, financial flows, and human flows in supply chain management. With the rapid advancement of technology and a fast-evolving market, understanding the factors influencing the decision to adopt digital transformation in supply chain management is essential for building a sustainable development strategy. Promoting digital transformation among small and medium-sized enterprises (SMEs) is therefore not only vital for regional growth but also for the broader national economy [2].

According to data from the General Statistics Office and related organizations, prioritizing and supporting SMEs in digital transformation can have a profound effect on the overall transformation of businesses across Vietnam. Despite the potential benefits, many SMEs face significant obstacles. A survey by the Ministry of Information and Communications reveals that only about 20% of SMEs have the workforce with the necessary skills and expertise to access and implement digital solutions effectively. This limited human resource capacity poses a significant barrier to their ability to embrace digital transformation in logistics flows, including material, information, financial, and human flows [2].

In addition, a study by the World Bank highlights another critical challenge—financial constraints. Around 45% of SMEs in Vietnam lack sufficient capital to invest in the digital technology and infrastructure essential for managing material, information, and financial flows effectively. This financial limitation further hinders their ability to adopt and integrate new technologies into their operations. As a result, these SMEs are at a disadvantage in the increasingly competitive market, struggling to keep up with larger enterprises that have more resources for digitalization. The combination of a limited skilled workforce and insufficient capital not only reduces SME competitiveness but also hinders long-term development, making it harder for them to survive in an intensely competitive market. Addressing these challenges is crucial to ensuring that SMEs can fully participate in and benefit from the digital economy, which is essential for the sustainable growth of Vietnam's business sector [2].

Research on digital transformation in supply chain management for enterprises in Vietnam, especially in the Southeast region, is essential to improving business efficiency and contributing positively to sustainable economic development. In the era of the digital economy, digital transformation is an unavoidable trend. This research will explore the factors influencing the decision to adopt digital transformation in supply chain management, focusing on optimizing material flows, information flows, financial flows, and human flows, while providing support solutions for SMEs in the Southeast region to enhance their efficiency and competitiveness in the market.

Given the urgent theoretical and practical needs, the author has chosen the topic "Key Drivers of Digital Transformation in Supply Chain Management: Insights from Enterprises in Vietnam's Southeastern Region". This study aims to provide a comprehensive overview of the digital transformation landscape in supply chain management and the current state of industry in the Southeastern region, while analyzing the factors influencing the decision to adopt digital transformation among businesses in this area.

2 Literature review

Currently, there is no comprehensive explanation of the origins and development of digital transformation in supply chain management for businesses. When studying this activity in the context of the Southeast Region, researchers often refer to various related theories to better understand the factors influencing the decision to adopt digital transformation. This paper will utilize specific theories based on the results of empirical studies and the applicability of these theories in the field of digital transformation in supply chain management, particularly focusing on businesses in the Southeast Region.

2.1 The Theory of Planned Behavior (TPB)

The Theory of Planned Behavior (TPB), proposed by Icek Ajzen, is a well-established psychological theory designed to explain human behavior, particularly in contexts such as adopting new technologies and determining the intentions behind specific actions. TPB is rooted in the idea that human behavior is not only a function of rational decision-making but also influenced by various psychological factors that shape an individual's intentions and their subsequent actions. According to Ajzen, one of the key components of TPB is perceived behavioral control, which plays a significant role in influencing whether a behavior will be carried out or not [3].

TPB has its origins in earlier theoretical frameworks that laid the groundwork for understanding behavior and intention. The theory evolved from initial assumptions made as far back as 1966 and incorporates elements from several foundational theories. For instance, Bandura's Social Cognitive Theory significantly influenced TPB by introducing concepts like self-efficacy, which focuses on an individual's belief in their ability to perform a task. Triandis' Subjective Culture Theory contributed by highlighting the role of cultural and social factors in shaping behavior, while Rosenstock's Health Belief Model provided insights into how individuals assess the benefits and barriers to certain actions [3].

Beyond these foundational theories, TPB also aligns with other psychological and behavioral theories, creating a comprehensive framework for understanding human behavior. Locke and Latham's Goal-Setting Theory is related to TPB in that it emphasizes the importance of setting clear goals as a precursor to intentional behavior. Fisher and Fisher's Information-Motivation-Behavioral Skills Model offers a perspective on how information and motivation contribute to the development of behavioral skills, which is closely aligned with TPB's focus on perceived behavioral control. Moreover, Technology Acceptance Model (TAM) parallels TPB in the realm of technology adoption, emphasizing how perceived ease of use and perceived usefulness shape individuals' attitudes towards technology and their subsequent intentions to use it [3].

Within the TPB framework, Ajzen defines behavioral control as the extent to which individuals have the necessary information, skills, and physical and mental capabilities to perform a specific behavior. This concept of behavioral control is crucial because it directly impacts an individual's ability to execute a behavior once the intention is formed. Perceived behavioral control, which is a new factor introduced in TPB, refers to the degree to which people believe they can successfully perform a behavior if they intend to do so. This concept is closely related to Bandura's theory of self-efficacy, which posits that individuals' belief in their ability to perform a task greatly influences their likelihood of actually performing it. Perceived behavioral control focuses specifically on the sense of control individuals feel they have over executed a behavior, considering both internal factors (such as skills and knowledge) and external factors (such as opportunities and obstacles) [3].

2.2 Technology Acceptance Model (TAM)

The Technology Acceptance Model (TAM), developed by Fred Davis, is one of the most widely cited and influential models in the field of information systems and information technology (ICT) research. TAM was specifically designed to predict and explain user behavior regarding the adoption and use of ICT by focusing on two primary factors: perceived usefulness (PU) and perceived ease of use (PEOU). These factors serve as the core determinants of how users form attitudes toward technology, which in turn influence their decision to accept or reject new technological systems [4,5].

TAM's simplicity and ease of application have contributed to its widespread adoption in various studies exploring technology acceptance across different contexts. This model has been particularly valuable in understanding the factors that drive individuals and organizations to embrace new technological solutions, making it an essential tool in ICT research [4,5].

TAM's contribution to understanding technology acceptance is significant because it highlights the importance of user perceptions in the adoption process. It suggests that for successful implementation of new technologies, organizations must not only ensure that the technology offers clear benefits but also make it as user-friendly as possible. By addressing both the perceived usefulness and ease of use, developers and organizations can increase the chances of positive user attitudes and, consequently, higher adoption rates [4,5].

TAM provides a robust framework for predicting and explaining user acceptance of ICT by focusing on the perceptions of usefulness and ease of use. Its application extends beyond the workplace, influencing how technologies are adopted in various fields, from education to healthcare, making it a cornerstone of research in technology adoption and user behavior [4,5].

2.3 Unified Theory of Acceptance and Use of Technology (UTAUT)

The Unified Theory of Acceptance and Use of Technology (UTAUT), developed by Venkatesh, is an extension and combination of several theories, including TRA, TAM, the Motivation Model, TPB, and the integration of TPB and TAM. UTAUT introduces new variables such as personal characteristics, situational variables, and organizational characteristics [6-8].

UTAUT explains users' behavioral intentions and actual behavior toward new technology through four main variables: performance expectancy, effort expectancy, social influence, and facilitating conditions. These factors play a crucial role in determining user acceptance and behavior toward technology. Moderating variables such as gender, age, experience, and voluntariness also influence the relationship between dependent and independent variables [6-8].

Despite its complexity, UTAUT's ability to integrate multiple factors provides a deeper understanding of the nuances that influence user acceptance, making it particularly valuable in diverse and dynamic environments. Its adaptability across various industries and settings continues to make UTAUT a go-to model for researchers seeking to explore and predict technology adoption behaviors comprehensively [6-8].

3 Methodology

Based on the research objectives, theoretical foundation, and previous studies to identify research gaps, the research focuses on exploring the impact of factors influencing the decision to adopt digital transformation by enterprises in the supply chain. Accordingly, the author inherits the models of TPB, TAM, and UTAUT, and based on the results of previous empirical studies, has identified eight research concepts used in the dissertation, including [9-11], (1) the impact of peer influence [11-13], (2) organizational capabilities [14-16], (3) conversion costs [17,18], (4) advantages of digital technology [19,20], (5) digital technology experience [21-23], (6) adaptation to digital technology [22-25], (7) usefulness [25,26], (8) ease of use [27], Policies and regulations, (10) Driving digital transformation and the decision to adopt digital transformation[28,29].

Based on previous studies, the author proposes the following hypotheses and research models:

H1: The impact of peer influence will positively impact the decision to apply digital transformation in supply chain management.

H2: Organizational capabilities will positively impact the decision to apply digital transformation in supply chain management.

H3: Conversion costs will positively impact the decision to apply digital transformation in supply chain management.

H4: Advantages of digital technology will positively impact the decision to apply digital transformation in supply chain management.

H5: Digital technology experience will positively impact the decision to apply digital transformation in supply chain management.

H6: Adaptation to digital technology will positively impact the decision to apply digital transformation in supply chain management.

H7: Usefulness will positively impact the decision to apply digital transformation in supply chain management.

H8: Ease of use will positively impact the decision to apply digital transformation in supply chain management.

H9: Policies and regulations will positively impact the decision to apply digital transformation in supply chain management.

H10: Driving digital transformation will positively impact the decision to apply digital transformation in supply chain management.

Figure 1 Research model

4 Results and discussion

The assessment of convergent validity for latent variables is based on the indicators of outer loading coefficients and the Average Variance Extracted (AVE). According to Fornell and Larcker, the AVE value should be 0.5 or higher to meet the requirement, indicating that the latent variable can explain more than half of its variance on average. If the AVE is less than 0.5, the factor or latent variable is typically considered for removal from the research model [30].

Reliability of the measurement scale is evaluated using two key indicators: Composite Reliability (CR) and outer loading coefficients. To assess reliability, CR should be greater than 0.7 and outer loading should be greater than 0.4 for the model to be considered reliable [31].

The analysis results show that all factors meet the required conditions, with AVE values greater than 0.5 (ranging from 0.613 to 0.769), composite reliability greater than 0.7 (ranging from 0.864 to 0.930), and outer loading coefficients greater than 0.4 (ranging from 0.713 to 0.897). Thus, all factors satisfy the requirements for reliability and convergent validity.

According to Henseler, discriminant validity is the degree to which a concept of a specific latent variable differs from the concepts of other latent variables. The square root of the Average Variance Extracted (AVE) for each factor is greater than the correlation coefficients between the corresponding variables. This indicates that the concepts in the study achieve discriminant validity [32].

The analysis results show that all square roots of AVE have coefficients higher than 0.5 (ranging from 0.783 to 0.877), meeting the requirement. Within each factor, the square root of AVE has a higher value than the correlation coefficients of other factors in the same column. Therefore, all factors achieve discriminant validity.

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According to Hu, the SRMR (Standardized Root Mean Square Residual) index should be less than 0.08 or 0.1. Additionally, Henseler suggest that the SRMR is a Goodness of Fit index for the PLS-SEM model, which can be used to avoid parameter bias within the model. With an SRMR value of 0.077, which is less than 0.1, the research model is considered to be a good fit for the study area in the Southeast region of Vietnam.

To generalize the research findings to the entire population, it is essential to reassess the reliability of the model. The study employs the bootstrapping technique with a resampling size of 1000 observations (n = 1000), based on the initial sample size of 495 observations.

With a 95% confidence level for the bootstrapping analysis, the results indicate that the 2.5% to 97.5% percentile range does not contain any values greater than 1. This ensures the discriminant validity of the model, and the estimates within the model can be considered reliable [33].

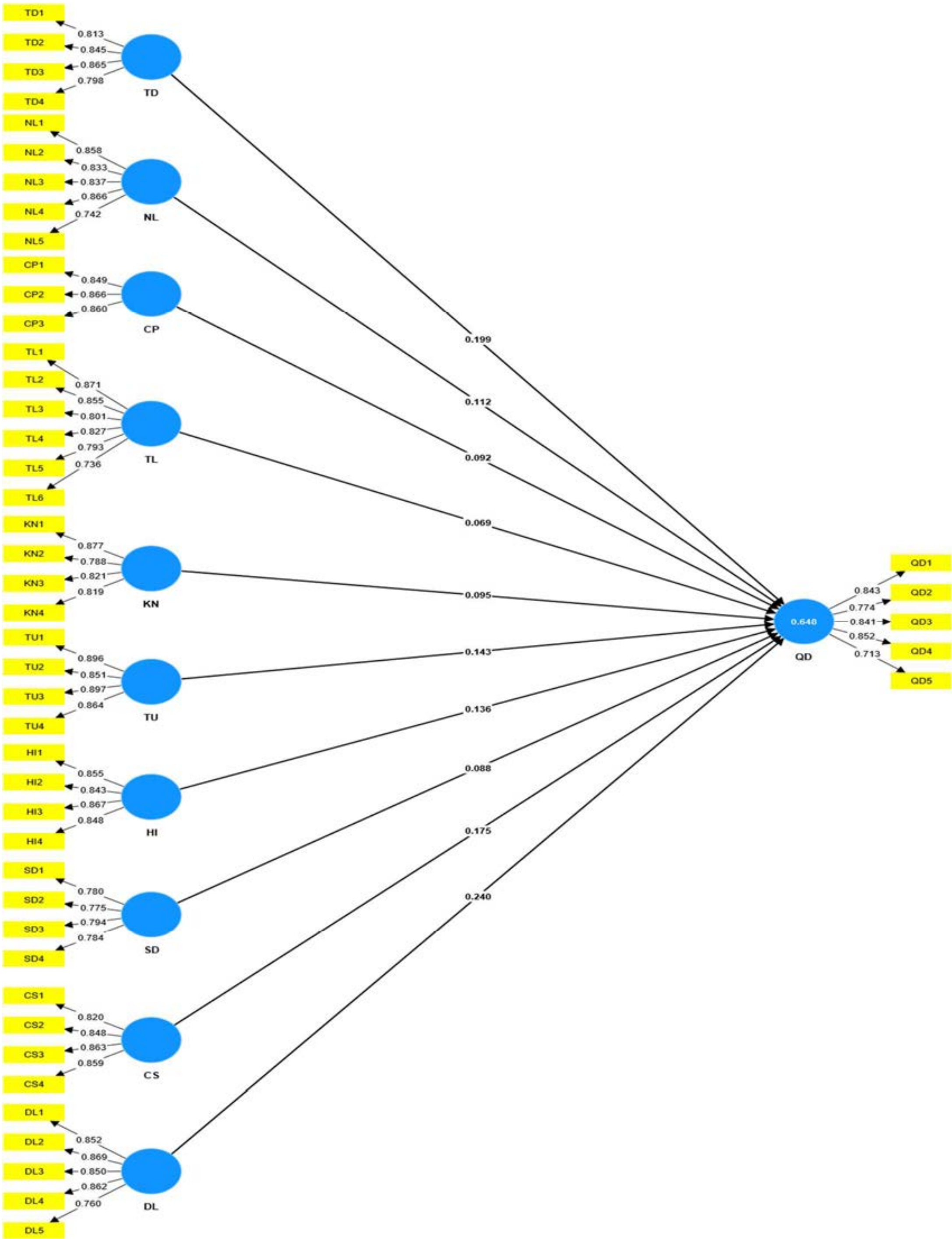

Figure 2 Standardized PLS-SEM results of the research model

Table 1 PLS-SEM model estimation results

	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T statistics (|O/STDEV|)	P values	Result
H1 -> QD	0.092	0.092	0.032	2.889	0.004	Accepted
H2 -> QD	0.175	0.174	0.028	6.218	0.000	Accepted
H3 -> QD	0.240	0.239	0.028	8.624	0.000	Accepted
H4 -> QD	0.136	0.136	0.037	3.642	0.000	Accepted
H5 -> QD	0.095	0.095	0.032	2.951	0.003	Accepted
H6 -> QD	0.112	0.113	0.033	3.409	0.001	Accepted
H7 -> QD	0.088	0.089	0.034	2.578	0.010	Accepted
H8 -> QD	0.199	0.200	0.033	6.038	0.000	Accepted
H9 -> QD	0.069	0.071	0.030	2.281	0.023	Accepted
H10 -> QD	0.143	0.143	0.037	3.905	0.000	Accepted

5 Conclusions

In summary, this study has developed an effective evaluation model to explore the factors influencing the decision to adopt digital transformation in supply chain management among enterprises in the Southeast region. The research confirms that several factors, including (1) the impact of peer influence, (2) organizational capabilities, (3) conversion costs, (4) advantages of digital technology, (5) digital technology experience, (6) adaptation to digital technology, (7) usefulness, (8) ease of use, (9) policies and regulations, and (10) driving digital transformation, significantly affect the attitude and decision of businesses to adopt digital transformation in supply chain management, particularly in optimizing material flows, information flows, financial flows, and human flows.

Many factors can directly impact the effectiveness of digital transformation in supply chain management, including the impact of peer influence (H1), organizational capabilities (H2), and conversion costs (H3). Support and collaboration from colleagues can create a synchronized work environment, facilitating a smoother transformation process. Organizational capability, encompassing management skills, technological proficiency, and innovation ability, also plays a crucial role in successfully implementing digital transformation strategies. Finally, switching costs, including investments in new technology and training expenses, must be carefully managed to ensure that they do not impose an excessive financial burden on the enterprise. Therefore, businesses must thoroughly evaluate these three factors before implementing digital transformation strategies to ensure effectiveness and success.

When digital transformation is effectively implemented, it brings significant benefits to supply chain management. These benefits include optimizing material flows, information flows, financial flows, and human flows, reducing operational costs, enhancing transparency and traceability, improving demand forecasting, optimizing inventory management, and increasing responsiveness to market changes. These advantages not only help businesses enhance their competitive edge but also increase the overall value of the supply chain. With successful digital transformation, businesses can achieve comprehensive improvements in operational performance, thereby increasing business efficiency.

Regular evaluation and continuous improvement are critical factors in maintaining and enhancing the effectiveness of the digital transformation process. Businesses need to establish key performance indicators (KPIs) to measure and monitor the effectiveness of each stage in managing material, information, financial, and human flows throughout the transformation process. This not only helps businesses promptly identify emerging issues but also allows them to adjust strategies to achieve the best possible outcomes. The effectiveness of digital transformation is not a destination but a continuous process that requires ongoing commitment and innovation from businesses. This ensures that companies not only maintain their competitive advantage but also continue to grow and adapt in an ever-changing business environment.

The advantages of digital technology (H4), the digital experience of personnel (H5), and the ability to adapt to digital technology (H6) are also crucial factors. The benefits of digital technology, such as modern features and integration capabilities, help businesses improve performance across activities from production to distribution, optimizing material, information, and financial flows. The digital experience of personnel is decisive, as employees with solid knowledge and skills in digital technology can effectively leverage new tools and solutions. The ability to adapt to digital technology is a key factor, as the quick adjustment of processes and working methods by businesses and staff to fit a digitalized environment helps maintain and enhance performance. Understanding and effectively managing these three factors will enable businesses to optimize performance during digital transformation.

Exploring, analyzing, and improving these factors will help enhance the effectiveness of digital transformation in enterprises. First, it shortens processing times and minimizes waste, thereby reducing operational costs. High performance also enables businesses to respond more quickly to market fluctuations, enhancing flexibility and competitiveness. Moreover, when performance is improved, businesses can better manage resources, optimize the flows of goods and services, and improve the quality of products and services delivered to customers. These benefits not only help businesses save time and costs but also contribute to increased customer satisfaction and the enhancement of brand value in the market.

The perceived usefulness of technology (H7) is a key factor, as employees will more readily accept and be willing to adopt technology if they perceive it to bring tangible benefits to their work and the organization. The more a technology demonstrates its value and improvement in job performance, the easier it will be accepted. The perceived ease of use of technology (H8) also plays an important role. If the technology is designed to be user-friendly, accessible, and easy to learn, employees will encounter fewer difficulties in using it, thereby enhancing the likelihood of acceptance and adoption of the new technology.

Policies and Regulations (H9) play a crucial role in promoting and shaping the digital transformation process in supply chain management for businesses. In the Southeast region, the development and enforcement of appropriate policies and regulations will create a favorable legal and business environment, enabling enterprises to easily access and apply digital technologies to their management processes, particularly in managing material, information, financial, and human flows. Clear policies and specific regulations provide guidance to businesses on the standards they must adhere to, as well as the opportunities and challenges associated with adopting new technologies. This not only helps businesses operate more efficiently but also protects their interests in an increasingly complex and competitive market.

Driving Digital Transformation (H10) is a key factor that motivates businesses to adopt new technologies in supply chain management, especially for enterprises in the Southeast region. This motivation stems from the need to improve operational efficiency, enhance competitiveness, and quickly respond to market changes. When the motivation is strong enough, businesses will have greater determination in implementing digital transformation strategies, ensuring that the process moves beyond just an idea and is effectively realized. Motivation also fosters internal consensus within the business, from leadership to employees, facilitating a smoother and more successful transformation process.

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Changes of competencies in the labour market caused by the implementation of Industry 4.0

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Keywords: competencies, change, labour market, Industry 4.0, future need.
Abstract: The digital transformation associated with Industry 4.0 is fundamentally changing the labour market, creating a need for new but also evolving employee competencies. This paper explores the future need for competencies that will be essential for successful employment in this dynamically changing environment. Based on a survey realized among Slovak industrial companies and using the AHP method, key competencies for employees at the operational management level were identified and ranked. The findings show that a successful operational manager must combine hard skills with digital systems and soft skills. The competencies that were identified as realistically the most important are in line with global trends. This confirms that employees who want to be prepared for the future and new challenges must integrate technological literacy with their personal and managerial competencies. Furethermore, the importance of efficient management of logistics processess, including the optimisation of material and financial flows, is increasing, which requires specific competencies in logistic and financial management. The paper highlights the need for companies to invest in education, reskilling and up-skilling of their employees to increase their competitiveness and at the same time to eliminate the factors that prevent them from successfully implementing Industry 4.0 principles and techniques. The paper concludes with an overview of the expected trends in the labour market and highlights the need to prepare for the new challenges and opportunities that Industry 4.0 brings.

1 Introduction

The labour market has been undergoing turbulent changes in recent years. First it was hit by the COVID-19 pandemic, which changed the shape of many jobs and the way they were performed. After the pandemic came rising inflation as a result of the conflict in Ukraine. Industry 4.0, described as the new fourth phase of the industrial revolution, is bringing further fundamental changes to the labour market. In addition to changes in jobs, the requirements for employees and their competencies are also changing.

The key attributes of this industrial revolution are automation, digitalization, high levels of interconnectivity between devices or Big Data analytics. Manufacturing operating under Industry 4.0 conditions is moving from traditional approaches to complex ones that are capable of prediction and decision-making, thus ensuring greater efficiency and flexibility of processes. The implementation of new technologies leads to increased productivity, reduced operating costs and improved product quality [1].

While Industry 4.0 brings many benefits, it also brings challenges, such as cyber security risks and the need to retrain the workforce, which need to be addressed in order to realise the full potential of the next industrial revolution. Industrial companies will need specialists with digital skills, technical skills in AI, Big Data or cybersecurity in particular, but we must not forget soft skills including critical thinking, communication and problem solving, as these are increasingly in demand as core competencies of the modern workforce [2].

The aim of the paper is to find and point out the differences between real competencies and competencies required from employees working in industry under Industry 4.0 conditions.

2 Literature review

Industry 4.0 represents the fourth industrial revolution, which is focused on the digitalization and automation of manufacturing processes through the use of advanced technologies such as the Internet of Things (IoT), artificial intelligence (AI), machine learning (ML), blockchain, cyber-physical systems (CPS), big data (Big Data) and cloud computing [3]. This concept was first introduced by the German government in 2011 to increase the competitiveness of manufacturing companies and support the transition to smart manufacturing [4].

Industry 4.0 means the transition from centralized production to decentralized and autonomous production systems where machines and equipment communicate with each other and make decisions based on real-time data analysis [5]. Industry 4.0 is a concept that according to the authors Demirbag and Yildirim (2023), means not only the use of digital technologies in manufacturing, but also the transformation of organizational management, strategy and the entire value chain. Thus, the essence of Industry 4.0 is not only technological innovation, but also the ability of countries and companies to adapt to global changes and use them to increase their competitiveness [2].

2.1 Evolution from Industry 1.0 to Industry 4.0

Industrial revolutions represent major milestones in the development of society, technology and the economy. Each of these revolutions has brought ground-breaking innovations that have fundamentally changed the way people produce, work and live. The gradual transition from Industry 1.0 to Industry 4.0 reflects the continuous technological progress and its impact on the economy and society as a whole [3, 6].

The first industrial revolution, referred to as Industry 1.0, began in the second half of the 18th century. It was characterised by the introduction of mechanisation into production, allowing manual labour to be replaced by machines. The main attributes of this period were the introduction of mechanization into industrial production, the emergence of large factories and centralized manufacturing, the increase in productivity and efficiency through the use of steam-powered machines, the change in the organization of work and the onset of industrialization [7]. Mechanization caused a significant increase in the production and availability of goods. Although production became more efficient, it was still heavily dependent on human labour and the organisation of work in factories, where the first forms of division of labour began to be applied [8].

The second industrial revolution, known as Industry 2.0, was characterised by the introduction of electricity into manufacturing processes and the emergence of mass production. Key attributes of this period included the use of electricity as the main source of energy in manufacturing, the emergence of assembly lines, the development of mass production and standardisation of products, the expansion of transport infrastructure and railway lines. Mass production meant a reduction in production costs and wider availability of products to the population [6]. Large industrial corporations and business models based on large-scale production emerged, laying the foundations for modern consumer capitalism [9].

The third Industrial Revolution, referred to as Industry 3.0, represented the advent of manufacturing automation and the use of electronics. The main attributes of this phase of industrial development were the introduction of computer numerical controlled machines (CNC machines), the use of programmable logic controllers (PLCs), the beginnings of robotization of manufacturing, the digitalization of processes and the interconnection of manufacturing with information systems [10]. Industry 3.0 has enabled more flexible production, reduction of manual interventions and automation of repetitive activities. Human work began to move into areas that required expert knowledges, creative thinking and decision making. This phase was also a preparation for the full digitalization of manufacturing processes [11].

The fourth industrial revolution, also known as Industry 4.0, represents the current phase of technological development in which manufacturing systems and processes are fully digitalized and interconnected through technologies such as the Internet of Things (IoT), artificial intelligence (AI), machine learning (ML), big data (Big Data), blockchain and cloud computing. The characteristic attributes of Industry 4.0 include Smart Factories, interconnection of devices and machines using IoT, Digital Twins, collaborative robots, use of AI and machine learning for predictive maintenance, manufacturing optimization and autonomous decision making, blockchain, additive manufacturing [4,12].

Industry 4.0 is not only changing the industrial environment, but also the labour market. Rapid technological progress is transforming employment - traditional manual jobs are replaced by automation, while the demand for professionals in the fields of data analytics, cybersecurity or artificial intelligence is growing [13].

The evolution from Industry 1.0 to Industry 4.0 is a story of constant progress, where each phase has brought new technologies that have fundamentally changed the way we produce, work and live. We are entering an era where artificial intelligence, automation and digitalization are becoming part of everyday life, which requires adaptation not only of companies, but also of educational systems and the whole society to face the challenges and opportunities that these changes bring [11,13].

At the same time, there is already discussion about the arrival of Industry 5.0, which is to focus on the return of the human being to the centre of manufacturing processes and on cooperation between humans and technologies. Industry 5.0 will emphasise personalised manufacturing, ethical responsibility, sustainability and the inclusive development of industrial companies [14].

2.2 Requierements for future competencies

As a result of continuously increasing technological progress and the advent of the fourth industrial revolution, Industry 4.0, not only the manufacturing processes themselves are changing, but also the expectations of the labour market. This is also linked to the growing demand for new competencies, which can be divided into two groups - hard skills, i.e. technological and digital skills, and soft skills, i.e. skills that support a person's ability to function in a dynamic, digital and globalised environment.

According to current research (Raveica et al., 2024; Kowal et al., 2022), the successful individual in the coming years will be those who can effectively combine high-tech skills with mature personality traits and the ability to work in a team, solve problems and adapt to rapidly changing conditions [14,15].

2.2.1 Hard skills – technological and digital competencies

According to Simoes et al. (2020), the growing automation and use of AI does not only mean the loss of some jobs, but also creating new positions that require the ability to interact with digital systems, understand their logic, and the ability to use them to make work more efficient [22]. Technical skills such as working with AI, Big Data, cybersecurity or digital systems are becoming a necessity for effective management of manufacturing processes. Equally important are competencies in logistics, especially the ability to optimize material flows and manage financial flows, which directly affect the efficiency and cost-effectiveness of the company. Within the framework of Industry 4.0, completely new jobs are being created and at the same time existing jobs are being transformed. In the future, companies will require employees to master a wide range of specific skills such as [4,5,9,15]:

- programming and automation,
- Big Data analysis,
- artificial intelligence (AI) and machine learning (ML),
- internet of things (IoT),
- additive manifacturing (3D print),
- blockchain and cybersecurity,
- simulations and digital twins,
- digital skills (ability to effectively use office applications and cloud services, data management and security, working with remote teams).

2.2.2 Soft skills

For all the technological advances of Industry 4.0, the role of the human being as a leader, team player and innovator remains crucial. That's why soft skills will always be an important success factor. Important soft skills include [12,16-18]:

- critical and analytical thinking,
- problem solving,
- teamwork,
- creativity and innovative thinking,
- flexibility,
- digital literacy and digital ethics,
- communication skills,
- emotional intelligence,
- leadership and motivation,
- time management and ability to cope with stress.

According to authors Hernandez-de-Menendez (2020) and Cretu (2025), the most successful employees and managers will be those who can combine highly technical skills with excellent soft skills. Modern companies will appreciate flexibility, lifelong learning, adaptability and openness to change as highly as the ability to handle the most advanced technologies [5,8].

2.3 Adaptability of employees and willigness to learn

In an Industry 4.0 environment where technological change is constantly occurring, adaptability and a willingness to continuously learn is one of the most essential competencies of the future. While technological innovations are evolving at an exponential rate, jobs are transforming and new professions are often emerging faster than education systems can respond to new labour market requirements. According to research by Deloitte and McKinsey, up to 50% of employees will need to be retrained or upskilled by 2030 [15].

Adaptability means the ability to respond flexibly to changes in the environment, whether technological, organisational or cultural. In practice, it is the ability to [19]:

- adopt new ways of working and adapt quickly to new processes,
- react promptly to unexpected situations,
- deal with unpredictable changes in projects, supply chains or markets,
- be open to job or project rotation.

Employees who are adaptable show higher resilience to stress and are able to embrace change as a challenge rather than a threat. Companies appreciate such qualities, especially because they can handle difficult times and become a factor that moves the company forward at the same time. Employee adaptability is key not only in production but also in the management of logistics processes, which are being fundamentally transformed by digitalization and automation [14,20].

2.3.1 Adaptability of employees in the conditions of Industry 4.0

Constantly adapting to new software solutions that change faster than standards can catch up [4]. Flexibility to move to new manufacturing processes (e.g. from traditional manufacturing to additive manufacturing or fully automated lines), as stated by Hernandez-de-Menendez (2020) it is the combination of simulation technologies, digital twins and automation that requires adaptability [5], the ability to collaborate with AI systems and understand their recommendations [8]. Willingness to change established routines and processes if they are inefficient, as Kubišová (2022) points out, where companies in Slovakia reported the need to change experienced processes in connection with the implementation of Industry 4.0 [12].

2.3.2 Adaptability in multicultural environment

In the Industry 4.0 environment, not only technology, but also the method of work organisation and collaboration are globalised. The ability to adapt to a multicultural environment and to work effectively with colleagues from different countries is becoming one of the key skills of the future. This flexibility includes [8,12,14,16]:

- Sensitivity to cultural differences - employees who can understand and respect different cultural customs are more valuable in companies because they can work more effectively in international teams.
- Ability to collaborate with teams in other time zones - working on international projects requires the ability to be time flexible and communicate across digital platforms across countries.
- Openness to other communication styles and differences of opinion - successful employees are those who can handle different approaches to problem solving and can communicate with foreign partners without conflict.
- Accepting feedback from other cultural contexts - the ability to accept other forms of criticism and positive feedback is key to personal growth and working in a multicultural environment.

2.3.3 Lifelong learning

Industry 4.0 gives importance to the concept of lifelong learning. This means that learning is no longer just a matter of formal study, but a continuous process. The main signs of a willingness to learn are [4,5,12,21]:

- active search for courses, seminars, webinars,
- regular updating of knowledge in the areas of new technologies (AI, IoT, blockchain, cybersecurity),
- ability to learn new digital tools and work with new platforms,
- openness to interact with experienced colleagues and ability to accept feedback.

According to the results of a study published in the journal Sustainability (Raveica et al., 2024), it was those students and employees who showed a high willingness to continuously learn who performed better in the labour market, obtained innovative assignments and were promoted more quickly to leadership positions [14].

Adaptability and willingness to continuous learning are key prerequisites for professional success in the Industry 4.0 environment. Flexibility, the ability to react quickly to change, the willingness to adopt new technologies and continuous learning are becoming mandatory equipment for every employee. In the future, companies will prefer employees who can „keep up with the future“ and see learning as an integral part of a career [8,14,15].

The Fourth Industrial Revolution represents a radical transformation in the way manufacturing processes, the company and society as a whole operate. Digitalization, automation, the Internet of Things, artificial intelligence, big data and other advanced technologies are significantly changing not only manufacturing itself, but also the labour market, education and the requirements for future workforce competencies. Industry 4.0 is therefore not only a technological phenomenon, but also an opportunity to create a more efficient, safer and sustainable economic system. The key to success will be the ability to combine innovative technologies with quality human work, creative thinking and a continuous drive for improvement [8,15].

3 Methodology

In order to find a solution and at the same time to answer the stated aim of the paper, a survey was realized in industrial companies in the period 9/2024 - 11/2024. The survey involved medium and large companies in the field of engineering, whose more specific focus was the automotive industry and broad suppliers for the automotive industry. There were 16 companies that participated in the data collection and all of them are located in Slovakia.

Industrial companies were asked to provide data from competency profiles at the level of operational management - focus on the shift leader position. This position was deliberately chosen because top management does not come into direct contact with automation and new technologies to the extent that they need to be required to have the competencies to work with them. The operational management level uses the most technical competencies, and it is also the lowest level of management, so they are also required to have competencies that will help them to effectively manage the team and lead the employees to achieve the goals, whether of the company or of the individuals.

Small companies were left out of the survey and data collection because jobs are cumulated in them and the implementation of Industry 4.0 is not of significant importance for them due to the volume of production and also in terms of the financial intensity of the measures.

From the collected data on competency profiles, a table was created in which the competencies are listed and ranked based on their frequency of occurrence. There are 39 competencies in the initial table (Table 1). From the table thus created, a further frequency analysis can be carried out, where a criterion has been set that competences with a frequency of occurrence of less than 25%, representing values of 3 – 1, will be removed from the table, as these competencies are not considered to be significant due to their low occurrence. As a result, we are left with 28 competencies for further analysis.

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Table 1 Collected data from industrial companies

competencies/skills	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	frequency
production/project management	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	16
knowledge OSH, FP, PPE	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	15
leadership	X	X	X	X	X		X	X	X	X	X		X	X	X	X	14
human resource management	X		X	X	X	X	X		X	X	X	X	X		X	X	13
communication / presentation skills		X	X		X		X	X	X		X	X	X	X	X	X	12
management planning		X	X	X	X	X	X	X		X			X	X	X	X	12
production and technical skills		X	X	X	X	X		X		X		X	X	X	X	X	12
goal orientation	X	X	X			X		X	X	X	X	X	X			X	11
Lean management	X		X	X		X			X	X	X	X	X	X	X		11
knowledge of MS Office	X	X	X				X		X		X		X	X	X	X	10
results orientation	X	X	X	X		X		X		X			X		X	X	10
organization		X	X	X	X		X	X	X		X	X				X	10
teamwork		X	X	X	X	X		X	X		X					X	9
employee motivation		X	X		X	X	X				X		X		X	X	9
knowledge of standards		X	X	X				X	X	X	X		X	X			9
employee development		X		X		X		X	X			X			X	X	8
responsibility					X		X	X	X				X	X	X	X	8
knowledge of P.I.S. (e.g. SAP)	X				X	X	X					X	X			X	7
problem-solving skills		X			X			X			X		X		X	X	7
sustainability orientation		X	X	X							X	X	X				6
flexibility			X		X				X	X	X					X	6
inovativness		X										X	X	X	X		5
creativity and imagination		X	X									X	X			X	5
language skills (AJ - B2)		X	X								X		X	X			5
controling						X	X		X		X				X		5
independence		X			X				X							X	4
analytic thinking			X				X			X				X			4
reporting												X		X	X	X	4
customer orientation		X											X	X			3
resistance to stress		X	X												X		3
technical thinking							X			X				X			3
openness to change		X												X			2
self-education and self-development		X									X						2
strategic thinking			X											X			2
knowledge of BIS	X																1
agile thinking		X															1
knowledge of ITC system		X															1
knowledge of CSR			X														1
assertivity					X												1

After the evaluation of the data, in the next step, the AHP (Analytical Hierarchy Process) method was implemented through Expert Choice software, which allowed us to evaluate and determine the most frequently required competencies from managers operating in Industry 4.0 conditions in an exact way. For easier work and better clarity, these competencies were divided into three groups, namely: managerial, technical and personal competencies. The criteria on the basis of which the competencies were assessed are: financial requirements for implementation, qualification requirements for employees, technical requirements for implementation and time requirements for implementation.

4 Results and discussion

To use the AHP method, we first need to create a hierarchical structure. We have entered the objective (Selection of competencies for the application of Industry 4.0 techniques) and the criteria (see above) into the Expert Choice software, to which we have then entered the individual variants (specific competencies). We then proceeded with a pairwise comparison of the individual criteria with respect to the main objective.

Figure 1 shows the hierarchical structure of our decision-making process, but we input three separate models into the Expert Choice software, one for each set of competencies. After pairwise comparing the criteria and determining their order of importance, we also pairwise compared the variants themselves, and thus the individual competencies, with respect to a given criterion. After pairwise comparisons with respect to all four criteria, the Expert Choice software produced a final ranking of the decision-making process for all three groups of competencies.

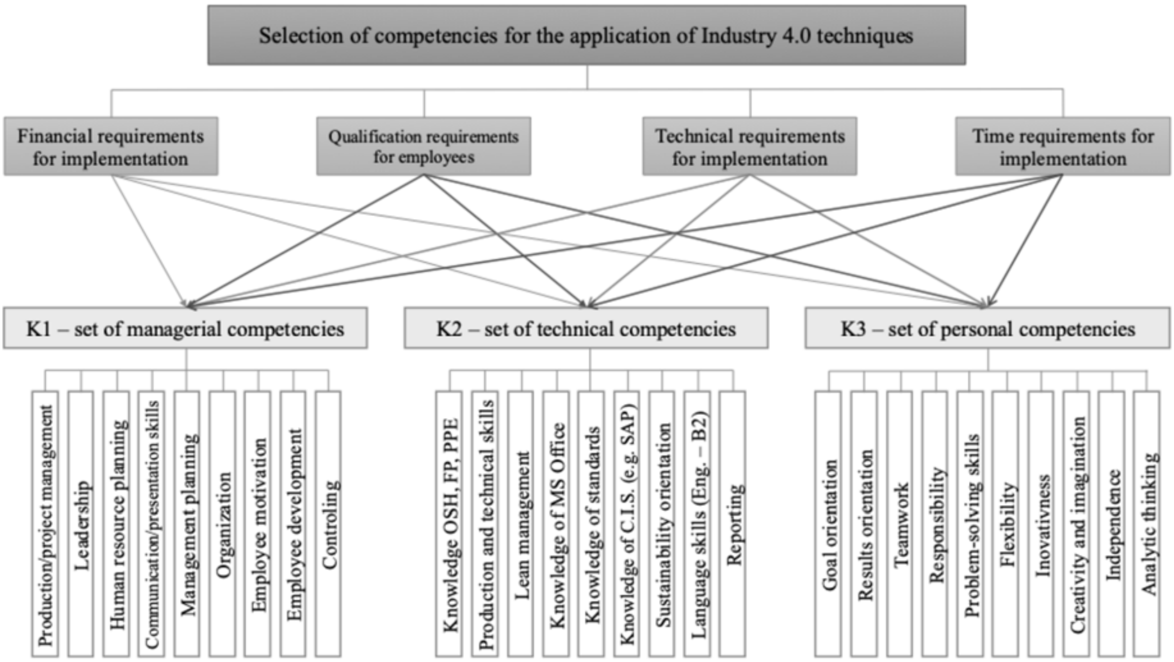

Figure 1 Hierarchical structure of decision-making process

Based on the information and knowledge gathered so far, the competency profile of a manager should generally consist of 10 to 12 competencies. With fewer competencies, it would be too simplistic and might not cover everything that is required of an employee in a managerial position. On the other hand, if there are more competencies, the profile would be too broad and difficult to apply in practice. As in our model, competencies in competency profiles tend to be divided into several sets (managerial, technical/professional, personal and interpersonal), their quantity and structure varying with the company's requirements, objectives as well as with the level of management for which the competency profile is created.

By realizing the AHP method in assessing the importance of competencies, we can in the result select the relatively most important competencies for operational managers to be able to lead teams and manage manufacturing processes effectively. In our decision-making process, there were 28 competencies identified by industrial companies as required, divided into three sets in approximately equal numbers. Based on knowledge, information and experience, we can argue that a competency profile should be made up of between 10 and 12 competencies, so we selected the four competencies with the highest scores from each competency set. In the set of personal competencies we added a fifth competency for the relevance of the results, because the base set in this case was 10 and not 9 as in the other two competency sets.

The final draft of the competency profile of the operational manager based on the results of the AHP method will therefore consist of the following competencies:

a) **Managerial competencies:**
   1. Production / project management
   2. Employee development
   3. Management planning
   4. Leadership

b) **Technical competencies:**
   1. Lean management
   2. Knowledge of C.I.S. (e. g. SAP)
   3. Language skills (Eng. – B2)
   4. Knowledge of standards

c) **Personal competencies:**
   1. Analytic thinking
   2. Problem-solving skills
   3. Innovativeness
   4. Creativity and imagination
   5. Teamwork

According to the latest Future of Jobs Report 2025 [23], the biggest barrier to the transformation of companies is the skills gap and missing competencies in the labour market, according to 63% of respondents. This is an even higher result than in 2023, which means that companies are increasingly aware that without the necessary competencies of their employees they will not be able to undergo a full transformation and their position in the market will not be competitive [23].

The Future of Jobs Report 2025 lists the competencies that are on the rise between 2025 and 2030 and companies are recognising their importance. To compare and possibly identify the differences between the competencies selected by us using the AHP method and the competencies selected in the global report, the following table is used.

Table 2 Selected required competencies from Expert Choice vs. „Skills on the rise 2025 – 2030“ from FOJR

Selected required competencies	***“Skills on the rise 2025 – 2030”***	***Net increase***	***Associated competencies***
Production / project management			Resilience, flexibility and agility
Employee development	Teaching and mentoring Curiosity and lifelong learning	30 61	Talent management
Management planning	Resource management and operations	24	
Leadership	Leadership and social influence	58	
Lean Management	Systems thinking	51	Technological literacy
Knowledge of C.I.S. (e.g. SAP)	Networks and cybersecurity	70	AI and Big Data
Language skills (Eng. – B2)	Multi-lingualism	16	
Knowledge of standards	Quality control	20	Environmental stewardship
Analytic thinking	Analytical thinking	55	
Problem-solving skills			
Innovativeness			Design and user experience
Creativity and imagination	Creative thinking	66	
Teamwork			Motivation and self-awareness Empathy and active listening

The first column of Table 2 shows the competencies that were selected based on the results of the AHP method. The second column shows the competencies from the Future of Jobs Report survey [23], which we matched based on their similarity to the competencies in the first column. The "Net increase" column is the difference between those companies that consider a given competency to be increasing and those that consider a competency to be decreasing over the specified period. In the last column are the associated competencies, so they are not exactly the same competencies as in the first column, but there is some affinity between them, and it can be argued that managers also need to have these competencies to perform effectively and reliably in their jobs.

On the basis of Table 2, where we compared our AHP method for selection of competencies for the application of Industry 4.0 techniques and the competencies identified in the Future of Jobs Report 2025 [23], we can confirm that the competencies that emerged as a result of our decision-making process are not only necessary for industrial companies operating in Slovakia, but are globally demanded competencies. However, it is not enough to identify competencies and find employees who possess them. Employee competencies need to be continuously developed, care needs to be taken to retrain employees, as well as to increase their qualifications and to place great emphasis on lifelong learning, which is essential for maintaining the competitiveness of both individuals and industrial companies in a dynamically changing environment. Companies must therefore strive to match the competencies offered by their employees with evolving requirements and reflect the needs of new technologies.

Technological progress, the transformation of industrial companies into companies operating in the Industry 4.0 era (in Slovakia, in the world we can already talk about Industry 5.0), the transition to a more environmentally friendly way of manufacturing are the driving force for changes in the labour market, which changes jobs and at the same time the requirements for employee competencies. AI and information processing technologies will have the biggest impact on companies, as stated by 86% of the companies participating in the survey [23].

Based on the survey of the Intelligent Industry Association - Industry4UM on the level of implementation of Industry 4.0 in industrial companies, only a third of companies are currently applying their digitalization strategy. The implementation is most limited by financial resources, which are mainly affecting small and medium-sized companies and companies with Slovak ownership. Based on the survey results, we know that the implementation of Industry 4.0 fails most on the financial side, with up to 60% of companies identifying financial constraints as an obstacle. Lack of digitalization skills of employees was identified by 39% of companies as a limiting factor. The skills gap is most pronounced in the areas of artificial intelligence, programming and data analytics, suggesting a need for education and re-skilling of employees, as well as improved hands-on learning for better implementation of Industry 4.0 or Industry X.0 [24].

5 Conclusions

Changes in labour market competencies in the context of the implementation and application of Industry 4.0 techniques are challenging and require adaptation on the part of both companies and employees. The research results showed that the key competencies of managers at the operational level are technical skills, but also soft competencies such as analytical thinking, creativity and teamwork. The AHP method allowed us to identify the most important competencies for successful operation in Industry 4.0 conditions. The competencies that resulted from the AHP method (see Table 2) are not only necessary for industrial companies in Slovakia, but are globally demanded competencies. However, in a constantly changing environment, where the degree of automation and digitalization is rapidly increasing and new technologies are entering the market, it is important to update the competency profiles and reflect the requirements of technological progress in them. The level of individual competencies may also vary, which emphasises the need for continuous learning and development not only of new competencies but also of those already acquired by employees.

The main contribution of this paper is the identification of a specific set of competencies that operational manager should have in order to be able to effectively manage production and human resources in Industry 4.0 conditions. The results from the AHP method can be valuable for industrial companies in planning training programs, creating competency profiles, but also in developing human resource strategies that correspond to the requirements of digitalization. Companies have to face challenges in implementation such as financial constraints and lack of competences and digital skills of their employees. In order to maintain their market position and remain competitive, companies will need to invest in retraining, upskilling and lifelong learning for their employees. At the same time, it will also be necessary to actively adapt competence profiles to the changing labour market situation.

But the study also has limitations, as the data were collected exclusively from industrial companies operating in Slovakia, mainly in the engineering and automotive industries. Therefore, future research could be extended to other industries, other regions (countries) and examine the implementation of new concepts such as Industry 5.0.

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Transport logistics key in disaster situations: a case study in Mexico

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Keywords: disasters, hydrometeorological phenomena, emergency declaration, humanitarian warehouse, vehicular route problem.
Abstract: Climate change has brought a significant series of environmental, economic, and social problems. An example is the disasters caused by natural phenomena, of which hydrometeorological phenomena stand out. The state of Veracruz is one of the five Mexican entities that has suffered most from these phenomena, and which is reflected in the number of emergency declarations by its municipalities. For this reason, it's essential to determine the location of humanitarian warehouses in Veracruz, to maintain the population's quality of life. With the objective of generating a strategy through which basic necessities can be supplied to victims, the Capacitated Vehicle Routing Problem is applied. This will allow for the establishment of a humanitarian warehouse located in the Altas Montañas (High Mountains) region to supply routes to 66 municipalities located in the aforementioned region together with the Capital Region, whose city governments have made emergency declarations during the period of 2012-2016. The results show 13 supply routes, with an average of 300 km traveled per route. In the normality assessments, the values of $p = 0.511$ for the kilometer variable and $p = 0.603$ for the time variable indicate that both variables do not significantly deviate from normality, suggesting that its distributions are normal.

1 Introduction

Logistic activity has increasing worldwide relevance, not only in the business and industrial fields, but also in social fields. It can be said that logistics is the tool through which an efficient and effective flow of resources and information is achieved as well as its integration with the activities along the supply chain, with the focus of strengthening and increasing levels of customer service. In the logistics field, the denomination humanitarian logistics is found (HL), which is derived from the concern in looking for solutions to diverse problems; among which are problems related to climate change, such as the presence, impact, and frequency of natural phenomena, which have also been a motive of interest of governments, organizations, and researchers all around the world.

For Gutiérrez-Guzmán et al. [1], humanitarian logistics refers to a logistics system dedicated to planning, implementation, and supervision of the storage and distribution of resources in areas affected by some type of crisis. Discussing climate change eludes to long-term changes in temperature and climate patterns; among the causes are: *a)* energy generation; *b)* product manufacturing; *c)* deforestation; *d)* use of transportation; *d)* food production; *e)* energy in buildings, and *f)* excessive consumption; thereby bringing consequences such as: 1. Rising temperatures; 2. More potent storms; 3. Increase in worldwide droughts; 4. Rise in ocean level and increasing water temperatures; 5. Disappearance of species; 6. Food scarcity; 7. Health risks, and 8. Poverty and displacement [2,3]. One of the main concerns of the foreseeable effects of climate change is the occurrence of disasters resulting from the combination of structural vulnerability and the incidence of hydrometeorological phenomena [4].

In this field, the United Nations Office for the Reduction of Disaster Risks [5] defines *disaster* as a serious interruption in the function of a society derived from threatening events that interact with conditions of vulnerability, exposure, and capacity, generating human, economic, material, and environmental losses and impact. The General Law of Civil Protection [6] mentions that *hydrometeorological phenomena* are disturbing agents generated by atmospheric agents such as tropical cyclones, extreme rains, floods, blizzards, hail, droughts, heat and cold waves, and tornados.

The National System of Civil Protection [SINAPROC] [7] mentions that Mexico is in an intertropical region which subjects it to being battered by hurricanes generated in the

Atlantic Ocean as well as the Pacific. The impacts of these phenomena mostly affect the coastal zones of the Pacific, the Gulf of Mexico, and the Caribbean. During the period of 2000-2020 2,223 declarations were made by SINAPROC, which were divided in *a)* climatological contingency declaration, 18.58%; *b)* disaster declaration, 30.72%, and *c)* emergency declaration, 50.70%. 92.85% were caused by hydrometeorological phenomena [8,9]. It is worth mentioning that among the states that have municipalities with "very high" risk from this type of phenomena are the states of *Veracruz*, Chiapas, and Guerrero [10].

Problem approach

With a surface of 78,815 km^2, the state of Veracruz represents 3.7% of the surface of Mexican territory and is located in the central part of the slope of the Gulf of Mexico and is adjacent to the state of Tamaulipas in the north, San Luis Potosí, Hidalgo, and Puebla in the west, Oaxaca in the south, and Chiapas and Tabasco in the southeast. Veracruz has 212 municipalities with 8,062,579 inhabitants [11].

The regions that make up Veracruz and are considered in the Veracruz Development Plan [12] are (1) Huasteca Alta, (2) Huasteca Baja, (3) Totonaca, (4) Nautla, (5) Capital, (6) Sotavento, (7) Montañas, (8) Papaloapan, (9) Tuxtlas and (10) Olmeca. The location of Veracruz and its regions are shown in Table 1.

Table 1 State of Veracruz [13,14]

Location of the state of Veracruz	Regions of the state of Veracruz
	

Throughout time, due to its geographical location, the state of Veracruz has been frequently and strongly affected by hydrometeorological phenomena, which has given rise to the declaration of natural disasters to help people affected. An analysis carried out with data emitted by the National Fund of Natural Disasters (FONDEN) during the period of 2012-2016 depicted in Table 2 shows the *a)* number of municipalities that make up each of the regions that are in the state of Veracruz; *2)* name of the region; *3)* percentage of municipalities in each region; *4)* number of emergency declarations emitted by each region; *5)* percentage of declarations, and *6)* the compound factor between declarations and municipalities.

Table 2 Emergency declarations [15]

Number of municipalities	Region	Percentage municipalities	Number declarations	Percentage declarations	Factor declarations/municipalities
11	Nautla	5.19%	89.00	11.08%	8.09
15	Totonaca	7.08%	39.00	4.86%	2.60
18	Huasteca Baja	8.49%	73.00	9.09%	4.06
15	Huasteca Alta	7.08%	39.00	4.86%	2.60
33	Capital	15.57%	153.00	19.05%	4.64
57	Las Montañas	26.89%	172.00	21.42%	3.02
4	Los Tuxtlas	1.89%	24.00	2.99%	6.00
25	Olmeca	11.79%	122.00	15.19%	4.88
22	Papaloapan	10.38%	45.00	5.60%	2.05
12	Sotavento	5.66%	47.00	5.85%	3.92
212		100.00%	803.00	100.00%	

We can see that the largest number of declarations is in the region of Las Montañas, followed by the capital region, regions that also have the largest number of municipalities, 26.89%, and 15.57% respectively, and that are next to each other. For the effects of this investigation, it is worth mentioning that Mexico has a social supply distribution network for communities with marginalized conditions. The state of Veracruz has three units of this network, through which service is given to the municipalities and communities with stores that have different characteristics derived from the supply zone, characteristics that make them apt to function as a humanitarian warehouse in case of disaster.

The aforementioned is why this investigation, cataloged as a case study, hopes to develop from a social supply unit in the Altas Montañas region and as of now we will call this unit a humanitarian supply warehouse, as well as the routing of vehicles through which products will be supplied to people affected by natural disasters in the Altas Montañas and capital regions in the state of Veracruz. The declaration of emergencies emitted during the period of 2012-2016 by FONDEN is used as a foundation for analysis of supply zones and victims.

The research is divided into four parts, the introduction, a revision of the literature, where a series of investigations that deal with and give solutions to the routing problem through different methods and combinations are presented. Finally, the conclusions are presented to finalize the study with consulted sources for the development of the manuscript.

2 Literature review

While climate change has brought environmental, social, and economic problems, it has awoken the interest of researchers all over the world who, through the application and/or generation of different methods, methodologies, and immersive techniques in different areas, have developed solutions that allow for the minimization of adverse effects. In the case of the present investigation, Table 3 displays articles that have years of developed material in humanitarian logistics, especially regarding the vehicle routing problem.

Table 3 Revision of the state of art

Title	Authors	Year	Description
Modeling integrated supply chain logistics in real-time large-scale disaster relief operations	A. Afshar & A. Haghani.	2012	- Response to natural disasters. - Mathematical model: a) optimal locations; b) Vehicles route; c) pickup and delivery schedules; d) capacity restrictions for each facility, and e) transportation system. - Evaluated through numerical experiments [16].
Transportation in disaster response operations	D. Berkoune, J. Renaud, Monia Rekik & Ángel Ruiz.	2012	- Emergency situations. - Modeling of a transport problem. - Development of an enumeration heuristic of collections and genetic algorithm [17].
An exact solution approach for multi-objective location–transportation problem for disaster response	R. Abounacer & M. Rekik	2014	- Humanitarian help. - Mathematical formulation of multi-objective localization and transport problems: a) minimizes the total duration of transportation of the necessary products from the distribution centers to points of demand; b) minimizes the number of agents to open and operate the distribution centers, and c) minimizes demand not supplied. - Modification of the algorithm for the generation of rough solutions - Comparison of results [18].
A bi-level optimization model for aid distribution after the occurrence of a disaster	J.F. Camacho-Vallejo, E. González-Rodríguez, F.J. Almaguer & R.G. González-Ramírez.	2015	- Humanitarian logistics. - Two-level mathematical programming model, with a reduction to a one-level non-linear mathematical model; linearized to obtain a mixed programming problem. - Distribution of humanitarian help after a disaster. - Real case study of the earthquake in Chile in 2010 [19].
A humanitarian logistics model for disaster relief operation considering	M. Ahmadi, A. Seifi & B. Tootooni.	2015	- Humanitarian logistical operations. - Two-level Stochastic Mixed-Integer Programming Models with random travel time to determine the location of local deposits and routing for last-mile distribution.

network failure and standard relief time: A case study on San Francisco district			- GAMS. - Case study of San Francisco, California [20].
A dynamic multi-objective location–routing model for relief logistic planning under uncertainty on demand, travel time, and cost parameters	A. Bozorgi-Amiri & M. Khorsi.	2016	- Humanitarian help logistics. - Facility location, inventory quantity, and vehicle routing. - Model of multi-objective mixed-integer programming: a) minimize the maximum quantity of scarcity between the areas affected in all periods; b) minimize the total time of the trip, and c) minimize the sum of the costs before and after the disaster. - GAMS/CPLEX. - Tehran case study [21].
Allocation of temporary disaster response facilities under demand uncertainty: An earthquake case study	F. Cavdur, M. Kose-Kucuk & A. Sebatli.	2016	- Short-term disaster assistance operations. - Two-level Stochastic Mixed-Integer Programming Models to minimize the total distance traveled, unsatisfied demand, and the total number of facilities. - Temporary assignment of facilities during disaster response problems. - Case study developed by the Prime Ministry Disaster and Emergency Management Authority [22].
Pre-positioning of relief items in humanitarian logistics considering lateral transshipment opportunities	S. Baskaya, M. A. Ertem & S. Duran	2017	- Humanitarian help chain - Development and comparison of mathematical models for the location, number of facilities and inventory: a) direct shipping model; b) lateral transfer model, and c) maritime lateral transfer model. - GAMS/CPLEX - Istanbul case study [23].
Plant Location, Inventory Levels, and Supply of Products to Areas Affected by a Natural Phenomenon	E. Barojas-Payán, E, V. Juárez-Rivera, R. Villafuerte-Díaz & J. Medina-Cervantes.	2019	- Humanitarian logistics. - Mathematical model that combines the facility location, inventory levels, and vehicle routing. - Lingo - Case study in Veracruz, México [24].
Logistics Solutions in the Preparation Phase for the Appearance of Disasters	E. Barojas-Payán, D. Sánchez-Partida, M.J. Heredia-Roldan, V. Juárez-Rivera, J. Medina-Cervantes	2020	- Humanitarian logistics - natural disasters - Evaluation of a logistic model of literature whose fundaments are *a)* the classic p-median problem for the location of a prepositioned warehouse; *b)* an extension of the model (*q-R*) for calculating the inventory of different products, according to different types of demand, and *c)* the Capacitated Vehicle Routing Problem. - Lingo. - Case study in Veracruz, México [25].
A Multi-criteria Decision-Making Framework for the Design of the Relief Distribution Routes	F. Regis-Hernández, A. Ruiz & J. Mora-Vargas	2022	- Humanitarian help. - Multiple criteria methodology for the design of a help distribution network using the Analytical Hierarchy Process. - Quantitative models to maximize the performance of the distribution network. - Academic case [26].

The previous Table offers a structured vision of a part of the existing literature about humanitarian logistics in natural disasters, facilitating the comparison and the analysis of different focuses, as well as distinct models and methods with which various researchers have offered solutions to the routing problem in case of disaster.

3 Methodology

The following methodology is displayed in Figure 1, dividing the collection of information as follows: quantity of people in need, distances between municipalities and information about the vehicle used for deliveries, as well as other information. Below is the supplied information and the execution of the model with Lingo® software, followed by the presentation of the results and the statistics of time and distance variables.

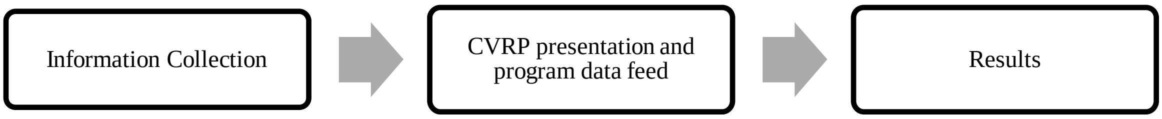


Figure 1 Methodology

Step 1. Information Collection

1. *Location of humanitarian supply warehouses (HSW)*, to carry out the present investigation, the humanitarian supply warehouse located in Orizaba was categorized as a supply point.

2. *Municipalities that declared emergencies*, from the data in [15], Table 4 is generated, where we can observe a total of 90 municipalities, 66 have been affected by a hydrometeorological natural phenomenon which has been the cause of a declared emergency, for which s supply points will be sixty-six.

Table 4 Municipalities with declared emergencies

Region	Number of municipalities	Municipalities with declared emergencies
Capital	33	17
Altas Montañas	57	49
Total	90	66

3. *Databases for the program which will be developed and supply data for the vehicle routing problem.*

- Distance matrix between municipalities that have declared emergencies and HSW, obtained with Google Earth®.
- Demand estimate from declared emergencies during 2012-2016.
- Vehicular capacity of 12000 kg of basic necessity products, this information is supplied by the document from Barojas-Payán et al. [27].

Step 2. Vehicular routing

To carry out the vehicular routing design for the supply of municipalities that have declared emergencies, a routing of capacitated vehicles is used, which is described below:

The objective of the classic vehicle routing problem (VRP) is to make routes for a fleet of homogeneous vehicles in order to serve a group of clients. Every client is visited once by one vehicle, every vehicle route begins and ends with a deposit and fulfills some lateral restrictions [28].

The Capacitated Vehicle Routing Problem (CVRP) case has a special twist: the cargo capacity that the driver has from the origin to the destination. A fleet of capacitated vehicles is located at a distribution center, the clients are in different geographical spaces and represent a demand. The distribution costs are integrated by *a)* a fixed cost associated with every truck, and *b)* a variable cost per unit of traveled distance. Every route starts and ends at the same distribution center, and the vehicle capacity should not be overloaded [29,30]. The description of the variables and parameters are shown in Table 5.

Table 5 Parameters and variables [30]

Parameters	Description
$\boldsymbol{A}$	*Capacity of each vehicle.*
$\boldsymbol{V}$	*Maximum number of vehicles.*
$\boldsymbol{F_{ij}}$	*Nuclear flow from node i to node j.*
$\boldsymbol{Z}$	*Total cost of transportation.*
$\boldsymbol{d_i}$	*Demand at node i.*
$\boldsymbol{c_{ij}}$	*Distance between node i and node j.*
Variable	**Description**
$\boldsymbol{X_{ij}}$	*1 if the vehicle moves from node i to node j, 0 if the opposite is true.*

According to [30] the general model for a CVRP is the following:

$$Min\,Z = \sum_{i=1}^{N}\sum_{j=1,j\neq i}^{N} c_{ij}x_{ij} \tag{1}$$

Subject to:

$$\sum_{l=2,k\neq 1}^{N} x_{lk} + x_{1k} = 1 \quad \forall k \tag{2}$$

$$\sum_{l=2,k\neq 1}^{N} x_{kl} + x_{k1} = 1 \quad \forall k \tag{3}$$

$$\sum_{k=2}^{N} x_{1k} \le V \tag{4}$$

$$\sum_{j=1,j\neq i}^{N} x_{ij} = \sum_{j=1,j\neq i}^{N} x_{ji} \quad \forall k \tag{5}$$

$$x_{kk} = 0 \quad \forall k \tag{6}$$

$$x_{lk} + x_{kl} = 1 \quad \forall k, l_{k\neq 1} \tag{7}$$

$$\sum_{j=1,j\neq i}^{N} F_{ij} = \sum_{j=1,j\neq i}^{N} F_{ji} + d_i \qquad \forall k \tag{8}$$

$$d_i x_{ij} \le +F_{ij} \qquad \forall i, j_{i\neq j} \tag{9}$$

$$F_{ij} \le (A - d_j)x_{ij} \qquad \forall i, j_{i\neq j} \tag{10}$$

Equation (1), represents the objective function of the model which is to minimize the total traveled distance; equations (2) and (3), establish that there is exactly one exit from node i; equation (4) establishes the total number of vehicles that should not be exceeded; equation (5) establishes the balance between the arrival and departure arcs in a determined node; equation (6) eliminates the flow from node i to node i; equation (7) is a trivial sub-tour elimination restriction, and equations (8), (9) and (10) establish the balance between the flow entering and exiting the node.

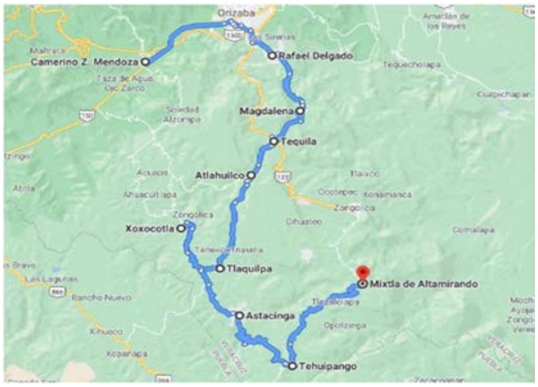
With Lingo 19.0® software and the obtained information in Step 1, we begin to resolve the capacitated vehicular routing problem, obtaining a total of 13 routes and 3,972.10 km traveled, for 66 municipalities that have declared emergencies. The route with the largest number of destination nodes is the first, with a total of 183.4 km traveled and a demand of 11,069 kg.

Step 3. Presentation of results

Table 6 presents one of the obtained routes through the programming of the capacitated vehicular routing problem: with a total distance traveled of 183.4 km for the delivery of products in the municipalities of Delgado, Magdalena, Tequila, Atlahuilco, Tlaquilpa, Xoxocotla, Astacinga, Tehuipango, Mixta Altamirano, Texhuacán, Zongolica and Los Reyes, supplying 11,069 kilograms of products, determined as route 1, while Table 7 shows that route 6 supplies Ixtaczoquitlán, Fortín de las Flores, Chocamán, Tomatlán, Ixhuatlán del Café, Tepatlaxco, Paso del Macho and Camarón de Tejeda, with a total of 210 km traveled. In addition to the description of the routes, the weight of the load, the distance traveled, and a map obtained with Google Maps® is shown with the respective route.

Table 6 Route 1. Optimization model

<table>
<tr><th>Route</th><th colspan="5">Delivery municipalities</th><th>kg</th><th>km</th></tr>
<tr><td rowspan="3">1</td><td colspan="2">Rafael Delgado</td><td>Magdalena</td><td>Tequila</td><td>Atlahuilco</td><td rowspan="3">11,885</td><td rowspan="3">183.4</td></tr>
<tr><td>Tlaquilpa</td><td>Xoxocotla</td><td>Astacinga</td><td colspan="2">Tehuipango</td></tr>
<tr><td colspan="2">Mixtla de Altamirano</td><td>Texhuacán</td><td>Zongolica</td><td>Los Reyes</td></tr>
</table>



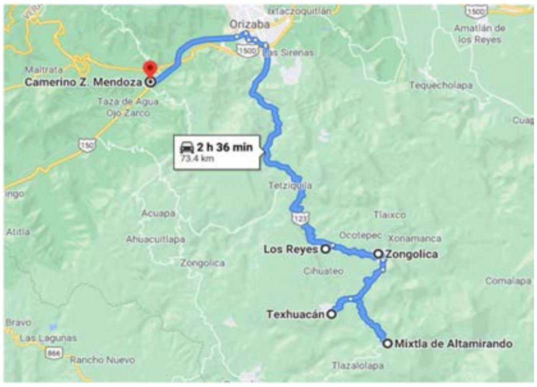


Table 7 Route 7. Optimization model

<table>
<tr><th>Route</th><th colspan="4">Delivery municipalities</th><th>kg</th><th>km</th></tr>
<tr><td rowspan="2">6</td><td>Ixtaczoquitlán</td><td>Fortín de las Flores</td><td>Chocamán</td><td>Tomatlán</td><td rowspan="2">11,664</td><td rowspan="2">210.0</td></tr>
<tr><td>Ixhuatlán del Café</td><td>Tepatlaxco</td><td>Paso del Macho</td><td>Camarón de Tejeda</td></tr>
</table>

4 Results

Table 8 shows the results of the application of the capacitated vehicular routing problem, with a total of 13 routes and 3900 km traveled for the supply of 66 municipalities. With an average of 300 km per route and a standard deviation of 178.62 km, likewise, the average delivery time is 478.62 min (7.9 hours). We can conclude that the delivery of products to people affected by natural phenomena can be carried out efficiently, supposing that there are no transit problems or issues on the highways or access routes to the affected municipalities.

Table 8 Lingo19® programming result.

Route	Kilometers	Minutes
1	183.4	387
2	561.0	755
3	596.0	896
4	385.0	579
5	259.0	475
6	210.0	384
7	535.0	804
8	124.0	179
9	230.0	397
10	52.9	135
11	326.0	507
12	343.0	499
13	94.8	225
Sum	3,900 km	6,222 min
Average	300.00	478.62
Dev.Std.	178.68	235.22

With the finality of examining the characteristic of the kilometer variable with a statistical focus that compares the distribution of the data with a normal distribution, Figure 2 shows the adjustment of the variable to the normal distribution through the graph, where we can determine whether the variable shows significant normality deviations which could have important implications for the validity of the statistical analyses and the conclusions of the investigation. The value of p for this normality test is greater than the $p > 0.05$ significance level, therefore, the data follows a normal distribution for this variable.

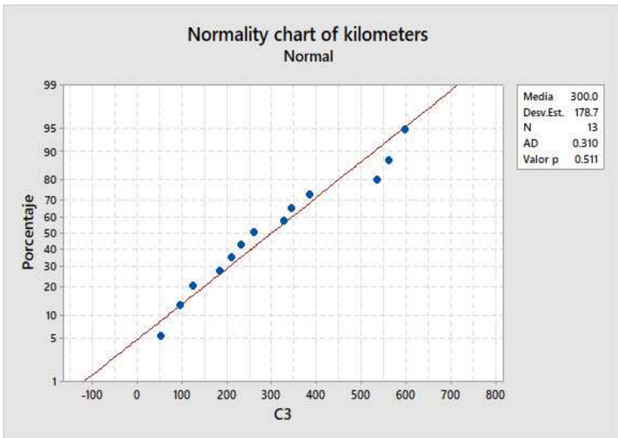


Figure 2 Normality chart of kilometers

With the normality chart, we observe that in the time variable, the value of p for the normality test is 0.603, therefore, the data follows a normal distribution for this variable (Figure 3).

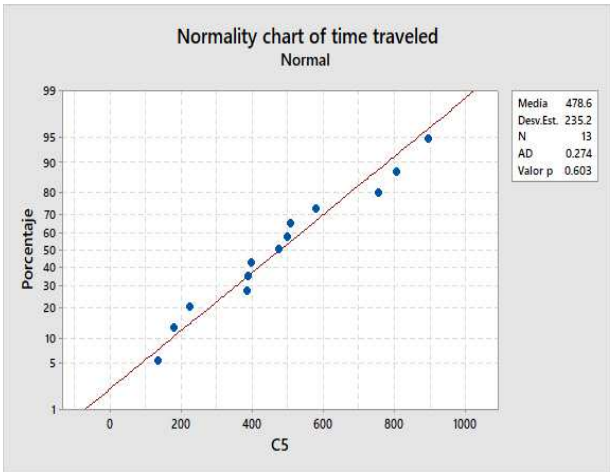


Figure 3 Normality chart of time traveled

5 Conclusions

One of the concerns with climate change is the presence of extreme natural phenomena, a situation that makes it imperative to develop plans that allow for quick and effective decisions for victims not only for the best assistance possible but also for it to be fast and efficient.

In the literature, several works have addressed the topic of humanitarian logistics in Mexico. For example, [24] have developed a model that combines the problem of facility location, inventory level establishment, and vehicle routing for one of the ten regions that constitute Veracruz. Unlike this work, they propose a new warehouse that would entail a considerable monetary investment in vehicles, since it would be in the city of Fortin de las Flores and have 14 delivery routes. Furthermore, [31] study vehicle routing in Chiapas, México. Chiapas is one of the five states with the greatest impacts derived from climatic phenomena. The authors weighed the variables to determine the location of two warehouses and their vehicular routing. They compare the results, selecting the best choice of infrastructure, viability, and response time. However, a considerable monetary investment is required.

The research presented shows the capacitated vehicular routing problem for the regions of the capital and the Altas Montañas in Veracruz, based on emergencies declared by FONDEN during 2012-2016, the municipalities that form part of the route are established with the goal of being supplied. They have a humanitarian supply warehouse in the city of Orizaba as an origin and destination point.

The objective of the generation of routes is to have complete coverage throughout the studied regions (Capital and Altas Montañas) allowing for an efficient supply by balancing deliveries, decreasing distances, and above all decreasing delivery times.

The results show the establishment of 13 routes with an average traveled distance of 300 km, in an average time of approximately 7.9 hours. In the same way, with the normality charts with the route time and distance variables, the adjustment of the normal distribution variables is shown. These results obtained in the normality charts show that the variable *kilometers* ($p = 0.511$) as well as the *time* variable ($p = 0.603$) have a normal distribution, which guarantees a validity of the analysis.

Unlike the articles mentioned previously, this document proposes a warehouse with characteristics and the infrastructure that allows reliable distribution, without a high investment. Also, the location of this warehouse will reach a greater number of municipalities per route, in an acceptable delivery time. As future work, we will integrate to the proposed model logistics elements such as warehouses and inventories, affected municipalities, temporary shelters, and collection points, among others.

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Optimizing suburban public transport through smart city logistics: a study on information flow and passenger management

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Keywords: smart city, public transport, optimization, intelligent transport systems, suburban mobility.
Abstract: The study explores how Smart City technologies influence logistics operations in suburban public transportation systems. By enhancing passenger and vehicle movement, the study assesses the role of sensor data, real-time information, and data analysis in improving the flow of materials, personnel, and information in suburban transit. Findings demonstrate that Smart City initiatives lead to shorter wait times, improved route optimization, and greater reliability, thereby boosting overall transport logistics. Through real-time data processing, suburban systems can manage flow dynamically, offering valuable insights for scalable implementations in both urban and suburban logistics.

1 Introduction

The advent of smart city technologies has transformed urban infrastructure, providing innovative solutions to persistent urban management and public service problems. As cities expand, it is important to ensure efficient and accessible public transport in suburban areas to promote social equity, economic health, and environmental sustainability [1]. Smart city technologies, which utilize data analytics, Internet of Things devices, and real-time information sharing, can potentially improve these transport systems [2]. Understanding their impact can provide valuable insights for enhancing public transport networks and strengthening connections between urban and suburban areas.

Despite the increasing implementation of smart city technologies, there is still limited understanding of their specific impact on the accessibility and efficiency of suburban public transport. Unresolved questions remain regarding the effect of smart city systems on the schedule and frequency of suburban transport services. The impact of real-time data on public transport accessibility in sparsely populated regions has also not been studied. It is unclear whether smart city solutions address the transport needs of suburban residents as effectively as they do for urban center residents.

This study aims to assess the impact of smart city systems on the accessibility and performance of suburban public transport. It analyzes the effect of advanced technologies on transport management and service delivery.

Research tasks:

1. To explore the integration of smart city technologies into suburban public transport, particularly data-based planning mechanisms and real-time information systems, and their impact on service accessibility.
2. To evaluate the impact of smart city solutions on the accessibility and efficiency of public transport in suburban areas by comparing regions with and without these technologies.
3. To identify challenges and opportunities in using smart city systems in suburban areas, including user satisfaction, operational efficiency, and potential for further technological development.

2 Literature review

Smart cities are attracting increasing attention due to the desire to integrate technologies to improve quality of life, sustainability, and efficiency. A key element of such cities is the modernization of transport networks. Technological innovations focus on improving accessibility, reducing environmental impact, and enhancing efficiency. The authors of the article [3] studied the impact of the COVID-19 pandemic on urban mobility and the role of smart city technologies in developing European transport policy. Their results demonstrate how these innovations have improved the resilience of transport systems, helping them adapt to new challenges. The researchers emphasize the need for a comprehensive transformation of transport infrastructure to social and environmental demands. The article [4,5] studied the socio-economic and sustainable impact of free public urban transport in the case of the City of Tallinn and the role of the Estonian ID card based on the national e-government system for data management.

The authors of the article [6] proposed an approach to studying social segregation based on smart card data in public transport. This allowed them to identify inequalities in access to transport among different social groups, showing how data analytics can influence the formation of transport policies with a focus on social justice. Meanwhile, the research [7] explored the latest innovations in public transport, particularly autonomous vehicles and predictive analytics. The authors emphasize the need to overcome barriers for effective implementation and improve system resilience.

This article [8] analyzes the overall impact of the smart city concept on public transport. They explored how data and technology integration has transformed transport infrastructure, noting increased efficiency and improved user experience. However, they indicated that more research is needed to assess the long-term consequences of implementing new systems. The authors of the article [9] focused on introducing electromobility into the transport infrastructure of smart cities, highlighting the role of electric vehicles in reducing carbon emissions. Although the study confirms the importance of such solutions, additional empirical data are needed to assess their effectiveness fully. The article [9] studied the utilization of autonomous delivery robots in the frame of the smart city concept and outlined a regulatory framework for the operation in public spaces.

Another research [10] analyzes the potential for using new transport vehicles in smart cities, such as autonomous buses and electric bicycles. She examined their advantages and disadvantages, critically assessing their integration into the existing transport infrastructure. The study shows the potential of these innovations for strengthening the future of urban transport. Studying the experience of organizing the transport system of Estonia, the article [11] studied the economic feasibility of using electric vehicles depending on the transportation volume using the example of the delivery sector. The authors of the article [12] studied the possibilities of applying innovative logistics technologies in this sector. One more article [13] also focused on forecasting the development of the electric vehicle market and its impact on the development of other modes of transport. A review of the advanced socially-oriented approach to urban transport development was carried out by the article [14]. The authors of the research [15] developed a model to assess the energy efficiency of transport systems, offering a foundation for analyzing the environmental, energy, and financial aspects. This is an important tool for decision-making regarding the development of public transport in urban environments.

The explorers of the public influence on the transport system in smart cities [16] emphasized the importance of public participation in resolving social conflicts in smart cities. They argue that inclusive planning involving the community can increase the success of projects and ensure social justice. The article [17] studied the world experience of state regulation of the development of production and use of motor transport. Another article [18] examined the legal issues of transport and logistics security in detail. The researchers [19] examined the challenges and opportunities of integrating smart city solutions into urban and rural areas. They highlighted the potential of such technologies to connect urban and suburban transport systems but also noted many obstacles to the widespread implementation of such systems in less densely populated areas. The article [20] extended the smart city concept and investigated its compatibility with the concept of smart logistics hubs. The research focused on maritime cities, resulting in a conceptualization of a smart port city ecosystem. The authors of this study [21] researched the use of bi-directional trams as a sustainable approach to urban public transport. Their study shows that this technology can significantly reduce travel time and improve the efficiency of transport networks. However, more data are needed to evaluate the scalability of this technology.

Despite the substantial amount of research devoted to the intellectualization of transport, it is important to continue studying specific challenges for suburban and rural areas. Understanding the needs of such regions will enable the adaptation of technological solutions. Moreover, it is worth exploring the impact of innovations on social justice and transport accessibility for different population groups, particularly marginalized groups. The successful implementation of smart city technologies requires overcoming regulatory and financial barriers and involving stakeholders.

3 Methods

3.1 Research procedure

The empirical study consisted of the following stages (Figure 1).

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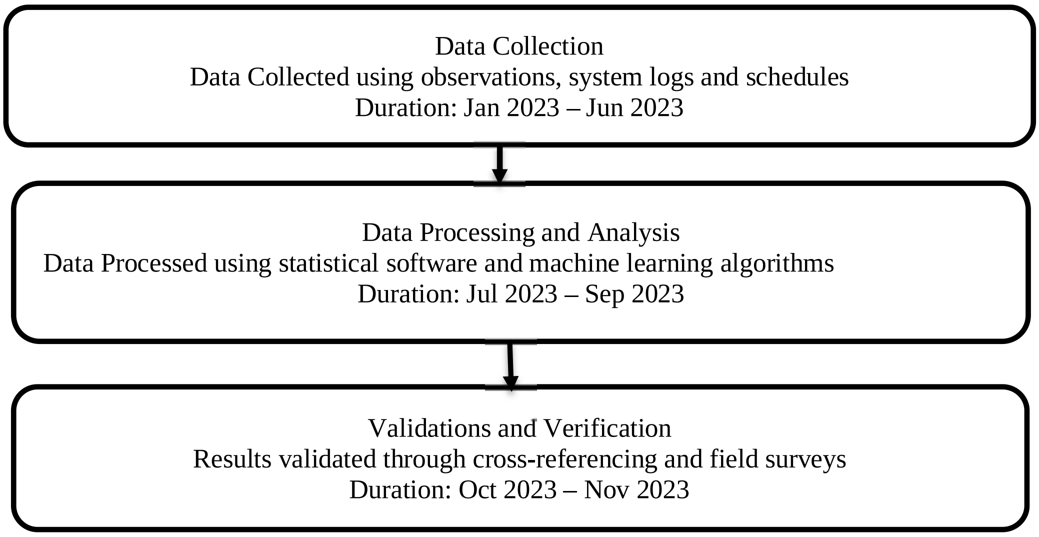

Figure 1 Research stages

3.2 Sample formation

The research focused on suburban public transportation systems in three large cities that utilize smart city technologies. The main subjects of the study were bus schedules, route efficiency, and real-time passenger data. The sample (Table 1) included 150 bus routes from the three cities.

Table 1 Sample formation

City	**Country**	**Details**
Berlin	Germany	A large city with an extensive smart city infrastructure.
Barcelona	Spain	A city known for its advanced urban mobility systems.
Copenhagen	Denmark	Renowned for its smart city initiatives and efforts toward sustainable development.

Each route was monitored over 60 days to gather comprehensive data. The sample of 150 routes was selected to obtain reliable data that reflect diverse suburban transport scenarios and varying levels of smart city system integration. The cities were chosen due to their advanced implementation of smart city technologies and the availability of detailed transport data, ensuring the relevance of conclusions for environments where smart systems are actively utilized. Selection criteria included the level of smart city system integration, diversity of suburban transport routes, and data availability. The chosen sample size and selection criteria ensure the statistical significance and applicability of the research results to similar contexts.

3.3 Methods

The research employs a combination of methods for data collection and analysis:

Sensor Data Analysis: Smart sensors and IoT devices monitor transportation operations in real-time. Data on the number of vehicles, service efficiency, and passenger counts are collected. Primary data processing and statistical analysis are carried out using Python and R. The data are aggregated by hours and days.

Service Frequency Calculation (1):

$$Frequency = \frac{Total\ Services}{Time\ Period} \tag{1}$$

Equation 1 calculates the frequency of services based on total services over a specific period, an essential metric for logistics flow management in transport systems.

1. Statistical Analysis: Statistical methods were applied to study the impact of smart city systems on transport accessibility and user satisfaction. Regression analysis was used to assess the relationship between the implementation of smart city systems and transport efficiency.

Regression Analysis for Transport Efficiency (2):

$$\gamma = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \epsilon \tag{2}$$

Equation 2 represents a regression model for evaluating transport efficiency, where γ denotes efficiency, X_1 and X_2 are variables representing Smart City integration and control factors, respectively, and ϵ signifies the error term.

2. User Survey Analysis. A passenger survey was conducted to collect qualitative data regarding their experiences with smart city systems. A structured questionnaire was created, focusing on aspects such as

service reliability, accessibility, and user satisfaction. Survey responses were processed using descriptive statistics and thematic analysis to identify common themes and patterns in user feedback.

The research tools included:

1. Data Sources: Intelligent sensors (IoT devices), GPS trackers, and Automated Passenger Counting (APC) systems provided quantitative data on transport operations. Surveys collected qualitative information about passenger experiences.

2. Analysis Tools: Python and R were used for data processing and analysis, enabling complex computations and result modeling.

4 Results

4.1 *Logistics flow optimization in suburban transport: the role of smart city systems*

Over 60 days, 150 bus routes in Berlin, Barcelona, and Copenhagen were monitored. Smart sensors and Internet of Things devices recorded the movement of buses, intervals between trips, and the number of passengers. The data were grouped into hourly and daily intervals for analysis. Table 2 contains the summarized results.

The research indicates that Berlin has the highest number of bus services among the three cities, demonstrating a developed transport infrastructure and effective implementation of smart technologies for route optimization. Despite having fewer services, Barcelona provides reliable service that enhances urban mobility. Copenhagen has the least number of services, which may be related to fewer routes or a smaller population.

Table 2 Overview of collected data

City	Total Services	Average Service Frequency (per Hour)	Average Passenger Load (per Service)
Berlin	45,600	4.2	32
Barcelona	39,000	3.9	29
Copenhagen	35,400	3.6	28

Berlin boasts the highest service frequency at 4.2 per hour, reflecting the effective use of smart solutions. Barcelona offers 4 services per hour, ensuring dependable service. In Copenhagen, the service frequency is 3.6 per hour, but the system remains stable. The average number of passengers in Berlin is 32 per service, indicating high demand. In Barcelona, this figure is 29 passengers, while in Copenhagen, it is 28 passengers per service, reflecting good occupancy rates. Thanks to the effective use of technologies, Berlin stands out with its high service frequency and passenger flow. Copenhagen maintains a stable level of service by integrating transport with cycling infrastructure. Figure 2 illustrates the relationship between service frequency and average passenger load in the three cities.

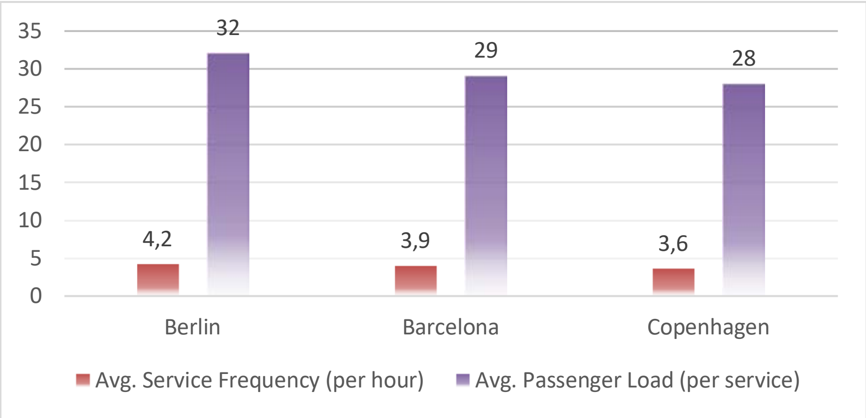

Figure 2 Service frequency and passenger load comparison in Berlin, Barcelona, and Copenhagen, illustrating logistics efficiency in suburban public transport systems

The graph shows that Berlin has the highest level of bus services and passenger flow among the three cities. Buses in Berlin operate more frequently and carry more passengers than those in Barcelona and Copenhagen. Although Barcelona shows slightly lower results, it still actively utilizes public transport. Copenhagen has the lowest frequency of services and passenger flow, possibly related to lower demand or limited resources.

The graph confirms a positive correlation between service frequency and the number of passengers: the more frequent the services, the more passengers per bus. Frequent services reduce waiting times and make transport more attractive to users. During peak hours, the number of services and passenger flow increase due to heightened demand for transportation services. Berlin stands out with the highest frequency of services and passenger flow, indicating the effectiveness of its transport infrastructure. Barcelona also demonstrates good effectiveness, although its figures are somewhat lower. Copenhagen has the lowest figures, which may result from lower demand or limited resources.

The positive relationship between service frequency and passenger flow suggests that more frequent services encourage greater transport use. Cities with advanced management systems, like Berlin and Barcelona, show better performance metrics. The difference between peak and off-peak periods reflects the systems' adaptation to changing demand (Table 3). The results also indicate that increased service frequency typically leads to higher passenger loads on transport.

Table 3 Variations in service frequency and passenger load during peak and off-peak hours

City	Peak Service Frequency (per hour)	Off-Peak Service Frequency (per hour)	Average Peak Passenger Load	Average Off-Peak Passenger Load
Berlin	5.8	3.1	40	25
Barcelona	5.3	2.9	37	23
Copenhagen	5.0	2.7	34	22

Berlin has the highest frequency of service and the largest number of passengers, indicating a high demand for transportation. Barcelona, while lagging, demonstrates a similar trend. Copenhagen has the lowest figures, indicating lower demand or a more efficient system. The regression model evaluates the impact of smart city systems on transportation efficiency. The results are presented in Table 4.

Table 4 Results of the regression analysis

Parameter	Coefficient (β)	Standard Error	p-value
Constant (β_0)	0.87	0.12	<0.001
Smart City Integration (χ_1)	0.34	0.05	0.002
Control Variable (χ_2)	0.15	0.04	0.023
Error Term (ϵ)	-	-	-

The constant reflects the baseline level of transport efficiency without considering smart city technologies and control variables. Without integrating the smart city (χ_1) and the control variable (χ_2), transport efficiency is 0.87 on a normalized scale, representing the baseline level without smart city technologies. The standard error is 0.12, indicating variability in the constant, and the p-value < 0.001 confirms its statistical significance, suggesting a low probability of random effects.

The value of 0.34 shows how smart city integration enhances transport efficiency. An increase in integration by one unit through real-time technologies or the Internet of Things raises efficiency by 0.34 units. This indicates a strong positive correlation between smart city technologies and the transport system. The standard error of 0.05 and p-value of 0.002 validate this effect's precision and statistical significance. The coefficient of 0.15 for the control variable (χ_2) demonstrates a positive impact of external factors on transport efficiency. An increase in the control variable by one unit enhances efficiency by 0.15. The standard error of 0.04 and p-value of 0.023 affirm this influence's accuracy and statistical significance. The regression analysis reveals a positive relationship between smart city integration and transport efficiency.

4.2 *Integration of smart city technologies in transport logistics*

Data on transport efficiency in the three cities show varying results (Figure 3). Berlin demonstrates the highest efficiency due to advanced smart city technologies that significantly enhance the transport system. Barcelona shows moderate improvements due to a higher level of integration, but these changes are less significant than in Berlin. Copenhagen has the lowest efficiency indicators among the three cities. Although implementing smart technologies in Copenhagen improves the situation, the effect is less pronounced compared to Berlin and Barcelona. The graph demonstrates a positive relationship between the level of integration of smart systems and transport efficiency. The data confirm that Berlin achieves the greatest improvements, while Copenhagen shows the least changes. Results from a survey of 1,500 passengers (500 from each city) complement the information about user satisfaction with suburban transport (Table 5).

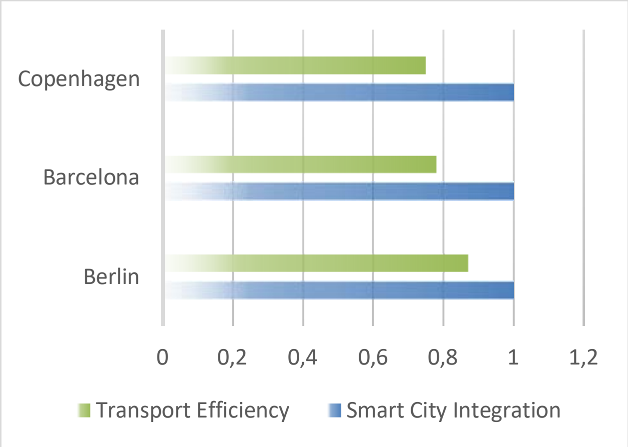

Figure 3 Impact of Smart City system integration on transport efficiency, indicating improvements in material and human flow management

Table 5 Passenger Satisfaction Survey results

City	Service Reliability (% Satisfied)	Accessibility (% Satisfied)	Overall Satisfaction (% Satisfied)
Berlin	82	76	79
Barcelona	78	72	75
Copenhagen	75	69	73

In Berlin, 82% of passengers are satisfied with the reliability of transportation services, confirming the effectiveness of "smart city" initiatives in improving the system. 76% of respondents noted good transport accessibility, indicating a high quality of service, including for individuals with special needs. Overall, 79% of passengers in Berlin are satisfied with the transportation, reflecting the success of innovative technologies.

4.3 Data-driven logistics management for suburban transport systems

In Barcelona, 78% of respondents are satisfied with reliability, slightly lower than Berlin's level but still high. Transport accessibility in Barcelona is rated at 72%, indicating a need for improvements. Overall satisfaction in Barcelona stands at 75%, and the system is positively evaluated, although it is lower than in Berlin. In Copenhagen, only 75% of passengers are satisfied with reliability, which may indicate service issues. Transport accessibility is rated at 69%, the lowest among the three cities. Overall satisfaction in Copenhagen reaches 73%, showing a positive perception but with noticeable problems. Berlin leads in all categories due to the successful implementation of technologies, while Barcelona shows good results, and Copenhagen needs improvement, particularly in accessibility and infrastructure costs (Figure 4).

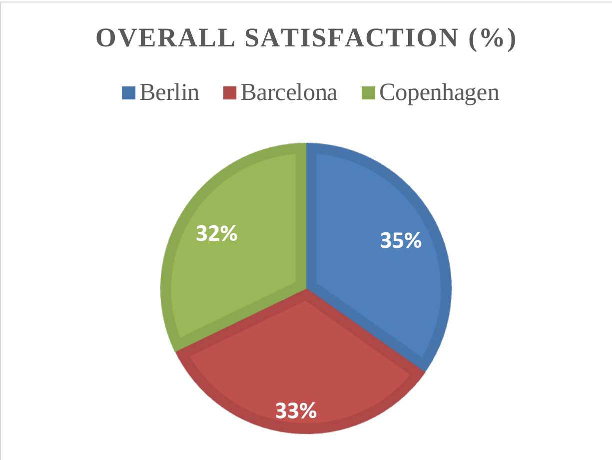

Figure 4 Overall passenger satisfaction

In Berlin, the user satisfaction level reaches 79%, marking the success of the city's smart transportation systems. Barcelona demonstrates positive results with a satisfaction level of 75%, but it has room for improvement. The lowest satisfaction level is observed in Copenhagen at 73%. This may be due to insufficient technology integration, logistical issues, or a mismatch with passenger expectations. The higher satisfaction level in Berlin is likely associated with more reliable smart city infrastructure and more effective transportation technologies. While Barcelona has high scores, it still lags behind Berlin, indicating potential for enhancement. The low satisfaction in Copenhagen may reflect difficulties in implementing technologies or differences in expectations. Calculations from the regression model assess the impact of smart city technologies on transportation effectiveness (Table 6).

Table 6 Projected transportation effectiveness with increased smart city integration

City	Current Effectiveness	Increase in Smart City Integration by 10%	Increase in Smart City Integration by 20%
Berlin	0.87	0.91	0.95
Barcelona	0.78	0.82	0.86
Copenhagen	0.75	0.79	0.83

Predictions of city effectiveness based on regression analysis indicate a significant impact of Smart City integration. For Berlin, with a 10% increase in integration, effectiveness will rise from 0.87 to 0.91, an increase of 0.04. This demonstrates the significant benefits of improving initiatives. In Barcelona, a similar increase will raise effectiveness from 0.78 to 0.82, also by 0.04, but with more moderate changes. Copenhagen will see growth from 0.75 to 0.79, which is an increase of 0.04 but is relatively greater due to the initially lower figures.

With a 20% increase in integration, the forecasts are 0.95 for Berlin, 0.86 for Barcelona, and 0.83 for Copenhagen. For Berlin, this is an increase from 0.87 to 0.95 (0.08), indicating great potential for development. Barcelona will grow from 0.78 to 0.86 (0.08), while Copenhagen will rise from 0.75 to 0.83 (0.08). Berlin will have the largest absolute improvement, while Barcelona and Copenhagen will also benefit but with less noticeable changes due to different initial levels of effectiveness.

5 Discussion

The study results confirm that innovative technologies, particularly systems that utilize real-time data and optimize routes, improve the regularity of transport and passenger flow management. This supports our hypothesis that Smart City technologies enhance the accessibility and efficiency of public transport for suburban residents. A comparison with the research [2], which analyzes the impact of Smart City technologies on urban mobility during the COVID-19 pandemic, indicates a commonality in confirming the adaptability of these technologies in crises. Our results demonstrate that innovative systems help create efficient suburban transport networks, focusing on the often-overlooked suburbs.

The article [8] examines social segregation in public transport, indicating unequal socioeconomic access to services. Our findings show an overall improvement in transport services but do not account for equity. The differing focuses of the studies can explain this discrepancy: our emphasis is on efficiency, while the article's authors [22] focus on social models. Future research should address equitable access to technological innovations in suburban transport.

The researchers [12] emphasize the innovative capabilities of smart public transport systems, noting the risks of cybersecurity and data integration. While our study confirms improvements in accessibility due to technological innovations, security issues were not a primary focus. Their work highlights the importance of considering these risks in future research, particularly concerning user data protection. Another study [1] confirms the positive impact of Smart City technologies on transport accessibility but focuses on urban areas. Our results show that suburban areas also benefit, although the implementation process is slower due to logistical challenges. Unlike the research [11], which proposes introducing new transport vehicles, our study indicates that improving transport system management, particularly through real-time data utilization, is more effective in enhancing accessibility.

The varying priorities explain the difference: the study [23] emphasizes infrastructural changes, while our research focuses on using existing technologies. The article's authors [24] confirm our position on route optimization for improving the energy efficiency of public transport, although their model centers on sustainable development, while ours focuses on passenger accessibility. Another research [25] studies public participation in resolving social conflicts in smart city transport systems. While our research does not directly cover public involvement, engaging suburban residents in planning can enhance the effectiveness and adaptability of transport solutions. This opens avenues for future research.

Comparing our findings with established logistics frameworks, it is evident that Smart City technologies significantly improve material flow and human flow management. Our study supports the hypothesis that real-time data processing can optimize vehicle and passenger flow, enhancing suburban transport efficiency. These findings align with research on logistics flow optimization in urban transit systems, particularly during peak demand periods. Our findings highlight the improvements in logistics efficiency brought about by Smart City technologies. These results are consistent with logistics management models emphasizing the importance of real-time adaptability. By effectively managing the flow of passengers and vehicles, we can enhance overall transport logistics, leading to a more efficient and responsive suburban transport system. These optimizations offer a blueprint for implementing logistics-oriented Smart City solutions in comparable urban and suburban environments. Practical implications include recommendations for suburban transport authorities to implement data management systems and real-time optimization to improve service reliability and accessibility. Future research should focus on the long-term challenges of sustainability and security associated with these technologies.

5.1 Limitations

Certain limitations exist when integrating Smart City technologies into suburban public transport. The primary issue is the uneven distribution of technological infrastructure among regions, which creates unequal access to services. High initial and operational costs may hinder widespread implementation, especially in resource-limited areas. Further research is needed to assess the sustainability and scalability of these technologies.

5.2 Recommendations

To enhance the accessibility of suburban transport, Smart City systems should be integrated that analyze real-time data for route optimization. AI can predict changes in passenger flow, providing more efficient transport for suburban areas.

6 Conclusions

The role of Smart City technologies in enhancing public transport accessibility in the suburbs is an important issue at the intersection of urbanization development, technology, and social infrastructure. This study addresses the significance of innovative solutions for improving the transport system in suburbs. This issue becomes particularly relevant due to the increasing demand for reliable transport connections between the city and suburban areas. Providing quality transport services plays a key role in promoting sustainable development, reducing environmental impact, and improving living conditions for suburban residents.

The study showed that implementing Smart City technologies significantly enhances the efficiency and accessibility of public transport in suburban areas. Using real-time data analysis, automated planning, and user-friendly interfaces contributes to more effective resource utilization, reduced waiting times, and optimized routes. Furthermore, these systems better adapt to passenger needs, ultimately increasing user satisfaction and improving access to transport services. The results obtained have significant practical value for sustainable transport infrastructure development, particularly in reducing carbon emissions and supporting inclusive mobility. This information will be useful for urban planners, policymakers, and transport companies seeking to create more efficient and sustainable transport systems. The practical application of the findings of this study may stimulate investments in Smart City infrastructure and the development of transport networks in suburban areas.

This study underscores the critical role of Smart City technologies in optimizing logistics flows in suburban transport. The findings demonstrate significant improvements in material and human flow management, offering valuable insights into the scalability of such systems in other suburban and urban logistics environments. Future research should explore the long-term logistical impact of real-time data integration in transportation systems.

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A study of vehicle speed distribution influenced by urban traffic conditions

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Abstract: The most common approach in forecasting vehicle speed is to estimate the average value of this variable on a short segment or at some cross-section on the road. Since many factors influence the speed variable, determining the speed distribution law remains actual. Given that the numerous studies confirm the normally distributed free-flow speed on intercity roads and a minority of urban speed studies, the mentioned task is especially relevant for urban transport planning which often requires consideration of traffic conditions far from the free-flow ones because of traffic signalling and other factors, which complicate driving and decrease the speed compared to the desired one. This paper explores the speed influenced by two types of places frequent in urban areas – signalized intersections and narrow carriageway sections. The data for the study were collected in Kharkiv, the second-largest city in Ukraine. During the study, it was determined that the narrow carriageway decreases the speed in a way that speed values can be described by the gamma distribution, while the influence of signalized intersections results in the possibility of using both exponential and gamma distribution to represent the speed variable. To measure the speed during the surveys, a novel methodology that considers the waiting for the green signal was applied. The research results showed that the urban traffic environment decreases the mean of the speed variable, increases its standard deviation and changes the normally distributed free-flow speed to the gamma-distributed.

1 Introduction

Vehicle speed is among the most significant performance measures in traffic management because it represents travel and transportation conditions as well as quality of service for drivers [1,2]. At the same time, even up-to-date transport modelling software makes calculations using the average vehicle speed despite the obvious fact that the speed is a random variable having its own distribution and influenced by many factors which are hard to predict [3-5] (driving styles, weather, time of day, personal reaction on traffic conditions, vehicle loading etc.). The appropriateness of this speed representation during modelling sometimes creates doubts, especially when assessing vehicle speed in the case of dense traffic. Accordingly, the issue of defining speed distribution is especially relevant for urban transport flow modelling since very often, corresponding flows are not free because of the following:

- first of all, the complications of traffic conditions in terms of speed appear at the influence zones of single-grade intersections, especially signalized ones, which are numerous in any city and create most restrictions on vehicle movement;
- the second most frequent complications occur at the narrow carriageway sections.

The complications arising at the listed places force drivers to slow down or stop, and this certainly affects the speed distribution parameters. Thus, the purpose of this paper is to study the vehicle speed variable in urban areas and establish its distribution in places with complicated traffic conditions, namely, at (i) narrow carriageways and (ii) zones before the stop-line of signalized intersections [6].

The first step in this study should be the hypothesizing of the type of speed distribution for these conditions. The places of the first type usually only decrease the speed. To adequately measure the speed affected by corresponding complications, it should be done outside the influence zones of intersections, pedestrian crossings, public transport stops, etc. As for vehicle speed measurements before the stop line, it is worth noting that vehicle full stops are possible at all signalized intersections. This causes methodological problems because in this case, it is inappropriate to measure the speed as the ratio of the distance l travelled to the travel time t – while waiting for the green, both l and t are equal to 0. Such a situation points to the need to develop a new methodology to measure the speed before the stop-line, which will allow for taking into account possible vehicle accelerations, decelerations, and full stops.

2 Literature review

Most of the present developments in the research of vehicle speed variable consists of observations of the free transport flow on intercity roads. In this case, the only speed limit is that prescribed by traffic rules, and most surveys on the mentioned roads aim to collect data on the speed, define the general speed trend, and assign rational speed range to ensure safety for drivers [7,8]. The similarity of approaches to study the speed led to the similarity of results, which testify that vehicle speed in free-flow conditions on interurban roads is normally distributed [8-10]. The general shortcoming of most of the analysed papers is the lack of statistical assessment of the correspondence between the empirical and theoretical normal distribution, but the plots shown in the papers fully indicate the similarity with the Gaussian density curve.

At the same time, there is a shortage of works devoted to vehicle speed distribution under conditions that decrease the speed compared to those that could be in the free flow. One of these works presents the results of the speed study that took place at 18 crash hotspot intersections on rural roads in Uttar Pradesh state, India [11]. The traffic was complicated by a lack of lane discipline. The authors of this study were able to fit normal, lognormal, logistic, gamma, Weibull, Burr, and extreme value (EV) distributions to the speed values for different traffic compositions.

The conditions which usually decrease the speed often occur in urban areas because of the dense traffic. For example, the paper by Dhamaniya and Chandra [12] examines vehicle speed on major urban roads in three Indian capital cities (New Delhi, Jaipur, Chandigarh) and shows the speed distribution plot which looks like normal distribution but has the left-shifted mode. These facts testify that the complication of traffic conditions as well as the urban environment change the trend in speed values specific to the free flow. Similar results are also presented in the paper by Rao A. and Rao K. [13] for the ring road in Delhi, India.

Urban traffic flows were also studied in the papers by Shi et al. [14] and Mondal & Gupta [15]. In the former paper, the gamma and Burr distribution were fitted best to the speed values recorded in Xi'an, China. Both distribution density curves have a left-shifted peak. In the latter paper, gamma, beta, Burr, and extreme value distributions appeared to be most suitable to represent the speed of vehicles at 16 signalized intersections in Delhi, Kolkata, Bhubaneswar, and Jaipur, India. The authors of this paper claim that the main reason for the deviation of the speed distribution from the normal is traffic heterogeneity. This explanation cannot be considered sufficient since many more factors influence the speed in urban conditions [15,16].

One more reason that makes drivers decrease their speed is the traffic lane (or carriageway) width insufficient for comfortable driving. This issue is purely studied in the literature, and only a few papers demonstrate that lane width influences vehicle speed, traffic accident frequency, driving behaviour, and movement trajectory [17,18].

The summary of the reviewed literature is presented in Table 1.

Table 1 The results of vehicle speed studies in different traffic conditions

Authors	Place of study	Speed distribution type
Hashim [8], Vadeby and Forsman [10]	intercity roads	normal
RSA [9]	rural roads	normal
Shuo et al. [18]	driving simulator	normal
Sarkar and Kumar [11]	intersections on rural roads	normal, lognormal, logistic, gamma, Weibull, Burr, EV
Rao A. and Rao K. [13]	urban arterial (ring road)	normal
Dhamaniya and Chandra [12]	urban arterials	normal (left-shifted mode)
Shi et al. [14]	urban roads	lognormal, gamma, Burr
Mondal and Gupta [15]	urban signalised intersections	lognormal, gamma, beta, Burr, EV

This table clearly shows the trend for the shift of the speed modal values to the left with the complication of traffic conditions particularly that specific to urban environment. Also, it should be noted that we have not found a clear explanation for this trend in available literature including those devoted to the concept of a fundamental diagram of traffic flow [19,20].

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The existence of different traffic conditions that complicate driving and decrease speed raises the task of developing the methodology for speed research considering the revealed trends in the speed values and the specificity of the mentioned conditions. The need for this methodology is premised upon the fact that most of the existing researches contain the measurements of the "instantaneous" speed on the road section chosen according to different manuals, most of which recommend avoiding influence zones of signalized and non-signalized intersections, pedestrian crossings, and other objects causing vehicle acceleration or deceleration. It is clear that these recommendations cannot be implemented in cities, especially in their downtowns with numerous signalized intersections.

Apart from that, the mentioned measurements were made using radars, LiDARs, microwave, acoustic, magnetic, and infrared sensors, pneumatic road tubes, inductive loops, video recording, etc. [1,21]. All these devices measure the speed over some time (like radars) or at some distance (like pneumatic road tubes). This way of measurement is not applicable for the places before signalized intersections in urban areas, because vehicle speed at these places can be equal to 0 for some time due to waiting for the green. So, it requires searching for how to consider this time during the speed survey.

Also, the important thing here is that in urban transport system modelling, the "travel speed" or "journey speed" is significantly more valuable than the instantaneous speed. During the calculation of travel or journey speed, it is necessary to consider that *l* and *t* are determined not by a measuring device, but by the road users. They are also dependent on traffic management measures, city logistics, traffic conditions, and the personal perception of drivers. These issues are of little attention in the existing studies on speed distribution.

Summarising the analysed literature, it can be concluded that there is a need for both developing a new methodology to measure the speed in urban networks concerning possible vehicle speed decrease or full stop as well as to properly apply a goodness-of-fit test when fitting the distribution to the recorded speed values.

3 Methodology

3.1 Hypotheses about speed distribution affected by urban traffic conditions

A prerequisite for hypothesising the type of vehicle speed distribution under urban traffic conditions is the probable change in the free-flow speed distribution curve conditioned by the decrease in average speed.

Since the speed variable is non-negative, the minimum speed value is 0. If a mean speed is $v \gg 0$, which is typical for the free flow, the left tail of the normal distribution $[-\infty;0)$ has a very low probability $F_0 \approx 0$. The question here is what change will be in the free-flow speed distribution curve in case of a considerable average speed decrease?

If the normal distribution is suggested for representing the vehicle speed, a decrease in the mean should cause a heavy negative tail, Figure 1. This tale is impossible due to the speed domain ($v \geq 0$). At that, the right tail remains valid, and it looks like the exponential distribution curve. Therefore, it is reasonable to suppose that the result of the average speed decrease will be the change of the normal distribution curve to an exponential one. A gamma distribution can be considered an intermediate point in this process because:

- gamma distribution with the shape parameter $g = 1$ is exponential distribution;

- gamma distribution approaches normal distribution when the shape parameter $g \to \infty$.

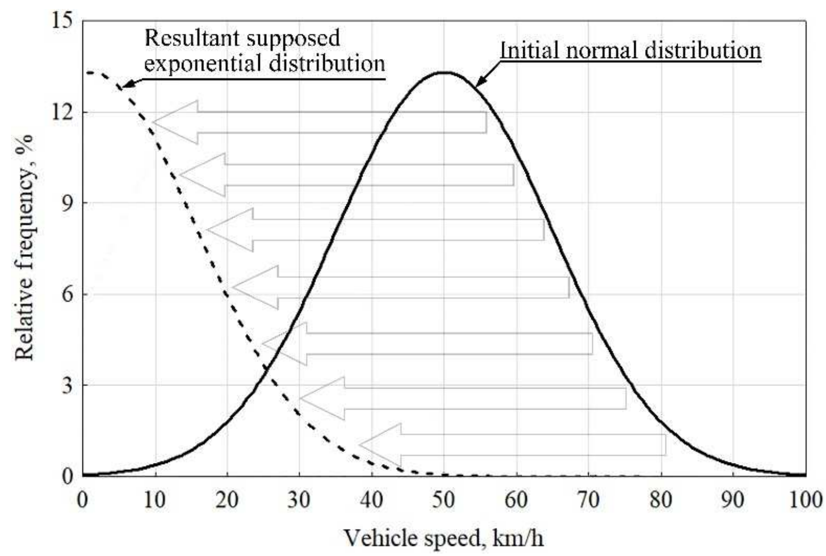

Figure 1 Supposed result of the decrease in the mean of the normally distributed speed

According to these prerequisites, the complication of traffic conditions should cause a decrease in average speed and, consequently, decrease the gamma distribution shape parameter bringing it closer to 1, i.e., to the exponential distribution. The reverse statement is also true.

Since the carriageway narrowing does not cause extremely complicated traffic conditions because it rarely forces drivers to stop a vehicle, the hypothesis about gamma-distributed vehicle speed at the narrow carriageway looks grounded.

Traffic conditions before the stop line are more complicated compared to those at a narrow carriageway, because a certain share of drivers must stop and wait for the green. It allows for further testing of the hypothesis in the conditions which should lead to an additional decrease in the gamma distribution shape parameter g.

Since g is the squared ratio of the average speed $\overline{v}$ to the standard deviation σ, i.e., $g=\left(\overline{v}/\sigma\right)^2$, to estimate it for different traffic conditions, it is necessary to estimate the main moments of the speed variable.

Compared to the narrow carriageway, the signalized intersection will make a certain share of speed values very close to 0 because of situations when vehicles arrive at the intersection on red, stop at the stop-line, and wait for the green. At the same time, the conditions for driving through the intersection on the green are complicated only by other road users, so the speed survey will also show rather high speeds. This should lead to a significant increase in the speed standard deviation compared to the situation of the narrow carriageway. So, there are no reasons to expect considerable changes in the average speed since the range of the speed extends due to the shift of both bounds. These considerations allow supposing that during the survey of vehicle speed before the stop-line, it is reasonable to expect a decrease in the gamma distribution shape parameter compared to that one for the narrow carriageway because of an increase in the standard deviation of sampled speeds.

3.2 Approach to measure the speed

It can be certainly stated that the use of instantaneous speed to evaluate traffic conditions had arisen as the simplest solution obtained by researchers in the effort to characterize a specific road section – there is no need to specify the distance at which the speed is measured, it is only necessary to implement recommendations of the most manuals mentioned in the literature review.

Such conditions cannot be met at the influence zones of signalized intersections. When calculating the vehicle speed before the stop-line of a signalized intersection, both the distance l travelled and the travel time t can be equal to 0 due to the situations when certain vehicles wait for the green. To address this issue, it is necessary to develop a special methodology for speed measurement.

To calculate speed using the ratio of l to t, it is necessary to specify a distance and measure the passing time, or specify a time span and then measure the distance passed. Specifying a constant time span for measuring the vehicle position in the zone before the stop-line is not suitable because of the wide range of speed values – any constant time span will lead to either omission of a part of the vehicles during measurement or multiple estimations of the position of the same vehicle. Specifying a road segment of a constant length will also result in unclear situations caused by the random distance between the places where vehicles stop at the stop line. To solve these problems, we came to the conclusion that it is reasonable to take the vehicle dimension as the distance for which the passing time is measured.

The proposed methodology for speed measurement is as follows:

- a researcher assigns the road cross-section for the speed measurement;
- during the observation of traffic flow, it is necessary to record two points of time - when the assigned cross-section is crossed by the front and rear points of each vehicle;
- it is necessary to record a vehicle’s length - the distance between the mentioned points;
- in the absence of special tools, the best way to make such measurements is to make a video record of traffic and process it.

To measure the speed, the cross-section before the stop-line should be assigned in a way that when waiting for the green, the body of the front vehicle in a queue should be within the cross-section. Then the waiting time will be taken into account in speed calculation, which is obligatory to assess the impact of signalized intersection.

To avoid uncertainties with the mode of estimated speed distribution, the speed survey should focus on vehicles of similar technical parameters. For this reason, during the survey, it is reasonable to cover the vehicles permitted for movement in city centres, most of which are cars. Considering the common lengths of the cars, it is reasonable to assign the cross-section at 1.5 m before the stop-line. The final aim of the listed measurements at a desired cross-section is to determine the average speed with which a car passes a distance equal to a car’s length. From here on, this average speed will be referred to simply as ‘speed’.

The feature and the advantage of the proposed methodology is the opportunity to assign the road cross-section for the speed measurements, which is not available in any existing approach and allows for avoiding difficulties with the situations when vehicles wait before the intersection as well as ensuring the comparability of the speed values measured in all considered urban traffic conditions. That is why this methodology was preferred for speed studies presented below.

4 Results and discussion

4.1 Vehicle speed at a narrow carriageway

The speed influenced by the narrow carriageway was studied in Kharkiv, Ukraine. This study is presented in detail in the paper by Horbachov et al. [22]. The main points which had conditioned the choice of the narrow section for speed observation were as follows:

- the considered section of Yaroslava Mudroho St. (Figure 2) is free of public transport;
- the section is outside the zones influenced by intersections that allow drivers to go faster before and after the narrowing;
- during the observation, the section had one traffic lane in each direction because of car parking in the right lanes, and there was the heavy snowfall that significantly narrowed the carriageway (up to 5.45 m for oncoming traffic flows) and caused the “bottleneck”. These conditions made it possible to study the drivers’ response to the carriageway narrowing and excluded their habituation to the lane width.

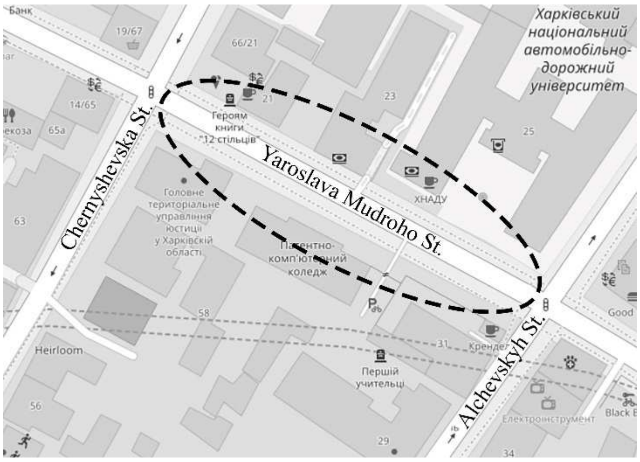

Figure 2 The segment of Yaroslava Mudroho St. (Kharkiv, Ukraine) selected for the study of speed influenced by the narrow carriageway

The traffic on the considered street section was filmed from 8:30 a.m. to 10:16 a.m. and then processed. Here, it is appropriate to show the final result of the speed survey with the statistical estimation of fitting the theoretical distributions – gamma and normal – to the empirical one. The video processing results are presented in Table 2. The results of fitting the distributions are shown in Figure 3.

Table 2 Speed statistics at the narrow carriageway section of Yaroslava Mudroho St. in Kharkiv (retrieved from [22])

No. of observations	-	216
Speed ($m \cdot s^{-1}$)	min	1.32
	max	12.50
	ave	5.99
	std. dev.	2.32
Gamma distribution parameters	scale	0.899
	shape	6.666

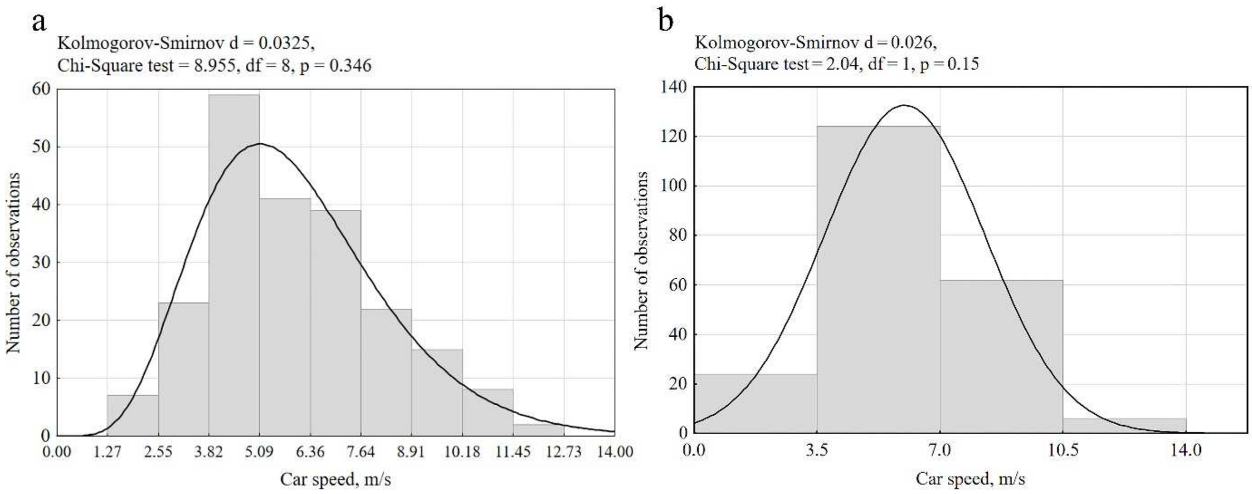

Figure 3 The distributions fitted to the values of speed influenced by the narrow carriageway: (a) Gamma; (b) Normal (retrieved from [22])

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The Kolmogorov-Smirnov and χ^2 test indicated a positive result in fitting the gamma distribution to the speed values recorded at the narrow carriageway section (Figure 3a). The normal distribution was fitted to the recorded speed values at the minimum sufficient number of bins (Figure 3b), which makes this result not so convincing but supports the connection between gamma and normal distribution considered at the beginning of subsection 3.2. These findings confirm the tangible impact of the traffic lane (carriageway) width on the vehicle speed variable [22].

The results obtained in the paper [22] correspond to the hypothesis of gamma-distributed vehicle speed variable but give insufficient data to anticipate the speed distribution type under more complicated urban traffic conditions.

4.2 Vehicle speed influenced by traffic signalling

The study of vehicle speed influenced by traffic signalling also requires choosing an intersection for observation. The key factor in making this choice is the possibility of video recording in conditions specified in subsection 3.3 - the camera should record the traffic passing through the cross-section 1.5 m before the stop-line. The opportunity to meet these conditions was found at the intersection of Yaroslava Mudroho Str. and Alchevskyh Str., namely, at the approach from Chernyshevska St. (Kharkiv, Ukraine), Figure 4a.

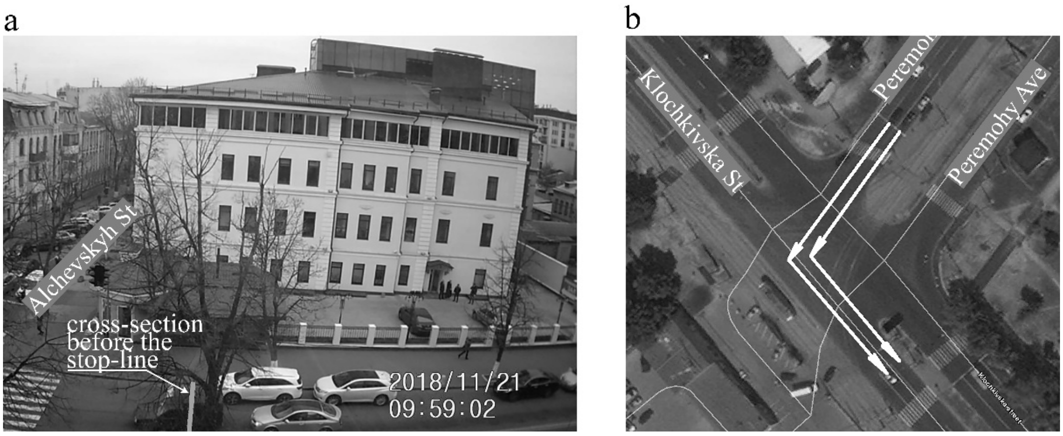

Figure 4 The approaches to the intersections selected for the speed study:
(a) the section of Yaroslava Mudroho; (b) the section of Peremohy Avenue

The cycle time at the intersection is 60 s, and the green time for the traffic direction under observation (in Figure 4a - from right to left) is 20 s. The observation was carried out on 21 Nov. 2018 for three hours, from 8:15 a.m. to 11:15 a.m. The recorded video was processed according to the methodology proposed in subsection 3.3. The processing results are presented in Table 3.

Table 3 Speed statistics for the zone before the stop-line at the approach to Alchevskyh Str. in Kharkiv

No. of observations	-	403
Speed ($m \cdot s^{-1}$)	min	0.07
	max	19.12
	ave	5.30
	std. dev.	4.94
Gamma distribution parameters	scale	4.602
	shape	1.152

This table shows that at the given signalized intersection, the speed has decreased compared to the speed at the narrow carriageway observed before. The standard deviation has increased more than twice which can be explained by a noticeable extension of the speed range. Major changes in the main moments of the speed variable have led to a significant change in the gamma distribution parameters - the scale parameter has grown significantly along with the significant decrease in the shape parameter that has approached 1.

The gamma distribution was fitted to the recorded speed values, Figure 5a, and the goodness of fit was evaluated using the Kolmogorov-Smirnov criterion. The evaluation allowed for the conclusion that the hypothesis of the possibility of describing the speed influenced by traffic signalling with the gamma distribution cannot be rejected because of achieving the acceptable 15-percent significance level of the used criterion. The Pearson criterion was not applicable in this case. This result can be considered preliminarily positive taking into account the significance level of the Kolmogorov-Smirnov criterion (less than 20%) and interpreted as a one-time non-rejection of the hypothesis that should not be considered as confirmation.

The proximity of the gamma distribution shape parameter to 1 makes it reasonable to test the hypothesis of the exponential distribution of the speed variable, Figure 5b. In this case, the significance level of the Kolmogorov-Smirnov criterion has decreased to less than 15%.

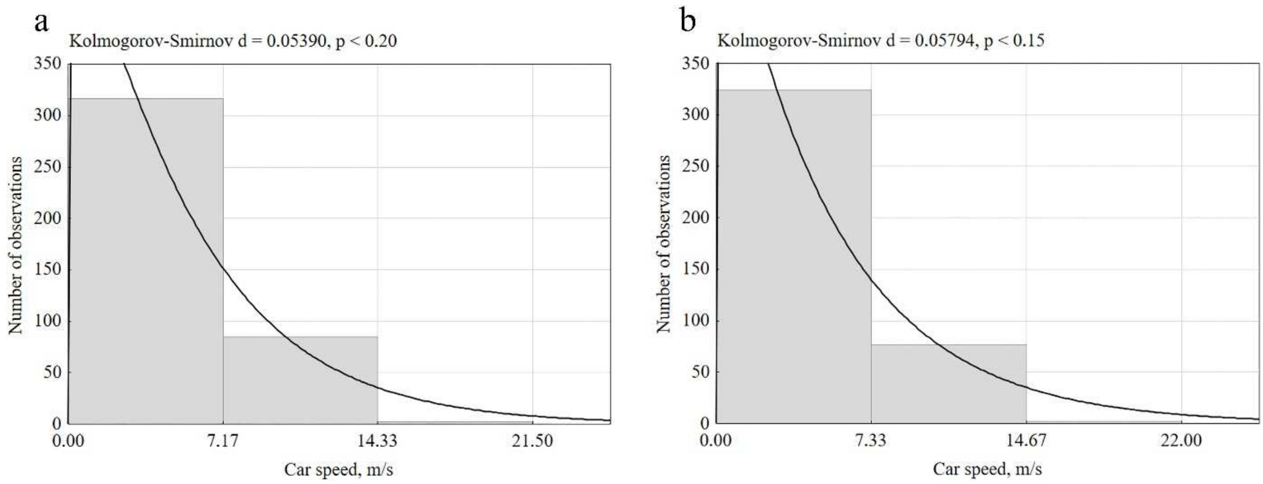

Figure 5 The distributions fitted to the values of speed influenced by traffic signalling at the approach to Alchevskyh Str. in Kharkiv: (a) Gamma; (b) Exponential

Consequently, it appeared reasonable to continue the research under conditions even more complicated in terms of speed. This research allowed for further testing of the hypothesis of the suitability of the use of gamma distribution to describe vehicle speed under various urban traffic conditions and define the relationship between traffic conditions and the gamma distribution shape parameter.

Traffic conditions complicated more than the above-described can occur before the stop-line at the approach to a signalized intersection where both a green time and its share in the cycle are even less. This complication can be observed at the secondary approach to a signalized intersection with a long cycle time. The conditions of this type are specific to the approach of Peremohy Avenue to Klochkivska St. in Kharkiv. At this approach, there exist two lanes and the left-turn phase, Figure 4b. The intersection has a large area and good road surface that allows driving in almost free conditions after the start from the stop-line. Therefore, these conditions can be considered similar to the conditions in the previous observation of the car speed before the stop-line. At the same time, the cycle time and the green time for the selected approach, which are 90 s and 16 s correspondingly, differ significantly from those in the previous case – 60 s and 20 s respectively. The green time for the selected traffic direction is not extremely short and equals 16 s which is 20% less than at the previous intersection. But the green share in the cycle time has decreased almost twice – from 33.3% to 17.8%. It justifies the observations at the intersection of Peremohy Ave and Klochkivska St, as it will extend the speed range that characterizes urban traffic conditions. The observation at this intersection was carried out for one hour on the weekday - Friday, 10 January 2020 - using video recording of the traffic passing the cross-section before the intersection stop-line. As a result of video processing, 260 values of car speed in more complicated traffic conditions were obtained, Table 4.

Table 4 Speed statistics for the zone before the stop-line at the approach to Klochkivska Str. in Kharkiv

No. of observations	-	260
Speed ($m \cdot s^{-1}$)	min	0.03
	max	11.50
	ave	2.423
	std. dev.	3.005
Gamma distribution parameters	scale	3.719
	shape	0.651

The data in Table 4 are consistent with the hypothesis that a decrease in average speed leads to an increase in speed standard deviation, which decreases the gamma distribution shape parameter. Compared to the previous observation, the average speed has decreased from 5.30 $m \cdot s^{-1}$ to 2.42 $m \cdot s^{-1}$, i.e. 2.2 times, and the standard deviation has decreased from 4.94 $m \cdot s^{-1}$ to 3.00 $m \cdot s^{-1}$, i.e. 1.45 times. At the same time, the ratio of the average speed to the standard deviation has resulted in the gamma distribution shape parameter taking a value that is very close to 1.

The results of fitting the distribution with this parameter have convincingly indicated the suitability of gamma distribution to describe the car speed, Figure 6a. The scale and the shape parameter have taken the values 3.011 and 1.005, respectively. At these parameters, the mean of the fitted gamma distribution approximately equals the standard deviation, and both moments are close to the value of the scale parameter. The gamma distribution shape parameter close to 1 indicates the possibility of describing the observed car speed distribution by the exponential one that was confirmed by the appropriate tests, Figure 6b. These results fully confirm the hypothesis of the gamma-distributed vehicle speed in urban traffic conditions.

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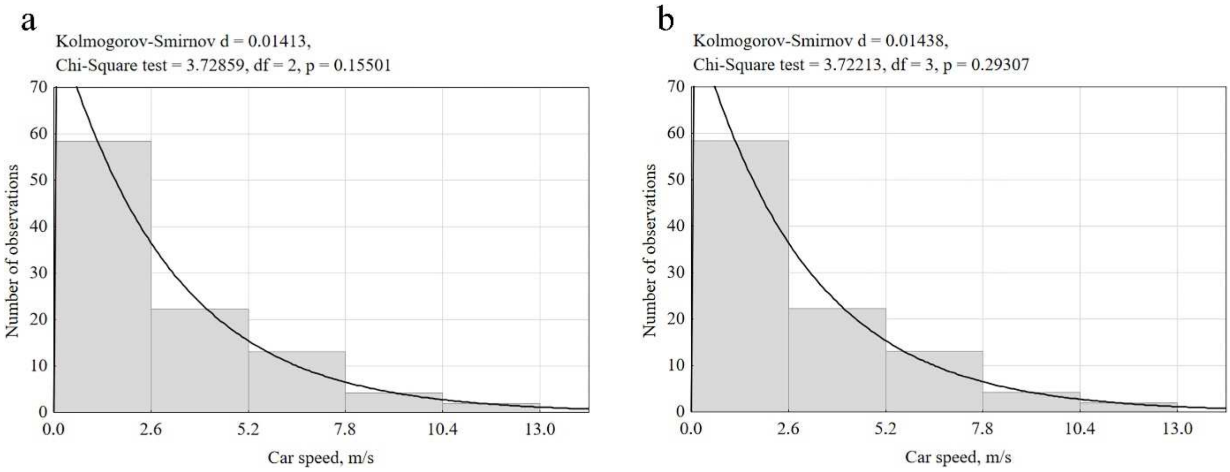

Figure 6 The distributions fitted to the values of speed influenced by traffic signalling at the approach to Klochkivska St. in Kharkiv: (a) Gamma; (b) Exponential

It is necessary to point out that in up-to-date literature, there is a lack of results similar to those presented above. Also, there are no convincing explanations for the revealed changes in the speed distribution type caused by an urban environment.

The way that can help to explain these changes is the study of the speed in the conditions that make driving even more complicated in terms of speed. These conditions can be found on the network links with limited overtaking opportunities and only one lane available for movement. A speed study of this type will deepen the knowledge about speed distribution in urban areas and allow for better clarification of the regularities reflected by the fundamental diagrams of traffic flow.

5 Conclusions

The research on the speed in places which are usual for urban areas and complicate traffic conditions in terms of speed – narrow carriageways and the zones before the stop-lines of signalized intersections – has discovered the change of normally distributed free-flow speed to exponentially distributed. The gamma distribution was considered the intermediate point in this change because of its relationships with the mentioned distributions.

To research the vehicle speed influenced by signalized intersections, the speed measurement methodology was proposed. According to the methodology, to obtain the speed value, the length of the moving vehicle should be taken as the distance for which the passing time is measured. This methodology ensures sufficient measurement accuracy, avoids restrictions on the choice of the place for observation without losing comparability of results, as well as provides a researcher with the possibility to verify them.

During the research, it was found that the gamma distribution shape parameter decreases with the complication of traffic conditions. It was confirmed by the following: at a narrow carriageway, which does not cause the most complicated traffic conditions, gamma distribution was suitable to describe the car speed; at a signalized intersection, which causes a noticeable complication of traffic conditions, exponential distribution appeared to be suitable to represent the speed variable. The reason for this change in speed distribution type is a steady decrease in average speed and an increase in speed standard deviation with the complication of traffic conditions.

The results obtained in this paper are sufficient to conclude that (i) gamma distribution is suitable to represent the vehicle speed variable influenced by urban traffic conditions and (ii) the discovered background for the changes of speed distribution type is fully appropriate for dealing with real-world issues related to the traffic management performance, city logistics, and urban transport planning.

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Conflict of interest
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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A business continuity-based framework for risk management in smart supply chains: a fuzzy multi-criteria decision-making approach

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Keywords: smart supply chains, business continuity, risk management, fuzzy risk assessment, multi-criteria decision making.

Abstract: The aim of this study is to develop a novel framework for managing risks in smart supply chains by enhancing business continuity and resilience against potential disruptions. This research addresses the growing uncertainty in supply chain environments, driven by both natural phenomena-such as pandemics and earthquakes—and human-induced events, including wars, political upheavals, and societal transformations. Recognizing that traditional risk management approaches are insufficient in such dynamic contexts, the study proposes an adaptive framework that integrates proactive and remedial measures for effective risk mitigation. A fuzzy risk matrix is employed to assess and analyze uncertainties, facilitating the identification of disruptive events and the selection of appropriate risk treatment plans. Moreover, the framework leverages a fuzzy reasoning system in conjunction with a multi-criteria decision-making method to process ambiguous information, thereby enhancing decision accuracy and reliability. The findings demonstrate that this comprehensive approach not only prioritizes risks effectively but also supports companies in refining their response strategies, ensuring the efficient delivery of services under challenging conditions. Ultimately, the study redefines resilience as a dynamic process of navigating and adapting to chaos rather than merely resisting it.

1 Introduction

Any unfavorable element that prevents companies from achieving their strategic, financial, or operational goals can be described as a risk. In this regard, the risk for profit-driven companies is a potential source of company losses [1,2]. Supply Chains (SCs) are becoming more vulnerable to disruptive events, putting all stakeholders at risk. For the supply chain to be robust, sustainable, and aligned with corporate goals, managing these risks and mitigating their consequences is essential. The uncertainties and risks involved in supply chain operations have increased because of the new reality and configuration of the supply chain [3]. Business Impact Analysis (BIA) and risk assessment are key elements of BCS, both of which look to find and rank the most important organizational resources. I have recently referred to this idea as Business Continuity (BC), i.e., the ability of the organization to support the supply of products and services within reasonable times with predefined capacity during an interruption (Schmid et al., 2021).

Smart technologies and recent advances in technology, as well as the emergence of big data technologies, have led to the emergence of the so-called Smart Supply Chain (SSC [4] . An interconnected network system optimizes the flow of information between physical infrastructure and cyberspace in smart factories and Industry 4.0. With the help of advanced data management and analytics tools, we expect the entire system to function optimally with the help of the smart supply chain [5]. A smart supply chain enhances competitive advantage in speed, flexibility, risk reduction, cost reduction, and storage control. The smart supply chain also plays a role in achieving environmental, social, and economic sustainability, and enhances the long-term performance of companies. A smart supply chain assists solve a lot of productivity and sales problems [6], as well as improved scheduling processes [7] which achieve customer satisfaction [8].

Risk assessment is one of the key stages in risk management, where managers and system developers can respond appropriately to various risks by assessing the potential threats and risks faced by the smart supply chain. Therefore, BC provides many risks treatment programs [9]. Risk assessment entails decisions about the acceptance of risks according to established criteria, while risk analysis involves the systematic use of information available to find risks. Risk assessment refers to the complete procedure of risk analysis and assessment [10]. The logical method of risk assessment is risk evaluation, which considers the potential effects of potential accidents on people, materials, goods, equipment, and the environment [11]. It is difficult for companies to make a final and exact decision about the level of risk and its consequences that sabotage their supply chains, which are considered one of their most essential capabilities. Thus, a wide range of methods is available for addressing fuzzy information through the utilization of fuzzy numbers, and these methods can likewise be extended to the analysis of fuzzy data obtained from experts., many papers have previously used fuzzy logic and the FMCDM approach to assess risk [9]. In the same context, the proposed framework is based on assessing the risks faced by the smart supply chain and proposing proper treatment plans according to the impact and consequences of the risk. It is worth mentioning that BC inspires the risk assessment process and treatment plans. The FBWM algorithm and the Fuzzy Inference System (FIS) are applied to process fuzzy information at the risk analysis stage.

In the first phase of the proposed Smart Supply Chain Risk (SSCR) framework, the researchers conducted a comprehensive survey of the earlier literature and consulted with experts to find the Main risk factors and sub-risk factors. In this way, we found the main SSCRs, which consist of information systems, reliability and integration, infrastructure, operational issues, the environment, and service risks. As for the second stage, the risks are analyzed and consist of two steps. In the first step, weight is decided by each risk according to the opinion of experts. In the second stage, two questionnaires are prepared. The first questionnaire consists of two axes: the vertical axis has risk factors, while the horizontal axis has risk impact, and it does this through the linguistic terms of TFNs. In addition, a list of risk impact factors that have disruptive effects on the company's performance is decided. As for the second questionnaire, it also has two axes, and it aims to show the relationship between risk factors and their consequences. The above stages are considered inputs to the third stage, as in this stage the risks whose impact and consequences on the supply chain have been calculated. At this stage, the fuzzy risk assessment matrix is applied, which consists of three different points of view (soft, standard, and hard) given by [12], based on this, the appropriate program is determined for each category of risks to which the SSC is exposed. BC inspires treatment plans. These plans consist of four programs: the first (accepted), the second (Mitigate), the third (stop), and the last (business continuity). Based on the above stages, a model of the proposed framework is prepared. The following is an outline of the proposed framework's main contributions.

2 Literature review

2.1 Smart supply chain

Since there is no widely agreed-upon definition of terms like "digital supply chain," "smart supply chain," "industrial internet," and "supply chain 4.0," all of which are closely related to the idea of industrial advancement through technological innovations, general descriptions are hard to fathom. What distinguishes the traditional supply chain from the smart supply chain is its reliance on the information network as the basis for information transfer [13]. Its purpose is to share information and highly integrate the information flow with each part of the supply chain, thus improving response time and product quality, reducing resource consumption, and increasing the company's ability to make quick and correct decisions [14]. On the other hand, supply chains are now more vulnerable to shocks and disruptions because of their increasing globalization and interdependence. No company is immune as supply chains grow more intertwined. Supply chains must become smarter to effectively manage risks and achieve company goals [15].

SSC is gradually becoming a key strategy to promote sustainable development [16], due to its feasibility in achieving economic, environmental, and social benefits [17], as well as to be able to face challenges [13]. By exchanging data in real-time, the underlying technologies help with faster selections and transactions. These enable cross-functional technologies such as the Internet of things, cloud computing, big data analytics, artificial intelligence, and blockchain. [18], as well as cloud computing and RFID systems [19]. A pivotal role in the shift towards the smart supply chain. A digital platform that connects all components in the supply chain enables flexibility, traceability, and visibility in a smart supply chain. We have found that SSC offers new insights and characteristics compared to traditional supply chains [17].

A smart supply chain has many financial, environmental, regulatory, and social challenges [20] The most prominent of which is the high cost of smart devices, particularly RFID, as the design and pricing of software and smart operation systems for the process are the main obstacles to the smart supply chain [19]. On the other hand, a smart supply chain needs regular attention and significant financial investment. In addition, the team will need to move towards more advanced technology applications, and this may require redefining the team [21]. Improved collaboration among supply chain participants has been shown to reduce overall costs and improve delivery service. Furthermore, [22,23] discovered that the intelligent supply chain supports collaboration between consumers and the entire organization, from the distribution of completed items to the production and acquisition of raw materials to interact with suppliers of goods and services. Studies have also shown that enhanced supply chain collaboration has resulted from increased digital transformation [4]. By carefully regulating the flow of suppliers, the idea of a smart supply chain performs the entire logistical chain from supplier to customer, no matter where they are located [24], On the other hand, a smart supply chain brings great benefits to the manufacturer [25]. It assists them implement smart manufacturing [5].

2.2 Smart supply chain risk and business continuity

Smart Supply Chain Risk (SSCR) refers to the process of creating a strategy and working to find, assess, and mitigate risks in the entire supply chain. Supply chain risk management is the second-biggest concern of any company's executives [15], For this reason, there are various methodologies adopted in the assessment and analysis of risks, such as the Failure Mode and Effects Analysis (FMEA) methodology [11], and ARAMIS methodology, which is used to meet the requirements of SEVESO II [26]. It should be noted that BC is part of the Risk Treatment Plans (RTPs) that companies adopt to face operational risks (i.e., risks that have a minimal impact but have high consequences for the critical activities of the organization). Someone proactively provides these plans to recover and resume disrupted activities post-disruption [9]. On this basis, BC is described as a strategic and comprehensive management process that relies on risk management techniques, identifies the risks to which the organization is exposed, which result from natural or man-made disasters, and provides alternative responses to the impact of such disasters that can enable organizations to deal effectively with a crisis with minimal disruption to their basic operations [27].

In the past ten years, organizations have become more aware that not being prepared to deal with disruptive situations can have disastrous results. Business Continuity Management (BCM) is a new strategy to mitigate these disruptive risks [28]. BC refers to the advanced planning and preparation made to guarantee that a company's critical business functions can function normally in an emergency [29]. Emergencies include things like pandemics, corporate crises, natural catastrophes, workplace crimes, and other incidents that stop regular company operations [30,31]. In this paper, the risks of the smart supply chain are found and analyzed to select treatment plans according to the impact of the risks and their consequences (Figure 1). It conducted this through a framework inspired by BC.

Organizations all around the world are increasingly aware of how important it is to create BC strategies [32]. Regardless of the business model, firms are working in a more complicated, dangerous, and global environment [33]. Events relating to the economy, society, politics, technology, and the environment may interfere with fundamental operations [34]. Growth and performance can be significantly affected by natural disasters, illnesses, terrorist attacks, strikes, financial crises, unreliable systems, logistical breakdowns, supply chain failures, and unanticipated shortages of key manufacturing inputs [35]. A goal should be the creation of established plans that consider the risk assessment of business interruption, the definition of strategic and tactical plans, initiative-taking management, and response readiness [36].

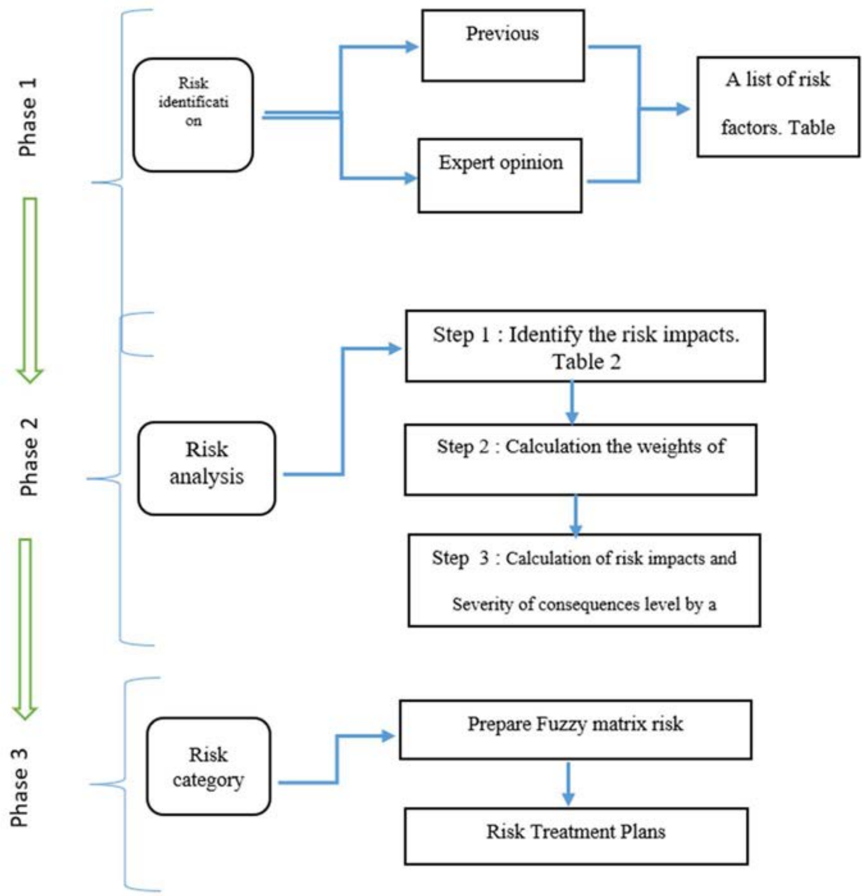

Figure 1 The response to (SSCR) inspired BC

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3 The proposed framework: preparing the fuzzy risk matrix

3.1 Risk identification

The smart supply chain faces various risks, so the first phase will be to show those risks (see Table 1), to include them in the proposed framework. We relied on earlier research papers to identify these risks, as well as the opinions of experts obtained through conducting many field interviews. The output will be a list of Main risk factors and sub-risks.

3.2 Risk analysis

After finding the risks facing the smart supply chain shown in Table 1 in the first stage, we analyze them in the second stage. This process requires three steps:

Identify the risk's impact: The impact of risks is determined by reviewing the relevant literature and expert opinions (see Table 2). It is worth noting that these factors may vary according to the organization's policies and capabilities, which are used to estimate the overall impact of risks [9].

Calculation of the weights of risk impact factors: In this step, the impact weights are calculated for each of the risks included in the list (see Table 4). In this regard, the method of [37], is applied, as is the consistency ratio calculated for each risk profile using the Fuzzy Best-Worst Method (FBWM) [38].

Calculation of risk impacts and severity of consequences: A questionnaire was prepared to collect expert opinions on the impact of each risk and the Severity of consequences. Therefore, the linguistic terms (TFNs) were prepared in Table 3. Due to the lack of correct quantitative data, this paper uses terminology to deal with uncertainties due to the lack of knowledge that experts have about providing correct parameters [39].

Table 1 Main and sub-risk factors

Main risk	Symbol	Sub-risk (SR)	References
Information Technology Risks	SR1	Security and system integrity	[20] [14]
	SR2	Complexity and collaborative risk across the chain	[20] [14]
	SR3	Unavailability of blockchain tools	[20]
	SR4	Database	[9]
	SR5	The risk of security breaches	
Reliability and integration	SR6	Cooperation	
	SR7	Control	[14]
	SR8	Transparency	New
	SR9	Sustainability	New
Infrastructure	SR10	Business Smart Support is weak	[14] [20]
	SR11	Network infrastructure failures or errors	
	SR12	Technology limitations	[20]
Operational issues	SR13	Lack of training for staff System documentation	[40]
	SR14	Not systematically managed	
	SR15	Inventory levels are unstable	New
	SR16	Operating costs	New
	SR17	Low predictability of supply and demand	(Omar F. Hassan Al-obaidy, 2023)
Environmental	SR18	Increased weste	[46]
	SR19	Water damage at the server	
	SR20	Lightning attacks Earthquake	
Service risks	SR21	Customer satisfaction	[14]
	SR22	Delay in providing the service	New

Table 2 Risk impact typer factors

Risk impact (RI)	References
Fragility of the supply chain. RI1	[41]
Difficulties in increasing production capacity. RI2	[41]
Difficulty maintaining a smooth flow of raw materials. RI3	(Omar F. Hassan Al-Obaidy, 2023)
Flexibility losses. RI4	[9]
Financial losses. RI5	[9]
Reputation losses. RI6	[9]
loss of cooperation. RI7	Experts
Weak competitiveness. RI8	[14]
Loss of time and control. RI9	Experts
Unexpected risks appear. RI10	Experts

Table 3 Triangular fuzzy numbers (TFN) Linguistic terms of FR and SC and RC

Risk impact		Severity consequences SC		Risk category RC	
Very high (VL)	(1,1,2)	Negligible (N)	(0,0,1)	Acceptable (A)	(0,0,0.5)
High (H)	(1,2,3)	Low (L)	(0,1,2)	Tolerable–acceptable (TA)	(0,0.4,0.7)
Moderate (M)	(2,3,4)	Moderate (M)	(1,2,3)	Tolerable–unacceptable (TU)	(0.5,0.7,0.9)
Low (L)	(3,4,5)	High (H)	(2,3,4)	Unacceptable (UN)	(0.85,1,1.3)
Very low (VL)	(4,5,6)	Catastrophic (C)	(3,4,5)		
Unlikely (U)	(5,6,7)				
Remote (R)	(6,7,7)				

The main and sub-risks constitute the cornerstone of this paper, so classifying these risks into main and sub-risks is due to the nature of the risk itself, as few research papers give a comprehensive classification of the risks of the smart supply chain, some of which focus on a specific company or a specific sector, such as [14] or the paper [20] that addressed barriers to implementing Blockchain in reverse logistics. In this sense, many of the classifications in Table 1 refer to the opinions of experts in showing some sub-risks. The current study focuses on identifying those risks that affect the organization's activities and critical activities. To understand the consequences of risks if they are not considered, this study identifies several types of factors for the impact of these risks on the organization. Hence, Table 2 has prepared for this purpose.

The impact of the risks referred to in Table 2 is not final. There may be other impact factors that were not included in the current study. The inclusion of these factors was based mainly on previous literature that dealt with these effects in its content. To achieve the main aim of this paper, the factors most affecting the critical activities of the organization were relied upon, which could have catastrophic results if neglected or ignored. Therefore, the focus was on these factors as more comprehensive factors.

Two questionnaires were designed; each of these forms has two main parts. The first form consists of two axes; it is the vertical axis that includes the risks that were collected based on earlier literature and expert opinions, i.e., using the collective decision-making model, these risks are divided into main risks and sub-risks. These risks differ from one organization to another and from one country to another, according to their ability, viability, and competitive position. However, there may be other risks that are not included in the list, and this is due to the nature of the database available on the research papers available on the Internet. The second axis that the questionnaire has is the horizontal axis, which includes the impact of risks. The second form also consists of two axes: the vertical axis has risk factors, while the horizontal axis includes Severity consequences for each of the risks included in the vertical axis. The factors that are criteria for measuring severity consequences were collected through earlier literature and after presentation to experts and filtering. To calculate the weight of each risk, reliance was placed on [37].

Table 4 Risk impact weights

Risk impct (RI)	**RI_1**	**RI_2**	**RI_3**	**RI_4**	**RI_5**	**RI_6**	**RI_7**	**RI_8**	**RI_9**	**RI_{10}**
Weights	0.0952	0.1111	0.0873	0.1190	0.1587	0.1507	0.0476	0.0714	0.1031	0.0555

4 Risk category: implementing a fuzzy risk matrix

After the process of finding the risks, their impact, and the consequences of those risks, their category in terms of impact and the consequences of this impact are determined. In this step, the Fuzzy Matrix Risk (FMR) is relied upon to classify risks: acceptable (A), tolerable-acceptable (TA), tolerable-unacceptable (TU), and unacceptable (UN). Where this classification was adopted as rules for determining the category of each of these risks and their consequences. Figure (2) shows a description of all four categories and the characteristics of each category. The FRM Fuzzy Risk Matrix (FRM) is a risk assessment tool that uses fuzzy logic to assess risk impact and severity consequences. This phase is considered one of the basic steps of the BC model, so the risk assessment process depends mainly on the risk identification process as its input. Figure 3 shows the risk matrices that will be adopted in determining the relationship between the impact of risks and their consequences and the category of each of these risks. The easy matrix is the one that has a low cost, but its layers of protection are less to provide safety against risks. On the other hand, there is the Hard matrix, which has a prohibitive cost but is more secure. As for the Standard matrix, it mediates between the two and is the most used.

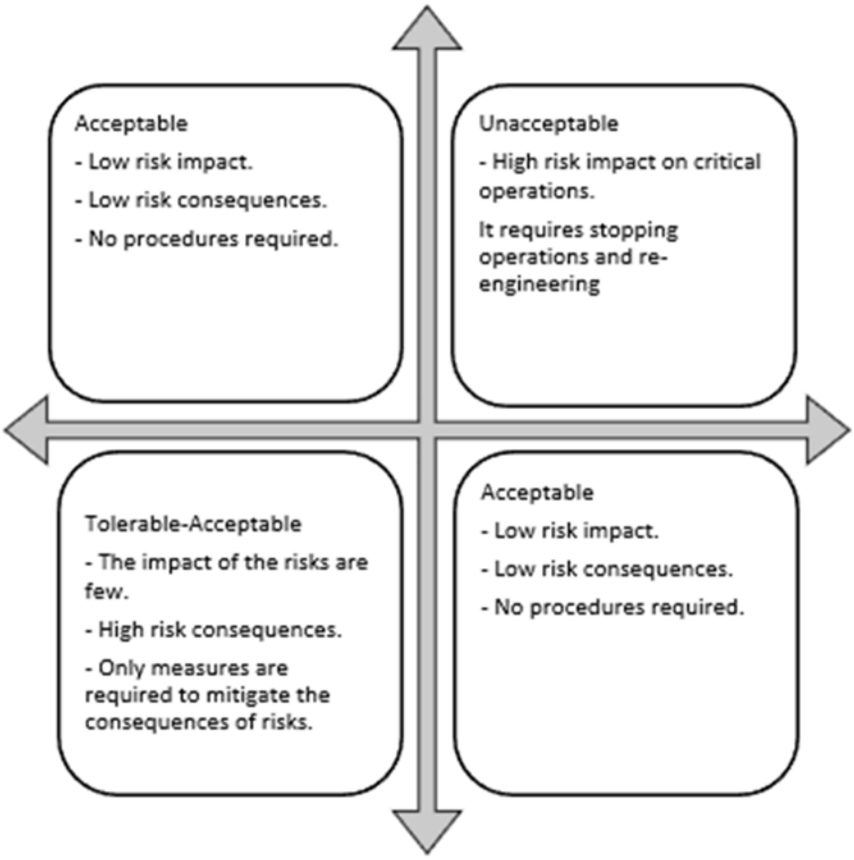

Figure 2 Characteristics of risk categories

The matrix is prepared for the purpose of determining the relationship between the impact of risks and the consequences of those risks on the critical operations of the organization. As we mentioned earlier, the risk categories are rules for defining the relationship between the impact of risk and its consequences to determine that relationship according to the rules that control that relationship. Four categories are taken into consideration for the risk scale [12]. Thus, by combining various levels of influence and consequences of influence (5 * 7 * 4), a total of 140 rules are extracted. However, only 35 of the 140 rules are accepted by experts and adopted in this paper [9].

The process of dealing with risks requires different procedures according to the category of each risk and its position in the matrix. Therefore, the main purpose of the matrices is to divide the risks into categories, determine the proper methods of dealing with each category, and identify those that require special tools, such as those provided by business continuity. [9] introduced an algorithm called Risk Treatment Plans (RTPs). This algorithm consists of four risk treatment programs according to each category:

- Acceptable: the risk impact and their consequences are low, do not require any procedures to deal with them, and are present in most organizations.
- Mitigate: Tolerable-Acceptable, meaning that risks have a low impact but high consequences. Therefore,

the organization requires measures to mitigate risks and a mixture of BC plans.

- Stop: Tolerable-Unacceptable, meaning that the impact of risks and their consequences is high, and therefore the organization needs to mitigate the risk and its consequences. If there is no treatment, the process can be stopped and re-engineered.
- Continuity plan: if the risks fall into the Unacceptable category, and thus the critical tasks of the organization are disrupted, the most proper solution is to use continuity plans to overcome such risks.

The algorithm provides the proper flexible decisions for each of the risk categories above by providing different treatments for each risk according to the matrices (easy, standard, and hard). These three matrices are used in this study according to the specified rules. These rules depend mainly on the approved inputs, which contribute to decoding the defuzzifier. To decipher this defuzzifier, the method of [42], was used. Figure 3 shows the inputs and outputs of the fuzzy data and processing it. On the other hand, the FRM is the most likely approach that is based on the total value of risk. To make the appropriate decision regarding the appropriate measures, confidence scores are calculated to determine the low, medium, and high-risk categories, while the confidence ratio is used to determine the acceptability of risks at a certain level to determine the appropriate treatments based on them [9].

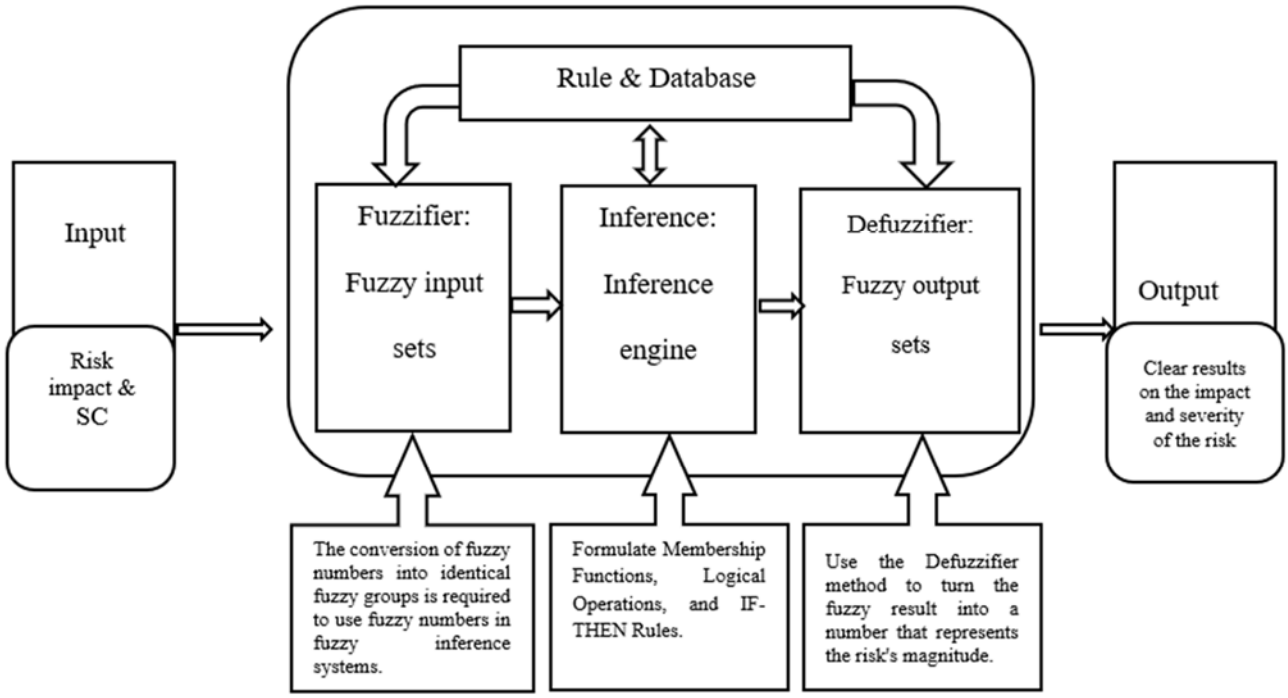

Figure 3 FIS used for constructing the SSC risk matrix

5 Results and discussion

In this section, a risk weight is calculated for each type of risk factor that was identified in the first phase. Therefore, the MCDM-enabled [38] algorithm was used for this purpose. So, acceptable, or unacceptable risks are determined according to the impact of the risks and their consequences, to determine the appropriate program and the extent to which each of these risks needs a mitigation, stop, or continuity plan. A risk weight is calculated for each type of risk factor identified in the first stage. Therefore, an algorithm that supports MCDM was used for this purpose. Thus, acceptable or unacceptable risks are determined according to the impact of the risk and its consequences. Consequently, the appropriate program is then determined and the extent to which each of these risks needs mitigation, cessation, or a continuity plan.

To measure the impact of risks and their consequences, the equations shown in Appendix 1 were used, as the impact of risks and their consequences are based on the questionnaire prepared for this purpose. It is worth noting that the impact of risk and its consequences, as well as the overall risk level, are measured using the equation used by [9], which is used to measure risk at the level of the three matrices (easy, standard, and hard). A threshold value is considered the main criterion in determining the type of program required for each risk category. Risks whose threshold value is low are considered acceptable. As for risks whose threshold value is critical, the Stop program must be approved, i.e., the risks impact and their consequences are high. On the other hand, when the impact of risks is significant on critical tasks, a program of continuity plans must be proposed. It is worth noting that some risks require merging more than one program, and this is what the threshold value determines for the impact of the risk and its consequences. The threshold value that we referred to is the difference between the impact of the risk and its consequences. In this study, a threshold value was determined for the merge, which is 18%–4%, and this means that if the difference ranges between 18%–4% according to the threshold value, then the Mitigate program can be adopted, but if the threshold value is 18%–26). Here, BC plans must be approved, and if this value is exceeded, the process requires stopping and acting. Also, the consistency ratio appeared within acceptable levels, amounting to 0.079. Whenever the consistency ratio is close to zero, it shows that there is consistency in the responses received from the experts [43]. On the other hand, Table 5 shows the necessary statistical tests, the aim of which is to ensure the reliability of the proposed framework, where the Reliability coefficient of α was measured, as well as the measurement of alpha, corrected, and correlation for each of the risk factors.

Table 5 Reliability analysis

Main risks	Sub-risk (SR)	Corrected and correlation	Alpha	Reliability coefficient of α
Information Technology Risks	SR1	0.6241	0.9014	0.8247
	SR2	0.5831	0.9102	
	SR3	0.4872	0.8724	
	SR4	0.2542	0.8724	
	SR5	0.3648	0.918	
Reliability and integration	SR6	0.5201	0.8814	0.7625
	SR7	0.6635	0.9153	
	SR8	0.4692	0.8614	
	SR9	0.6103	0.8714	
Infrastructure	SR10	0.6541	0.8913	0.7991
	SR11	0.3648	0.89471	
	SR12	0.5935	0.9075	
Operational issues	SR13	0.5671	0.9054	0.8402
	SR14	0.5534	0.8725	
	SR15	0.6203	0.8941	
	SR16	0.6154	0.9087	
	SR17	0.5107	0.8646	
Environmental	SR18	0.6482	0.8936	0.8354
	SR19	0.4725	0.8874	
	SR20	0.5032	0.9254	
Service risks	SR21	0.5165	0.9158	0.7862
	SR22	0.5948	0.8725	

To obtain weight for the impact of risks, a standard questionnaire was prepared for this purpose. The weights shown in Table 4 show the impact of each risk. It is worth noting that these weights are the opinions of the 34 experts, where experts in different companies accounted for 62%, while experts in the academic field amounted to approximately 38%. The goal of diversifying experts is to achieve a balance between practical and academic realities. As shown in Table 4, there is a discrepancy in the impact of risks on the basic functions of the company, where financial losses and reputational losses are the highest weight; in contrast, the loss of cooperation constitutes the least impact. As we mentioned before, to calculate the overall impact of risks and their consequences for the three matrices (easy, standard, and hard), Table 6 was prepared for this purpose.

Table 6 The overall risk scale

Sub-risk	Severity consequences	Impact of risk	Overall risk	Sub-risk	Severity consequences	Impact of risk	Overall risk
SR1	0.084018	0.183788	0.210467	SR12	0.262239	0.573641	0.656912
SR2	0.177808	0.38895	0.445411	SR13	0.090244	0.197405	0.226061
SR3	0.22489	0.491941	0.563352	SR14	0.271181	0.5932	0.67931
SR4	0.23192	0.507319	0.580962	SR15	0.242302	0.53003	0.60697
SR5	0.114338	0.250112	0.286419	SR16	0.198972	0.435246	0.498427
SR6	0.264799	0.579242	0.663325	SR17	0.153724	0.336267	0.38508
SR7	0.216942	0.474555	0.543442	SR18	0.119152	0.260642	0.298477
SR8	0.076856	0.16812	0.192524	SR19	0.028148	0.061572	0.07051
SR9	0.196064	0.428885	0.491143	SR20	0.027511	0.060179	0.068915
SR10	0.230256	0.503678	0.576793	SR21	0.27858	0.609386	0.697845
SR11	0.188678	0.412728	0.47264	SR22	0.24574	0.53755	0.615582

Risks that have a high impact require more time, effort, and costs, so that executives can face the consequences of these risks. The results presented in Table 6 indicate the total risks according to the easy, standard, and difficult matrix. Where the easy matrix requires less effort, time, and cost, given that it does not take the size risks proactively with important levels of preparation and therefore does not require resources at elevated levels. The hard matrix is the opposite of the easy matrix, as it requires more resources to prepare for expected risks proactively, and this is what makes it a costly matrix. On the other hand, the standard matrix is considered the most balanced, as it requires resources at medium levels, and this is what makes it the most used by companies. Deciding the type of mitigation plan depends on threshold values, and these represent the difference between the impact of the risk and its consequences. Referring to the threshold values, it becomes clear that most of the risks require a mixed plan, see Table 7. It is worth mentioning that many risks need to be re-engineered, that is, a stopping program must be adopted, given that the specified risk limits are exceeded. Some risks can be accepted, see Figure 4, and they do not need any measures, due to their minimal impact and consequences. On the other hand, there are risks whose consequences are high and their impact is low or vice versa. Therefore, such risks need mitigation measures inspired by BC plans, that is, a combination of mitigation plans and business continuity.

Table 7 Threshold values between the impact risk and severity consequences

Sub-Risk	**SR1**	**SR2**	**SR3**	**SR4**	**SR5**	**SR6**	**SR7**	**SR8**	**SR9**	**SR10**	**SR11**
Threshold Values	0.099	0.2111	0.2670	0.2753	0.1357	0.3144	0.2576	0.0912	0.2328	0.2734	0.224
Sub-Risk	**SR12**	**SR13**	**SR14**	**SR15**	**SR16**	**SR17**	**SR18**	**SR19**	**SR20**	**SR21**	**SR22**
Threshold Values	0.3114	0.1071	0.3220	0.2877	0.2362	0.1825	0.141	0.0334	0.0326	0.3308	0.291

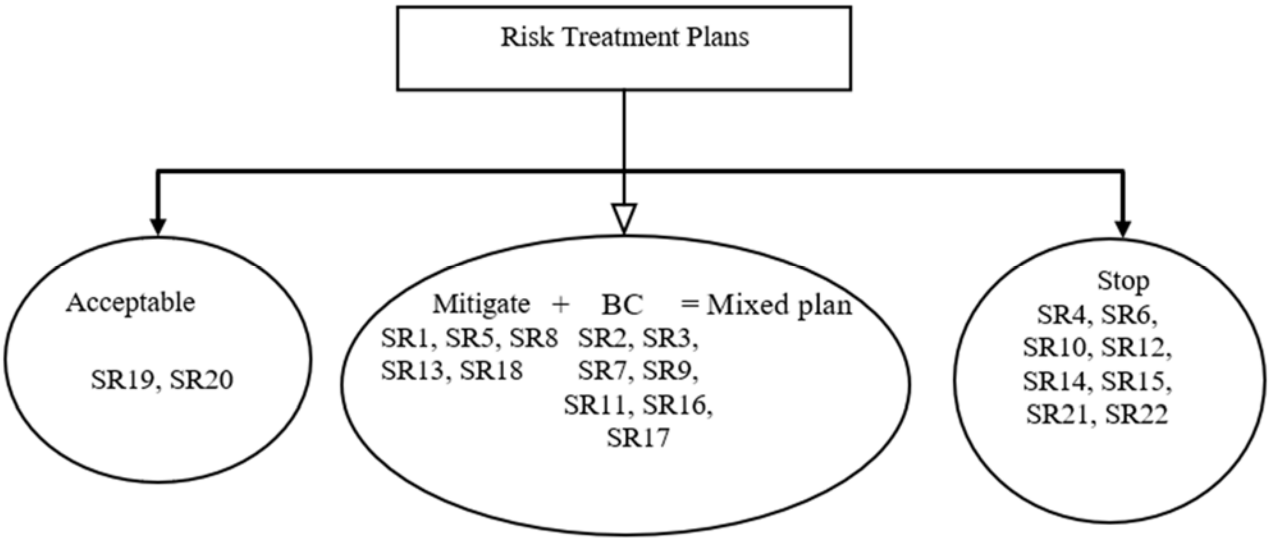

Figure 4 Classification of risks according to the risk treatment plans

6 Managerial implications

The supply chain of any company is like a lifeline. Therefore, the risks that affect it are like a deadly epidemic. On this basis, this study provides a framework to mitigate the effects of this epidemic by presenting programs that mitigate risks inspired by BC faced by the smart supply chain. Therefore, there are several administrative implications for the proposed framework, whose application could improve the performance of the supply chain. The proposed framework helps line managers visualize risks that have devastating effects on the supply chain and thus develop proper actions proactively.

The proposed framework helps companies expect the impacts (Table 3) that could affect them in case of the expected risks (Table 1). The proposed framework offers many advantages, most notably the classification of risks in terms of impact and consequences and, thus, the ability to understand the application of the ISO 22301:2019 standard. On the other hand, companies can receive help from measuring risks in a quantitative manner and through three different points of view (easy, standard, and difficult), which makes the risk assessment and analysis process more comprehensive and correct. The proposed framework was based on three basic stages. In the first stage, risks, and the effects of risks on SSC were found. In the second stage, the risks that were found in the first stage were analyzed using several appropriate techniques. In the third stage, risks were classified. According to threshold values, proper mitigation plans are decided for each risk category.

In addition, the proposed framework offers practical guidance for companies, as some risks related to information technology can be avoided through organizing training courses and improving infrastructure, while others require the presence of skilled human resources. It is worth noting that some risks require building resilience as well as using risk transfer mechanisms such as insurance and diversifying suppliers.

7 Conclusion remarks

In the last ten years, the expansion of the virtual world and technology, as well as the integration of artificial intelligence, have heightened organizations' awareness of the importance of addressing disruptive incidents. The lack of preparation to manage these disruptions can lead to catastrophic consequences, as evidenced by the COVID-19 pandemic. BC is an approach capable of mitigating such disruptive risks. This study proposes a practical framework inspired by BC to identify and manage risks in the smart supply chain. The proposed framework utilizes the BC approach to demonstrate, analyze, and classify risks, encompassing three fundamental stages. In the first stage, risks and their impacts are identified through a review of existing literature and expert opinions, using the Fuzzy Multi-Criteria Decision-Making (FMCDM) approach. The second stage involves analyzing the risks via a meticulously prepared questionnaire. In the third stage, risks are classified, and risk measures are calculated using the Fuzzy Inference Approach (FIA). A FRM is employed to determine risk levels from three perspectives: easy, standard, and hard.

The impacts of risks and their consequences are derived from expert opinions, making the selection and methodology of experts crucial for obtaining accurate data that contributes to the framework's implementation. Using linguistic terms such as fuzzy numbers provide a strategic method for addressing risks that are difficult to analyze or predict. The proposed framework is versatile and can be applied across various industrial and service sectors. Future research should focus on enhancing this model to cater to organizations with extremely high risks due to the nature of their business. Additionally, incorporating other techniques, such as simulation, would be beneficial for further studies.

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Identification of the bottlenecks in the non-production conveyor system using a simulation model

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Keywords: simulation, conveyor non-production system, bottlenecks, Tecnomatix Plant Simulation, Anylogic.
Abstract: The performance of industrial systems is influenced by external factors, such as supply chain disruptions. The system usually cannot influence them much and must actively adapt to those external factors. On the other hand, there are also internal factors such as process synchronization and communication or resource allocation, which are entirely within the control of the system. Communication and synchronization need to be continuously monitored and assessed for various standard and non-standard situations. For such complex problems, which usually cannot be solved in acceptable time and resources by simple or exact methods, simulation is suitable and often used. This study uses simulation models to identify bottlenecks and propose corrective measures in a conveyor system used for processing customer-returned goods. Two simulation tools, Tecnomatix Plant Simulation (TPS) from Siemens PLM Software and AnyLogic software from AnyLogic Company, were used to model the system and test potential optimizations. The analysis identified critical bottlenecks, allowing targeted interventions, such as increasing conveyor speeds and optimizing input rates, which led to significant improvements in throughput and operational efficiency. Furthermore, the study demonstrates how simulation results can guide decision-making in areas such as resource allocation, capacity planning, and maintenance scheduling. While TPS proved more effective for detailed bottleneck analysis, AnyLogic's multi-method capabilities highlight its suitability for hybrid applications. The findings underscore the value of simulation in optimizing complex systems and provide insights applicable to other industrial sectors, emphasizing the potential of emerging technologies such as digital twins and AI-enhanced models to drive further innovation.

1 Introduction

The industrial system and its efficiency can be influenced by internal and external factors. Internal factors such as process synchronization and resource allocation are crucial for optimizing system performance, while external factors like supply chain disruptions, fluctuating customer demand, or material shortages impact efficiency. It is usually easier for a company manager to look for bottlenecks in the system caused by internal factors that can be more easily changed. Bottlenecks can be found in both production and non-production systems. In both systems, a bottleneck may be a machine with a low process speed or a long process time [1]. Weaknesses may include a logistics area with a limited flow rate causing congestion, the longest process time, the process with the lowest production line capacity, or delays in delivery to other parts of the system caused by repairs and maintenance of parts. For manufacturing systems, products or parts with the longest processing times, lowest speeds, or highest process requirements are usually the main bottlenecks [2]. A bottleneck may also arise on the human resources side, where there are few or insufficiently qualified workers. Bottlenecks arise when a particular process slows down overall operations. Identifying and mitigating bottlenecks improves efficiency by optimizing process flow and resource utilization. Several methods and techniques can be used to find bottlenecks, ranging from soft tools such as effective communication to sophisticated tools such as optimization [3] or simulation models [4]. Efficient communication and synchronization across system components is important as it significantly reduces downtime and enhances productivity. Simulation can help managers visualize and test coordination improvements without disrupting real operations. Properly aligned workflows ensure that conveyor processes operate smoothly, minimizing bottlenecks [1].

Simulation models are often used to reproduce a real system with its dynamic processes in a computer model. The main reason for using computer simulation in the analysis of managerial problems is the impossibility of using standard analytical tools due to complexity of real processes. The main task is to find knowledge that is applicable in the real system. In a broader sense, simulation can be understood as the preparation, implementation and evaluation of concrete experiments with a simulation model [5]. Simulation is a suitable method for the analysis of large-scale production and non-production systems that cannot be investigated using conventional analytical tools and their direct observation is not possible or would be very expensive in terms of time and money. The method is used in industrial environments as well as by researchers. As Kovbasiuk et al. [6] mentioned, the benefits of simulation include reducing investment risk, minimizing waste, improving efficiency, reducing energy consumption and even increasing worker health. Simulation can be used in the phase of operation of an existing system, in the planning of modifications to this system and in the phase of designing a completely new system. Simulations can be used to find bottlenecks in existing systems, to determine the use of workers and machines, or to test the system's response to extreme situations [7]. When designing modifications, it is possible to create different scenarios based on the results of the experiments carried out and by comparing them, it is possible to select and implement the most effective modifications to the system relatively quickly and easily [5]. When using a simulation model for the design of new systems, it is possible to eliminate the emergence of bottlenecks in the systems, to determine the response of the systems to extreme situations and to design a system specifically adapted to the process to be operated in it [8]. The great advantage of simulation is that it does not directly interfere with the running system. The simulation model considers only the factors that affect the operation and response of the system, so that it can reliably represent the system's response to real or hypothetical situations, and the results obtained lead to the design of meaningful measures to improve the system's efficiency [9].

Models can be created in different types of software, depending on the problem being modelled and the time variations involved in running the simulation [9]. There are many simulation models available, and the choice depends on the type of problem to be solved. Simulation models are divided into deterministic (the input and output variables remain constant) and stochastic (at least one of the input or output variables is determined by probability). Both of these categories can be static (time is disregarded) or dynamic (time-dependent interactions among variables are considered). Dynamic models in both cases are further divided into continuous (they rely on differential equations and attempt to measure changes in the system continuously over time due to control) and discrete (they react immediately to specific discrete events) [10]. If no time sequences are needed, only the application of Monte Carlo simulation could be effective, especially for iterative evaluation of a deterministic model. Monte Carlo simulation is associated with the systems affected by randomness when several different scenarios are randomly generated to obtain the probability description of the selected results [5]. Monte Carlo simulation repeats a lot of random experiments to find out the possible outcomes. But real simulation is usually made via discrete event simulation model or continuous simulation. Discrete event simulation (DES) is suitable for dynamic, stochastic systems that change in a discrete manner [11]. DES is common for models of economic and business processes, such as production and manufacturing systems [6-8,12-19] call centers or emergency medical services [20] or different scenarios and company strategies [8]. The detailed distribution of the simulation models is shown in Figure 1.

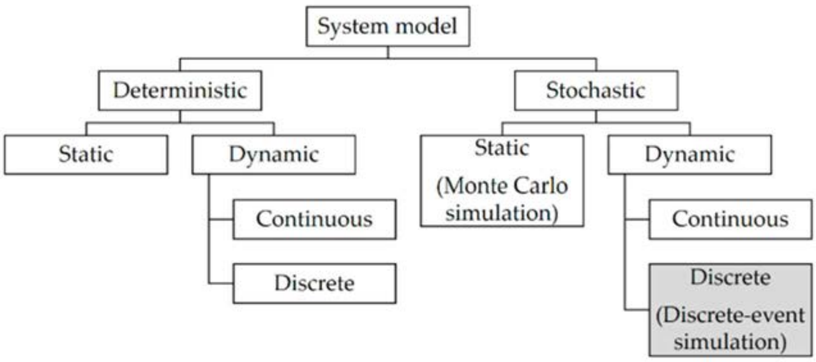

Figure 1 Diagram of simulation model types [10]

There are many applications or software for creating simulation models today. According to Captera.com [13], there are dozens of options for choosing the right program. Some of the most commonly used simulation programs within DES include AnyLogic, Arena, FlexSim, Plant Simulation, Simio, SIMUL8 or Witness. Kovbasiuk et al. [6] tested six DES packages – Arena, Anylogic, FlexSim, SIMUL8, TPS and WITNESS – all of the selected simulation software packages are aimed at analyzing the bottleneck processes, exploring possible "what-if" scenarios, providing "as-is" models, improving the existing systems and they are decision-making tools for enterprises. They concluded that TPS and FlexSim can be taken as the best covering all 11 simulation approaches such as 3D imaging, Agent-Based Modelling or stochastic and dynamic modelling. AnyLogic as the second tool in this comparison covers 10 simulation approaches as it does not have an industry specific database. Yakovlev et al. [21] used the AnyLogic software platform to build a complex simulation model of the conveyor line based on the discrete-event and two agent-based models. As a result of the simulation, the optimal number of pallets and the optimal batch size of products were determined. AnyLogic was also used to simulate and optimize the coal mine production logistics system [26]. TPS was used e.g. in a case study [23] to present the possibilities of this software for simulation of production and logistics processes, identification of bottlenecks in the production process and experiments leading to increased factory performance. Ashrafian et al. [24] used FlexSim software to optimize the operation of a fully automated modular conveyor system in a large-scale warehouse. A full-scale 3D DES model of the system was built and time-dependent statistical models were carefully designed and implemented in the model in order to capture the randomness and complex dynamics of the operation. The application of simulation program SIMUL8 to the analysis of production process in company Alteko, Inc. producing radial fans was presented by Fousek et al. [14]. The main purpose was to identify the bottleneck processes and to suggest the management the appropriate solution. Within the framework of the conveyor line control system development, a simulation model was created in Emulate3D [15] to verify the correct operation of the system control logic. During the simulation phase, errors in the logic were found and eliminated, resulting in an improvement in the operation of the system while reducing the time required to run the physical device.

Simulation also finds its application in the creation of a digital twin in Industry 4.0. For the robotics sector, RobotStudio has proven to be a simulator suitable for medium-performance computers with a wealth of functionality, which the user can also supplement with his own programming [16]. The simulator also enables the integration of the OPC UA communication protocol, which is enjoying growing acceptance in the industry. In the environment, a digital twin of the robotic laboratory system, mainly used for research, development and education, was created, consisting of several devices such as robotic arms, conveyors, automated warehouses and vision systems. RobotStudio is also suitable for selecting and optimizing the parameters of a robotic packaging process for one type of product. The main element of the research [7] was a computer simulation station based on the Picking PowerPac package. It was assumed that the products on the process line are generated pseudo-randomly, reflecting the actual working conditions. As a result of the tests performed, the optimal working speed of industrial robots and conveyors was obtained.

2 Methodology

The basic procedure for creating a simulation model has already been outlined by Banks et al. [25] in 12 steps from problem formulation, through data collection, model creation, model verification, validation, experiments with the model implementation of changes in a real system. This procedure is more or less still followed, or some steps are structured in more detail with respect to the nature of the system being modelled. Banksow et al. [5] mention these 8 steps: 1. Formulation of problems, 2. Test of the simulation-worthiness, 3. Formulation of targets, 4. Data collection and data analysis, 5. Modeling, 6. Execute simulation runs, 7. Result analysis and result interpretation, 8. Documentation. Sharma [19] described the process in 11 steps: 1. problem formulation, 2. objectives settings, 3. decision about the type of the model, 4. conceptualization of the problem, 5. data collection, 6. software selection, 7. building a simulation model, 8. verification and validation of the model, 9. model testing and change of inputs, 10. results description, 11. documents or reports creation. Finally, Saderova and Ambrisko [23] put all the methodology steps into the scheme (see Figure 2) which we followed in this paper.

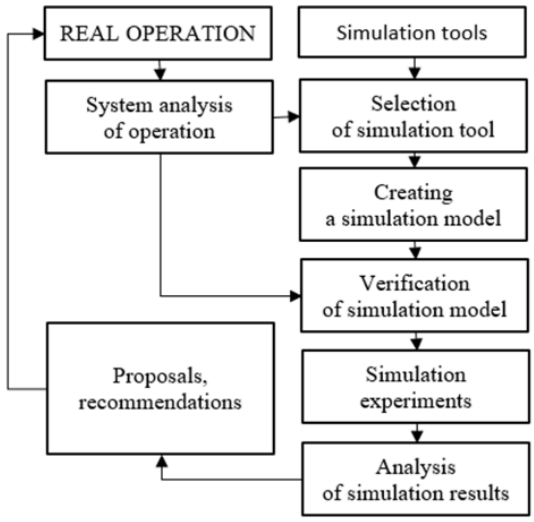

Figure 2 Steps of methodology based on [23]

System analysis (problem and targets formulation) was made by the client, which also gave us a data and the complete description of the system. The main task was to create a simulation model to find out all bottlenecks and to test the changes in the input rates and conveyors speed.

The choice of simulation tool (software selection) was influenced by our capabilities and the needs of the modelled system. As the objective was also to compare the two selected simulation programs, we decided for Tecnomatic Plant Simulation [26] and AnyLogic [27], which were available for download and testing (student version) without payment.

The following chapters contain further steps, i.e. in particular the description of the system, the creation of the model and its verification, simulation experiments, comparison of results and recommendations for real system changes. Key metrics used in simulation models are based on the statistics taken from several runs with confidence intervals to estimate the precision of the metrics such as throughput rate, utilization rates or blocking and idle times. Finally, we compare the advantages and disadvantages of the chosen simulation software.

3 Problem formulation and description

The described methodology was used to find the bottlenecks in the conveyor network, correct them and subsequently increase the efficiency of the system. Another objective is to compare the functionality and evaluate the use and results obtained with two selected freely available versions of simulation tools. The diagram of the conveyor system and its components are shown in Figure 3. For better clarity, the names in the diagram have been abbreviated: So denotes Source, St denotes Storage, C_ denotes Conveyor, M_ denotes Machine and W_ denotes Workplace. Each element is also assigned a numerical designation within the network for better orientation in identifying bottlenecks.

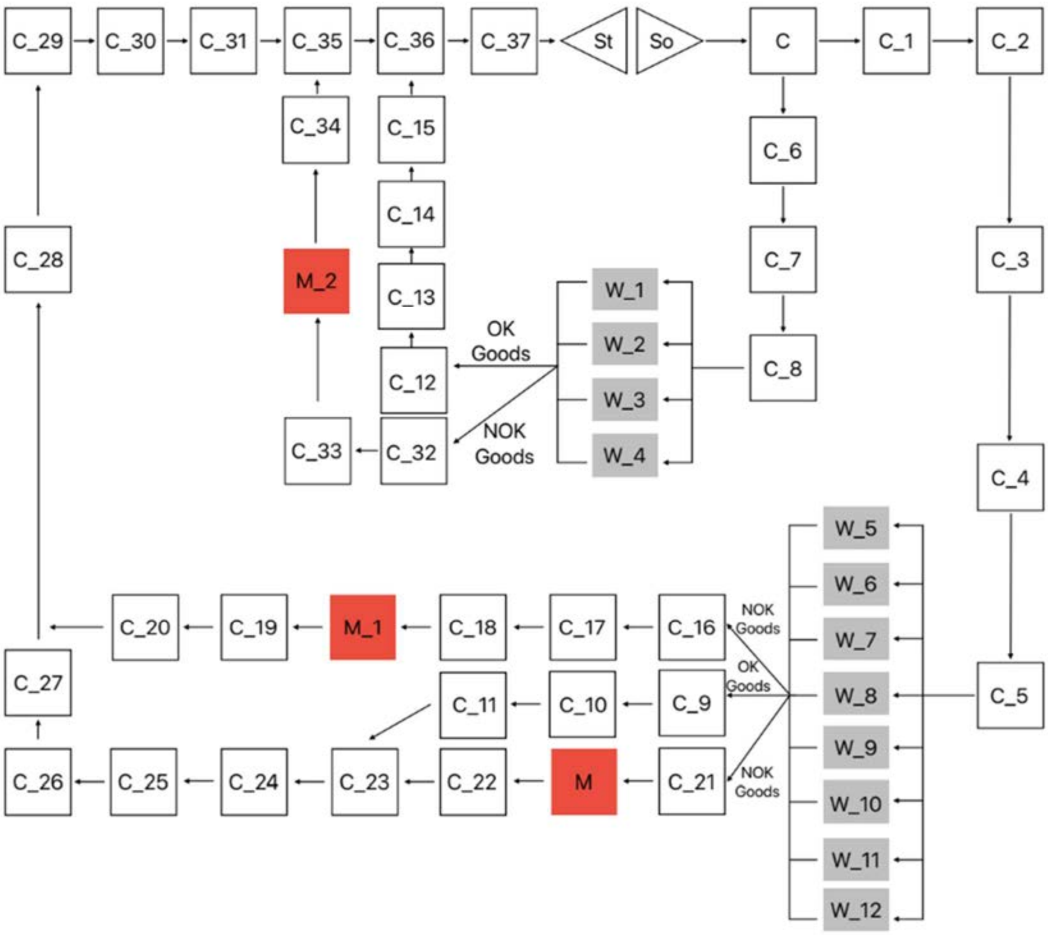

Figure 3 Diagram of the conveyor system (conceptualization of the problem)

The existing system under study consists of a set of roller conveyors connected to each other. The conveyors are used to transport parcels of returned goods. Within the conveyor network, there is a large main branch and a smaller secondary branch through which the goods can pass. In each branch there is a workstation with entry control staff that decides on the further progress of the returned goods. If the goods are free from defects, they are passed onto the violet conveyor and go to the bin where they await further processing. If the inspection station assesses that the returned goods are not free of defects, they pass them to the yellow or green conveyor. Each of the conveyors passes through machines that clean the returned goods. After passing through these machines, the goods go back into the storage bin where they await further processing. The source of the goods is the warehouse on the lower floors of the building, which is continuously stocked and has sufficient inventory to supply the system with packages for a full eight-hour shift. All conveyors are 640mm wide and the parcel size is 500x400x100mm. The individual conveyors consist of multiple parts that are driven by their own motors. Motor speeds range from 0.1 – 1.5 m/s. The speed of parcels entering the system is 30 pcs/min. The other parameters of the simulation model were set to the values shown in Table 1.

Table 1 Table with system input data

	Branches description	Usage by incoming inputs [%]	Workstation capacity [pcs/hr]	Number of workers/machines [pcs]	Total capacity [pcs/hr]	Speed [m/s]
Blue main branch	**Conveyor**	80	Transport of goods only		Transport of goods only	0.8
	Conveyor_1 - 4	80	Transport of goods only		Transport of goods only	0.1, 0.8, 0.4, 0.8
	Conveyor_5 (Workplace_5 - Workplace _12)	80	121	32	3872	0.56
Blue secondary branch	**Conveyor_6 - 7**	20	Transport of goods only		Transport of goods only	0.35, 0.55
	Conveyor_8 (Workplace_1 - Workplace _4)	20	90	16	1440	0.8
Violet main branch	**Conveyor_9 - 11**	10	Transport of goods only		Transport of goods only	0.8, 0.69, 0.69
	Violet secondary branch					
	Conveyor_12 - 15	2	Transport of goods only		Transport of goods only	0.8, 1.2, 0.8, 0.53
Yellow main branch	**Conveyor_16 - 18**	35	Transport of goods only		Transport of goods only	0.8, 0.8, 0.8
	Conveyor_19 (Machine1)	35	800	1	800	0.1
	Conveyor_20	35	Transport of goods only		Transport of goods only	0.33
Green main branch	**Conveyor_21**	35	Transport of goods only		Transport of goods only	0.8
	Conveyor_22 (Machine)	35	800	1	800	0.1
	Conveyor_23 - 31	35	Transport of goods only		Transport of goods only	0.1, 0.7, 0.8, 0.8, 0.6, 0.8, 0.8, 0.8, 0.8
Green secondary branch	**Conveyor_32**	18	Transport of goods only		Transport of goods only	0.8
	Conveyor_33 (Machine2)	18	800	1	800	0.8
	Conveyor_34	18	Transport of goods only		Transport of goods only	0.8
Green end conveyors	**Conveyor_35 - 37**	100	Transport of goods only		Transport of goods only	0.8, 1.5, 0.8

4 Simulation models

TPS is a 3D object-oriented program used for DES [26]. Machines, conveyors, people and embedded clicks to analysis tools are referred to as objects. The program can create digital twins containing manufacturing or non-manufacturing processes, robots, automation, systems containing material handling and workers. It is a tool suitable for simulating, evaluating and implementing advanced manufacturing techniques, equipment and operations to increase system flexibility. The program contains predefined objects and functions, but it also allows to write own methods or conditions necessary for the correct functioning of the system. The application is produced and distributed by the German company Siemens PLM Software, which has long been engaged in providing support and appropriate solutions in the field of innovation and optimization of business processes. The application can be obtained in various versions from paid professional versions to student free versions, which are limited by the number of objects used in the model being created. The program allows the use of tools such as bottleneck analysis, statistical reports, graphs or Sankey diagrams to evaluate the efficiency of the system or the suitability of proposed measures. Compared to AnyLogic, the simulation model does not stop the simulation run in case of system overload, but records the progress in statistics and distinguishes the time for which individual objects of the model are working, waiting for the arrival of new goods or are blocked by goods.

For the purposes of this paper, the Student version was used, which is limited to 80 placed objects, but is not otherwise functionally limited. The resulting model of the original conveyor system is shown in Figure 4.

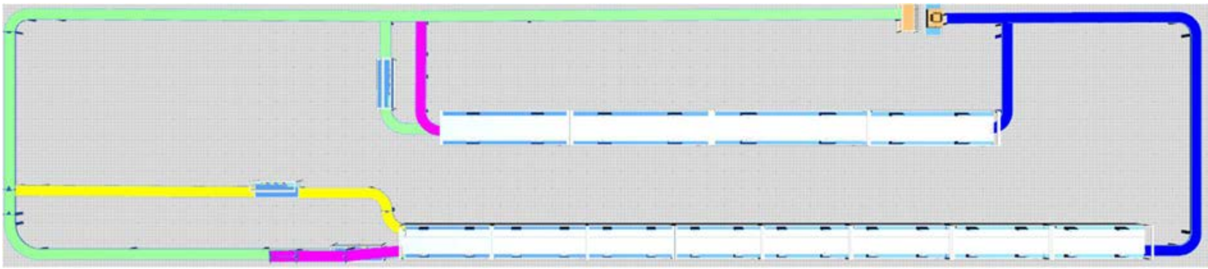

Figure 4 Digital twin of the analyzed conveyor system in TPS

To compare the functionality of the simulation programs, the same model was created in the aforementioned AnyLogic program, which is also available in different versions. For the purposes of this paper, the free version Personal Learning Edition was used, which is limited by the insertion of more sophisticated objects (only conveyors and simple workstations or machines can be inserted), but also by the length of the simulation run to 1 hour. Figure 5 shows a model of the original conveyor system in AnyLogic.

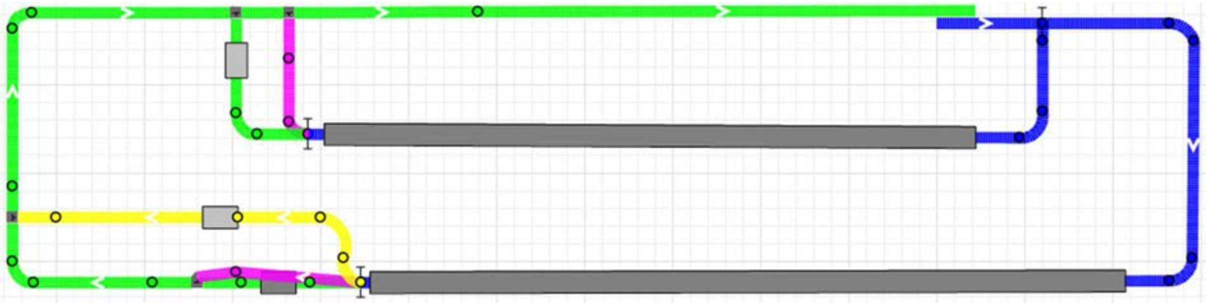

Figure 5 Digital twin of the analyzed conveyor system in AnyLogic

Due to limitations in simulation programs, the workplaces are modelled as stations and the input control personnel are not physically represented in the models. Parameters of the stations (speed and method of work, procedure for goods inspection) correspond to the input control workers in their settings. Verification of the functionality and effectiveness of the proposed measures was carried out only in TPS, as it allows for a simulation run of one shift.

5 Simulation

The simulation was always run for 30 runs of the length corresponding to one shift in TPS and for 1 hour in Anylogic in case no bottleneck was found in the shorter time. In the following subsections, the individual experiments and their results are presented.

5.1 Identification of AnyLogic bottlenecks

When setting the parameters specified in the problem formulation, the system crashed after 82 seconds of running the simulation in Anylogic and thus stopped running completely. In Figure 6, the red ellipse indicates the point of system collapse.

Figure 6 Identification of a bottleneck in AnyLogic

The program stopped running due to the fact that it was not possible to send more goods to the system. The bottleneck of the system is the first conveyor of the main branch (Conveyor_1), whose speed is 0.1 m/s, which was only able to send one package further into the system during the simulation run. It is not possible to restart such a stopped run, only to repeat the complete run. Thus, AnyLogic cannot identify multiple bottlenecks at once, because it stops the run on the first one found.

5.2 Identification of Tecnomatix Plant Simulation bottlenecks

With identical settings of the model parameters, TPS performed a simulation run of the entire shift without stopping. 6,762 returned packages entered the system, 5,400 packages passed through the main branch, 1,350 through the secondary branch and 6,672 packages were stored for further processing. In Figure 7, the red ellipse again highlights a bottleneck in the system. It is clear that the bottleneck will be on the blue main branch and will be either Source, Conveyor or Conveyor_1 (see Table 1), as the rest of the system is not overwhelmed.

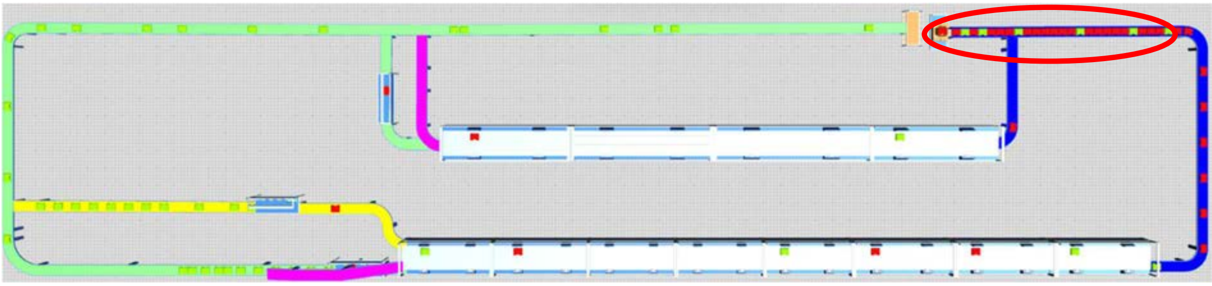

Figure 7 Identification of a bottleneck in TPS

In this situation, it is not possible to clearly say which of the mentioned parts is the bottleneck, so in addition to the simulation, TPS also records statistics. The most important fragment of the statistics record is shown in Table 2. In addition to the name of the object, the statistics contain data on what percentage of the working time the object worked, what percentage waited for the arrival of the next goods to be processed, and what percentage of the working time was blocked by goods that could not be passed on to the next object. Finally, it combines these 3 data into a diagram, where the work time is represented in green, the waiting time in grey and the blocking time by goods in orange. The statistics also contain other data such as rebuilds, power on/off and faults, but these have no input data in the model and therefore cannot take values other than 0. The statistics show that Source and Conveyor are blocked most of the time because the following Conveyor_1 link is too slow, even though it is running at full performance. The simulation results were the same in all 30 cases.

Table 2 Statistics for potential bottlenecks in the blue main branch

Object	Working	Set-up	Waiting	Blocked	Powering up/down	Failed	Stopped	Paused	Unplanned	Portion
Source	0.00%	0.00%	0.13%	99.87%	0.00%	0.00%	0.00%	0.00%	0.00%	
Conveyor_3	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Conveyor_2	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Conveyor_4	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Conveyor_5	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Conveyor_6	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Conveyor	15.71%	0.00%	0.00%	84.29%	0.00%	0.00%	0.00%	0.00%	0.00%	
Conveyor_1	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	

6 Newly proposed scenarios

In the following subsections, individual proposals for eliminating the identified bottlenecks in the system are presented. The individual proposals are considered both in terms of simulation capabilities and applicability in practice. As a possible remedial action, the sponsor has allowed the replacement of the conveyor motors with new ones with a speed of 0.8 m/s and the simulation has been able to identify the motor that needs to be replaced. The corrective actions are now only verified in TPS to better see the impact of the changes on the entire system throughout the working time.

6.1 Replacing motors of selected conveyors

The simulation runs showed that there is clearly 1 bottleneck in the system (Conveyor_1) for which the motor was replaced with a new one with a speed of 0.8 m/s. Newly 13,500 packages with returned goods entered the system, 10,798 packages passed through the main branch, 2,700 through the secondary branch and 13,350 packages were stored for further processing. When the motors were replaced, the speed of the parcel through the conveyor system was increased and the quantity processed was also increased. After the motor replacement, new bottlenecks appeared, see Figure 8, where the system is after the

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application of the corrective measure and the bottlenecks are marked with red ellipses.

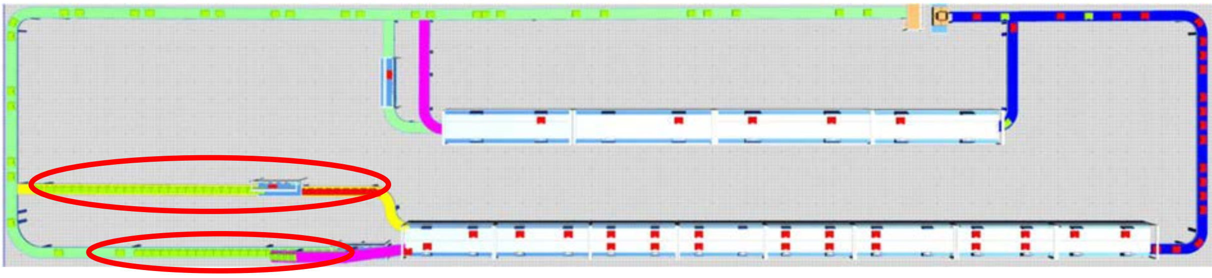

Figure 8 Newly identified bottlenecks

Potential bottlenecks in the yellow main branch are Conveyor_18, Machine1 or Conveyor_19 (see Table 1). The statistics (see Table 3) show that the bottleneck is Conveyor_19, because the previous section Machine1 is blocked almost 20% of the working time by goods it has already processed but cannot send on.

Table 3 Statistics for potential bottlenecks in the yellow main branch

Object	Working	Set-up	Waiting	Blocked	Powering up/down	Failed	Stopped	Paused	Unplanned	Portion
Conveyor_19	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Machine1	79.32%	0.00%	1.13%	19.55%	0.00%	0.00%	0.00%	0.00%	0.00%	
Conveyor_18	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	

Potential bottlenecks in the green branch are Machine, Conveyor_22, or Conveyor_23 (see Table 1). The statistics based on the results of all simulation runs (see Table 4) show that the bottleneck is Conveyor_22, because the previous article Machine is blocked more than 50% of the working time by goods that it has already processed but cannot send on.

Table 4 Statistics for potential bottlenecks in the green main branch

Object	Working	Set-up	Waiting	Blocked	Powering up/down	Failed	Stopped	Paused	Unplanned	Portion
Machine	47.94%	0.00%	0.46%	51.60%	0.00%	0.00%	0.00%	0.00%	0.00%	
Conveyor_22	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Conveyor_23	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	

Conveyor_22 and Conveyor_23 are 1 conveyor in the real system, which must be divided into 2 fragments in the model for the reason that the correct transfer of goods between the green and violet main branch occurs in the program. For this reason, it will be proposed to replace the motors of both conveyors (both parts in the real system).

Replacing motors on Conveyor_19 and Conveyor_22 + Conveyor_23

The simulation runs showed that there are 2 additional bottlenecks in the system (Conveyor_19 and Conveyor_22 + Conveyor_23) for which the motors were replaced with new ones with a speed of 0.8 m/s. Newly 13500 returned packages entered the system, 10,798 packages passed through the main branch, 2,700 through the secondary branch and 13,417 packages were stored for further processing. The replacement of the motors resulted in a faster passage of the parcel through the conveyor system, not an increase in the quantity of parcels processed, only an increase of 67 parcels stored for further processing. Figure 9 shows the system after the corrective actions have been implemented.

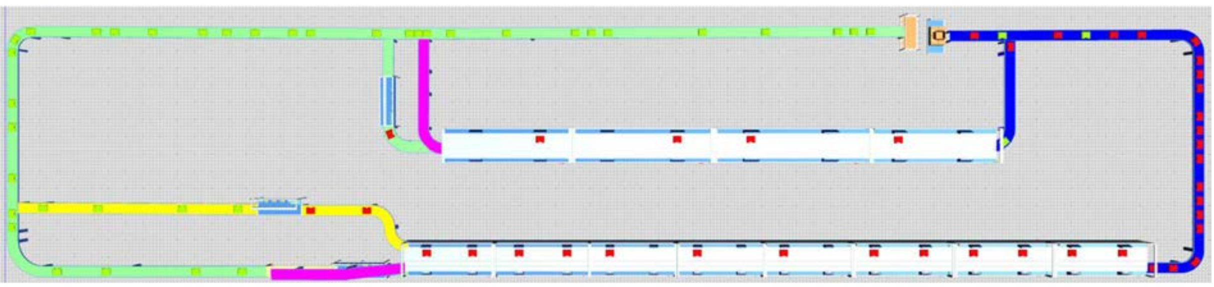

Figure 9 The system after the implementation of the second wave of corrective actions

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At first glance, there are no more bottlenecks in the system. The statistics no longer show any objects that are blocked by goods that cannot be sent on. Table 5 shows a fragment of the statistics, which shows that machines for repairing returned goods have to wait for a relatively large part of the working time for the goods to arrive.

Table 5 Statistics for inefficiently used machines

Object	Working	Set-up	Waiting	Blocked	Powering up/down	Failed	Stopped	Paused	Unplanned	Portion
Machine	63.59%	0.00%	36.41%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Machine1	63.97%	0.00%	36.03%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Machine2	31.53%	0.00%	68.47%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	

Given the lower use of working machines, another proposed action is to increase the speed of entering packages into the system, which should increase the amount of processed packages and thus the use of working time.

6.2 Changing the intensity of parcel entry into the system (input rate)

The speed of the system will be gradually increased by 5 pcs/min until the system is stable and no bottlenecks occur. If a speed is found at which the system is not stable and new bottlenecks are created, a new speed change will be performed using sensitivity analyses.

Input rate 35 pcs/min

The new speed is set to 35 pcs/min. 15,790 packages with returned goods entered the system, 12,630 packages passed through the main branch, 3,157 through the secondary branch and 15394 packages were stored for further processing.

There are no newly generated bottlenecks visible in the system and the statistics did not show any newly generated bottlenecks. Table 6 again shows the statistics for the repair machine, the new machine utilization increased to more than 74% for machines on the main branch and to more than 36% for machines on the secondary branch.

Table 6 Statistics for inefficiently used machines

Object	Working	Set-up	Waiting	Blocked	Powering up/down	Failed	Stopped	Paused	Unplanned	Portion
Machine	74.15%	0.00%	25.85%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Machine1	74.65%	0.00%	25.35%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Machine2	36.87%	0.00%	63.13%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	

Input rate 40 pcs/min and 45 pcs/min

The new speed is set to 40 pcs/min. The system has now received 18,000 returned parcels, 14,390 parcels have passed through the main branch, 3,600 through the secondary branch and 17,889 parcels have been stored for further processing. The system is still stable, there are no newly generated bottlenecks and the statistics have not shown any newly generated bottlenecks. Table 7 again shows the statistics for the repair machine, the new machine utilization increased to 85% for the machine on the yellow branch, more than 84% for the machine on the green branch and more than 42% for the machine on the secondary branch.

Table 7 Statistics for inefficiently used machines

Object	Working	Set-up	Waiting	Blocked	Powering up/down	Failed	Stopped	Paused	Unplanned	Portion
Machine	84.48%	0.00%	15.52%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Machine1	85.00%	0.00%	15.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Machine2	42.03%	0.00%	57.97%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	

For the next 30 simulation runs, the new speed is set to 45 pcs/min. 20,256 returned parcels entered the system, 16,202 parcels passed through the main branch, 4,050 through the secondary branch and 20,127 parcels were stored for further processing. The system is still stable, no newly generated bottlenecks are evident and the statistics did not show any newly generated bottlenecks. The new machine utilization increased to over 95% for the machine on the yellow branch, over 94% for the machine on the green branch and over 47% for the machine on the secondary branch.

Input rate 50 pcs/min

The new model is set to a speed of 50 pcs/min. Newly 21,256 packages with returned goods entered the system, 16,995 packages passed through the main branch, 4249 through the secondary branch and 21,067 packages were stored for further processing. Table 8 shows the results - it is clear that the system is no longer stable (blocked objects) and new bottlenecks have appeared.

Table 8 Statistics for potential bottlenecks in the green main branch

Object	Working	Set-up	Waiting	Blocked	Powering up/down	Failed	Stopped	Paused	Unplanned	Portion
Source	0.00%	0.00%	9.14%	90.86%	0.00%	0.00%	0.00%	0.00%	0.00%	
Conveyor	53.54%	0.00%	0.00%	46.46%	0.00%	0.00%	0.00%	0.00%	0.00%	
Conveyor_1	79.96%	0.00%	0.19%	19.85%	0.00%	0.00%	0.00%	0.00%	0.00%	
Conveyor_2	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Conveyor_3	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Conveyor_4	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Conveyor_5	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Workplace_5	98.61%	0.00%	0.21%	1.18%	0.00%	0.00%	0.00%	0.00%	0.00%	
Workplace_6	98.67%	0.00%	0.21%	1.12%	0.00%	0.00%	0.00%	0.00%	0.00%	
Workplace_7	98.93%	0.00%	0.21%	0.86%	0.00%	0.00%	0.00%	0.00%	0.00%	
Workplace_8	98.83%	0.00%	0.22%	0.95%	0.00%	0.00%	0.00%	0.00%	0.00%	
Workplace_9	99.02%	0.00%	0.22%	0.76%	0.00%	0.00%	0.00%	0.00%	0.00%	
Workplace_10	98.85%	0.00%	0.23%	0.93%	0.00%	0.00%	0.00%	0.00%	0.00%	
Workplace_11	98.68%	0.00%	0.24%	1.08%	0.00%	0.00%	0.00%	0.00%	0.00%	
Workplace_12	99.02%	0.00%	0.24%	0.74%	0.00%	0.00%	0.00%	0.00%	0.00%	
Conveyor_16	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Conveyor_17	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Conveyor_18	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Machine1	99.64%	0.00%	0.36%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	

The statistics show that the bottleneck is one of the Conveyor_16 - Conveyor_18 (see Table 1), because the workstations are blocked by goods for a small part of the working time. There is no way to change this situation as all conveyors are already at the maximum speed of the new motors of 0.8 m/s.

6.3 Sensitivity analysis of input rate

The maximum tolerable value for the input rate of packets into the system is between <45;50) pcs/min. To find a specific value, a sensitivity analysis will be performed where the intensity will be increased from 45 pcs/min one piece at a time and 30 runs of simulation will be performed again with the newly found value. The system will be subjected to an input rate of 46 pcs/min.

Input rate 46 pcs/min and 47 pcs/min

The new speed is set to 46 pcs/min. 20,770 packages with returned goods entered the system, 16,631 packages passed through the main branch, 41,53 through the secondary branch and 20633 packages were stored for further processing. Figure 10 shows the system after the introduction of the new action. The system is still stable, there are no newly generated bottlenecks and the statistics have not shown any newly generated bottlenecks. Figure 20 again shows the statistics for the repair machine, the new machine utilization on the main branch is close to 100% and 49% for the machine on the minor branch.

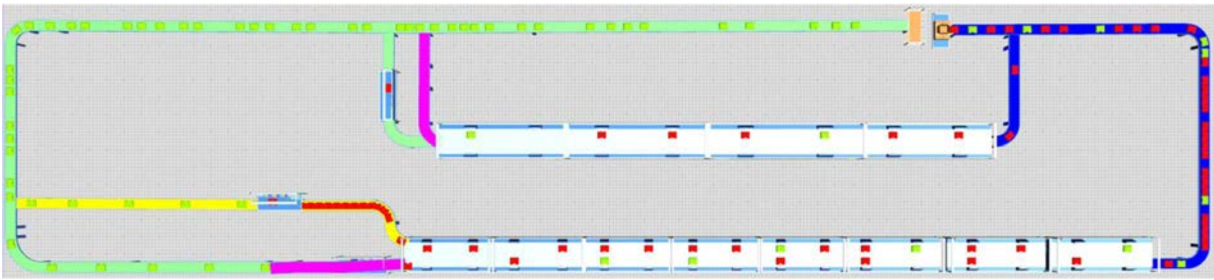

Figure 10 System after increasing the rate of parcels entering the system to 46 pcs/min

The new speed is set to 47 pcs/min. 21,144 packages with returned goods entered the system, 16,912 packages passed through the main branch, 4,228 through the secondary branch and 20,990 packages were stored for further processing. Figure 11 shows the system after the introduction of the new measure. It is very clear from the figure that the system is no longer stable and new bottlenecks have emerged.

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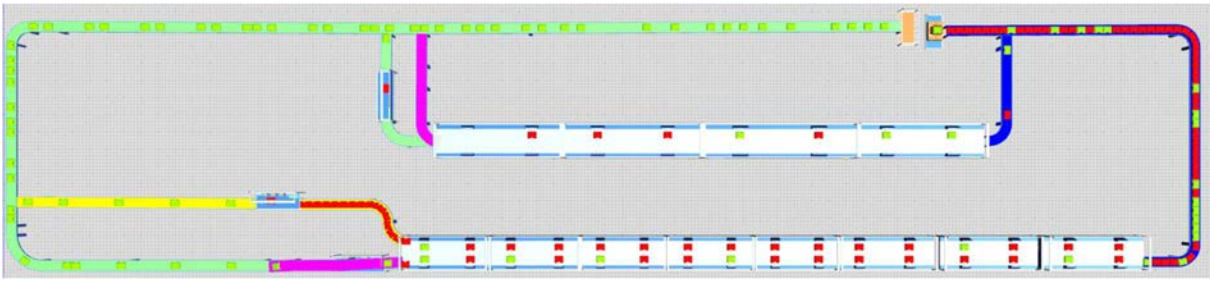

Figure 11 System after increasing the intensity of parcels entering the system to 50 pcs/min

The statistics (see Table 9) show that the bottleneck is one of the Conveyor_16 - Conveyor_18 (see Table 1), because the workstations are blocked by goods for a small part of the working time. There is no way to change this situation as all conveyors are already at a maximum speed of 0.8 m/s. Based on the above simulation experimental results, the maximum allowable value of packet intensity entering the system is 46 pcs/min.

Table 9 Statistics for potential bottlenecks in the green main branch

Object	Working	Set-up	Waiting	Blocked	Powering up/down	Failed	Stopped	Paused	Unplanned	Portion
Conveyor	81.28%	0.00%	0.00%	18.72%	0.00%	0.00%	0.00%	0.00%	0.00%	
Conveyor_1	88.76%	0.00%	2.30%	8.94%	0.00%	0.00%	0.00%	0.00%	0.00%	
Conveyor_2	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Conveyor_3	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Conveyor_4	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Conveyor_5	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Workplace_5	99.20%	0.00%	0.22%	0.58%	0.00%	0.00%	0.00%	0.00%	0.00%	
Workplace_6	99.05%	0.00%	0.22%	0.73%	0.00%	0.00%	0.00%	0.00%	0.00%	
Workplace_7	99.14%	0.00%	0.22%	0.64%	0.00%	0.00%	0.00%	0.00%	0.00%	
Workplace_8	99.00%	0.00%	0.24%	0.76%	0.00%	0.00%	0.00%	0.00%	0.00%	
Workplace_9	99.10%	0.00%	0.23%	0.67%	0.00%	0.00%	0.00%	0.00%	0.00%	
Workplace_10	99.11%	0.00%	0.25%	0.64%	0.00%	0.00%	0.00%	0.00%	0.00%	
Workplace_11	99.07%	0.00%	0.27%	0.66%	0.00%	0.00%	0.00%	0.00%	0.00%	
Workplace_12	99.07%	0.00%	0.26%	0.67%	0.00%	0.00%	0.00%	0.00%	0.00%	
Conveyor_16	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Conveyor_17	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Conveyor_18	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Machine1	99.35%	0.00%	0.65%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	

7 Results comparison

Based on experiments with simulation models created in AnyLogic and TPS to test potential improvements and efficiency of the conveyor network, a total of 3 bottlenecks were identified. These were the conveyors with the slowest motors. The primary proposed corrective action to eliminate the bottlenecks is to replace the old conveyor motors with new ones with a speed of 0.8 m/s. Key metrics used to assess the performance of the conveyor system include throughput rate, utilization rates, blocking and idle times, and input rate stability. The proposed changes were tested under conditions identical to the original system, and the simulation results were used to derive additional suggestions for increasing the efficiency of the conveyor network system, such as increasing the speed of packages entering the system. Due to the lower utilization of working time for the repair machines, system stability tests were performed for the new values of the intensities of the packages entering the system. The quantities of returned parcels in pieces for the main model fragments are shown in Table 10.

Table 10 Results of the experiments

Model	Input	Main branch	Secondary branch	Output
Unmodified digital twin	6,762	5,400	1,350	6,672
Corrective action 1	13,500	10,798	2,700	13,350
Corrective action 2	13,500	10,798	2,700	13,417
Input rate 35 pcs/min	15,790	12,630	3,157	15,394
Input rate 40 pcs/min	18,000	14,390	3,600	17,889
Input rate 45 pcs/min	20,256	16,202	4,050	20,127
Input rate 50 pcs/min	21,256	16,995	4,249	21,067
Input rate 46 pcs/min	20,770	16,631	4,153	20,633
Input rate 47 pcs/min	21,444	16,912	4,228	20,990

The throughput rate increased significantly following the simulation interventions, with the system stabilizing at a maximum input rate of 46 pcs/min. Compared to the original setting, an increase of 16 pcs/min has been made.

Machine utilization increased by more than 30% on the main branch and almost 17% on the secondary branch.

In addition to improving the state of the system, the aim was also to compare the AnyLogic and TPS simulation programs and several differences in the functionality of both were found. The biggest difference is in the functionality of the freely available versions of the program, with TPS being limited by the number of objects placed and AnyLogic, on the other hand, being limited by the length of the simulation run in addition to the insertion of different types of objects. Another major difference is in the way the programs work, where AnyLogic terminates the run at the first bottleneck found in the system, while TPS terminates the run only after a set time is reached and any bottlenecks can be identified quite well from the generated statistics.

Currently, the model contains machines that are fault-free and their maintenance is carried out off-shift. It is also considered that the goods returned by customers are only with minor defects that can be corrected by the repair machine. In the future, it would be useful to include the failure rate of machines in the model, to define the rejection rate for sorted goods or to determine the financial and energy intensity for individual objects in order to obtain even better results. In the case of a full version, it would also be useful to include the input inspection staff in the model and to create shift schedules for them. It would also be useful to consider changing the probabilities for the distribution of goods at the first crossroads. The distribution currently used corresponds to the setup of that system, but changing it to, for example, 75:25 or 70:30 could further increase the efficiency of the conveyor system once the new measures are in place. However, such a change is an intervention that is not yet foreseen by the contracting authority in the future development of the system and thus has not been considered at present.

8 Conclusion

This study highlights the critical role of simulation models in identifying and addressing inefficiencies within conveyor systems. By employing targeted strategic adjustments, such as replacing low-performing conveyor motors and optimizing input rates, the system's throughput increased significantly while maintaining operational stability. These interventions underscore the potential for simulation to guide decision-making, enabling managers to prioritize resources effectively, plan maintenance schedules, and test scenarios for enhanced resilience.

The main goal was to find all the bottlenecks in the system with conveyors and test the effect of the speed changes on the output of the system. At the same time, the aim was also to compare the capabilities of 2 freely available simulation tools - TPS and AnyLogic. According to the rules and system data provided by the client, a simulation model was created in both of these programs: TPS and AnyLogic. Due to the limitations of AnyLogic, which stops the simulation run when the first bottleneck is detected, preventing a complete analysis of the entire shift, we decided to perform all further experiments using the more robust TPS model. Through complex simulation runs, three significant bottlenecks were identified that hindered the throughput of the system. To mitigate these constraints, a series of experiments were conducted by varying the input speed and adjusting the conveyor speed in the target segments of the system. The results of these scenario tests allowed us to evaluate different configurations and determine the optimal operating parameters that effectively minimized or eliminated the bottlenecks. The throughput rate increased significantly following the simulation interventions, with the system stabilizing at a maximum input rate of 46 pcs/min. Machine and workstation utilization also improved, particularly for critical machines, which operated near full capacity. Blocking times decreased, signaling smoother process flow and enhanced synchronization among system components. This study underscores the importance of using advanced simulation tools that allow for system analysis to identify and resolve complex bottlenecks. The findings provide practical insights into the dynamic behavior of conveyor systems and highlight the potential for improving operational efficiency through strategic adjustments. This approach can serve as a valuable framework for similar analyses in other non-production conveyor applications, contributing to the development of more resilient and efficient material handling processes. The broader significance of these findings extends beyond conveyor systems to other industrial applications, where similar methodologies can be leveraged to optimize workflows, reduce downtime, and improve overall productivity.

For the simulation tools' comparison, we can conclude (similarly as in [6]) that both tools have their strengths and are best suited for different applications. AnyLogic is ideal for projects requiring a blend of methodologies (e.g., combining agent-based and discrete event simulations) and those needing flexible output visualization. Its graphical interface and drag-and-drop functionality make it easier to create models without extensive coding and it also provides clear, detailed, and customizable visualization options for simulation results. As one main disadvantage we see the fact that it can stop simulation runs when the first bottleneck is detected, which can hinder comprehensive long-term analysis. The other problem lies in the model creation: while basic modeling is user-friendly, mastering more complex functionalities and custom Java coding requires significant learning time.

TPS excels in detailed manufacturing and logistics systems with built-in tools for complex conveyor and production line modeling. This tool is suitable for this type of problem offering built-in tools for detailed analysis, such as bottleneck detection and throughput statistics, provide clear insights into system performance. Unlike AnyLogic, Plant Simulation can run through the entire shift or time period to show complete results for long-term analysis. The disadvantages of using this software include e.g. that the tool's extensive capabilities can be more challenging to learn, especially for users unfamiliar with simulation software, its coding capabilities are not as flexible or extensive as AnyLogic's Java-based system and simulating very detailed models can be resource-intensive and may require powerful hardware.

The biggest advantage of these type of simulation models lies in the ability to test system changes only within the model without having to incorporate them into the real process. This research demonstrates the value of integrating simulation-based approaches into strategic planning, fostering data-driven decisions that drive efficiency and competitiveness. Analyzing key performance metrics such as throughput rate, utilization rates, blocking and idle times, and input rate stability provides valuable insights into conveyor system efficiency. These metrics help identify bottlenecks, underutilized resources, and workflow inefficiencies, enabling informed decisions on equipment upgrades, process adjustments, and maintenance scheduling. By leveraging this data, organizations can optimize operations, enhance productivity, and proactively address potential issues, leading to improved overall performance.

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ESG reporting in the automotive industry

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Abstract: The aim of the article is to discuss the reporting of environmental information regarding sustainable development and ESG regulations in automotive companies listed on the Warsaw Stock Exchange. The article presents the results of own research on the scope of disclosure of information on ESG reporting in the field of environmental information among 5 companies from the automotive sector listed on the Warsaw Stock Exchange in 2022-2023. The methodology was based on a review of the literature on the subject, legal acts and own research, in which non-financial reports of listed companies in the automotive sector concerning environmental information and indicators were used. The research problem addressed by the authors was to investigate whether automotive sector companies disclosed environmental information in the period prior to mandatory regulations in this area. The results of the research confirmed the authors' assumptions that these companies published such information. At the same time, the scope of information disclosed varied significantly between companies. According to the authors, the article adds value to the literature on the subject, especially in terms of the collection, presentation and discussion of source material. The information collected in the empirical chapter can be used, among other things, to compare the scope of environmental information disclosed by companies from Poland with companies from other countries in the automotive sector. The subject of the article can provide a basis for further detailed empirical research in this area.

1 Introduction

The term ESG (Environmental, Social, Governance) refers to issues related to the environment, social responsibility and corporate governance. It should be noted that these are key areas of information for a company's stakeholders and therefore often not possible to capture within a traditional financial report. On the one hand, the company's activities in these areas can generate significant risks, but on the other hand, they can generate significant benefits. In practice, ESG/sustainability reporting means that companies provide stakeholders with information on environmental, social, employee and corporate governance issues through so-called ESG reports. This type of reporting is an expression of contemporary changes related to the growing importance of the concept of sustainable development, but also the growing importance of ESG factors in investment decisions (sustainable finance).

The ESG concept and methodology defines the scope of non-financial reporting to which a growing group of European companies is committed, estimated at around 50,000 companies from 2026 onwards. ESG defines specific areas and risk groups that should be included in a non-financial report. The main EU legal acts that form the regulatory context for the ESG concept include:

- Regulation (EU) 2020/852 of the European Parliament and of the Council of 18 June 2020 on the establishment of a framework to facilitate sustainable investment and amending Regulation (EU) 2019/2088 (EU L 198).
- Regulation (EU) 2019/2088 of the European Parliament and of the Council of 27 November 2019 on sustainability-related disclosures in the financial services sector (Official Journal of the EU L 317).
- Directive (EU) 2022/2464 of the European Parliament and of the Council of 14 December 2022 amending Regulation (EU) No 537/2014, Directive 2004/109/EC, Directive 2006/43/EC and Directive 2013/34/EU as regards company sustainability reporting (Official Journal of the EU L 322).
- European sustainability reporting standards.

In addition, it should also be noted that the EU taxonomy emphasises six environmental objectives, the achievement of which allows for the assessment of economic activity as sustainable [1]):

- Mitigation of climate change (reduction of greenhouse gas emissions),
- Adaptation to climate change (offsetting the harmful effects of climate change on people and nature),
- Protection of water and marine resources,
- Transition to a circular economy,
- Pollution prevention,
- Protection of ecosystems and biodiversity.

The main objectives of the article include an introduction to the concept of sustainable development and ESG reporting, including in particular the issue of environmental reporting by companies from the automotive sector listed on the Warsaw Stock Exchange. The research methodology was based on a review of the literature on the subject, legal acts and the authors' own research, which used non-financial reports of listed companies in the automotive sector containing environmental information and key indicators. The main research problem addressed by the authors was to examine whether automotive companies disclosed environmental information in the period prior to mandatory regulations in this area, and therefore the study was conducted to determine whether these companies reported environmental information before 1 January 2024 and what the scope of these disclosures was (satisfactory or unsatisfactory).

2 Literature review

The environment plays a key role in the functioning and development of companies. It can be said that companies consciously taking co-responsibility for the state of the environment has become a key issue in today's world. Companies should strive to significantly reduce their direct negative impact on the environment by optimising the social and environmental benefits of using modern and environmentally friendly technical and technological solutions. Companies that operate in this way are perceived as socially responsible [2]. According to data from a report by the auditing firm KPMG [3], nearly 76% of the G250 companies surveyed included environmental information in their ESG reports, despite, among other things, the lack of mandatory regulations in this area before 2024. According to Shimshack, disclosures must be very carefully designed to take into account the psychological and behavioural realities of how users react to information. Disclosures must also be evaluated and adjusted ex-post to maximise their effectiveness and social efficiency. Environmental disclosure policies aimed at consumers and public regulators may have a better chance of achieving socially desirable outcomes than those aimed at company managers, investors and employees [4]. The truthfulness and reliability of the environmental information provided by companies, as well as information on the products manufactured or services provided, is also becoming a key issue. Therefore, it is important to audit this information, for example, in terms of greenwashing, i.e. dishonest practices used by companies to present themselves as implementing sustainable development principles by creating a false impression or providing misleading information about a product or service.

There are also very specific programmes in the European Union aimed at ensuring an even smoother transition to a greener economy. One of the most well-known initiatives in recent years is the adoption of the European Green Deal programme. Many proposed and existing programmes, but also EU policies, aim to achieve these environmental goals, even if they are not explicitly formulated in terms of the Sustainable Development Goals [5].

Sustainability reporting is becoming part of management reporting, which means increased responsibility for the company's management bodies in this reporting area. Sustainability reporting is the process of measuring, disclosing and being accountable to internal and external stakeholders for an organisation's sustainability performance [6]. As F. Rosati and L.G. Faria [7] voluntary disclosure of sustainability information in accordance with recognized standards, such as GRI, among others, may indicate that companies already have the skills and mindset necessary to include sustainability goals in their reports. On the other hand, it is also worth noting that many companies do not see sustainability policies as an important part of their financial and operational priorities [8].

The ESG report is the source of information about the company's activities in the field of sustainable development. The information contained in the report is addressed primarily to key stakeholders, such as investors, financial institutions, as well as customers. The ESG reporting obligation applies to:

- from 2024 - large public entities and companies with more than 500 employees and meeting 1 of 2 financial criteria: balance sheet total above 20 million euros and/or revenues above 40 million euros;

- in 2025 - all large companies (including private companies) meeting 2 of 3 criteria: employment of more than 250 employees in a given tax year; balance sheet total above 25 million euros and/or annual revenue above 50 million euros;

- in 2026 - small and medium-sized enterprises (SMEs), with the possibility of postponing data collection and reporting until 2028 and 2029 respectively, meeting 2 of the 3 criteria: Average number of employees in the fiscal year is more than 10; balance sheet total is more than 350.000 EUR and/or revenue is more than 700.000 EUR.

ESG regulations can contribute to better energy management and reduce fuel and electricity consumption within a company. For many industries, the area of environmental reporting seems to be key among ESG indicators. In this area, the most important issue is the entity's impact on the environment and the potential challenges that environmental issues may pose to the company. The scope of reporting in this area mainly concerns: greenhouse gas emissions, greenhouse gas emission intensity, energy consumption and sources, environmental policies. Climate change reporting is suggested as a mechanism to mitigate the impact of companies on climate change, in particular carbon dioxide emissions [9].

Figure 1 shows the evolution of ESG reporting in Poland from 2009 to 2023.

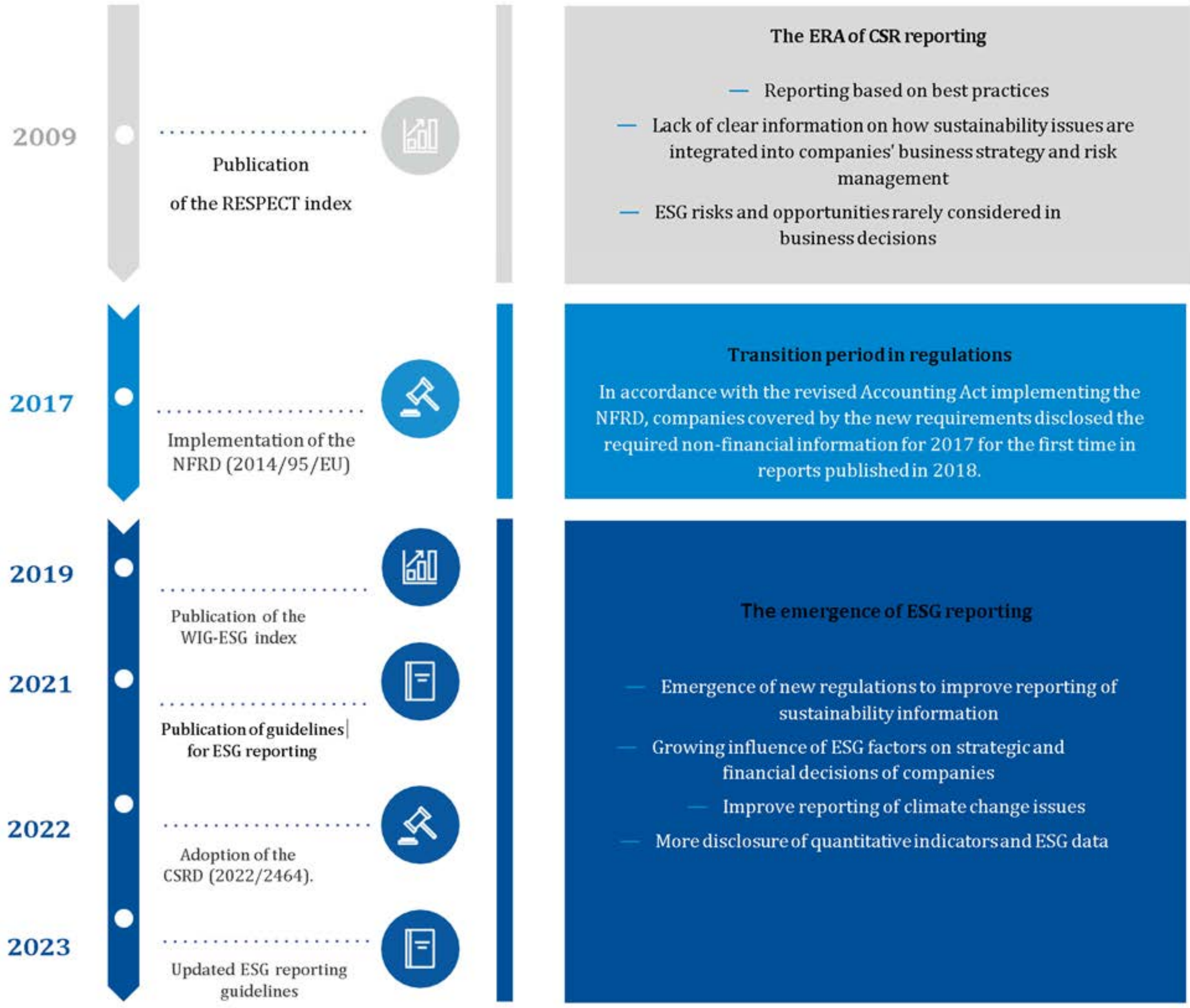

Figure 1 Evolution of ESG reporting in Poland 2009-2023

Modern companies must include ESG factors in their strategies to drive sustainable production processes [10]. This emphasises the need for a sustainability approach that is compliant with regulations and can take into account the changing values of consumers and stakeholders [11]. Studies conducted in the USA indicate a growing number of companies from various sectors, including the automotive sector, in terms of increasing company spending on improving their ESG aspects and activities and making these efforts public through ESG reporting, e.g. More than 90% of the companies in the S&P 500 index publish ESG reports in some forms, as do around 70% of the companies in the Russell index [12]. Research results are also available, which indicate the quality of ESG reporting in public companies in the EU (via the ESG index) and its impact on the market capitalisation of these companies. The authors of the study found that 50% of companies listed on stock exchanges in old EU member states and only 5% of companies in new EU member states reported ESG indices in any year of the study period [13].

The usefulness of non-financial information for the recipients of information generated by the business sector, but also by the public sector, remains an important and current issue. On the one hand, more and more attention is being paid to the fact of ‘information overload’, while on the other hand, it is pointed out that the information is still insufficient for a proper assessment of the entity's performance [14].

ESG reporting is also influenced by problems related to environmental quality and the formulation of problems from the perspective of various stakeholders [15]:

- industry stakeholders, whose primary objective is usually economic optimization within environmental regulation standards;
- communities, which seek to balance socioeconomic welfare through access to jobs while reducing associated environmental contaminants;
- more affluent communities, which would rather have polluting industries re-moved or distanced

from their communities to optimize environmental quality and public health;
- government agencies, whose primary objective is to administer regulations at the nexus of these competing demands.

The key aspect is also the identification of risks, conducting an audit and implementing standardised regulations for reporting ESG information, which can be presented as follows [16]:

1) reporting companies:

- increasing stakeholder engagement to improve risk recognition,
- improvement of risk management and risk reporting, including the presentation of uncertainties at different levels (economic policy uncertainty, business uncertainty, accounting uncertainty, audit uncertainty, ESG performance uncertainty and ESG certainty),
- improvement of results-based reporting, avoidance of standardised disclosures and jargon,
- increasing stakeholder trust through internal and external audit mechanisms,
- improving ethical approaches by prohibiting fraud and greenwashing;

2) controllers (regulators, auditors and creditors):

- increasing monitoring activities to improve the quality of reports in terms of disclosing the impact of uncertainty at different levels of its impact on responsibility,
- ensuring the effectiveness of audit mechanisms;

3) regulators:

- building risk-specific strategies into reporting standards in uncertain times, ensuring that measurement uncertainty issues are properly identified, resolved and verified (by taking into account the impact of uncertainty at different levels of its impact on responsibility).

What is also important is that, according to stakeholder theory, companies should priorities the priorities of each stakeholder involved in the company, not just the priorities of the owners or investors [17].

3 Key environmental indicators of ESG reporting

Regulatory changes have contributed to the growing demand from stakeholders for information and indicators that allow them to assess how companies manage climate-related issues, but also the impact of the company on the environment. As indicated in the literature on the subject, the most common framework for measuring companies' sustainability performance to date is the environmental, social and governance (ESG) perspective [18].

ESG criteria have become key indicators of management competence, risk management and non-financial performance. Furthermore, in contrast to the concepts of Corporate Social Performance (CSP) or Corporate Social Responsibility (CSR), ESG explicitly covers a wide range of issues relating to the environment (e.g. climate change), social responsibility (e.g. employee welfare) and governance (e.g. independence of the board of directors) [19].

Table 1 shows the environmental indicators of ESG reporting in terms of their compliance with EU regulations and other reporting frameworks. The following list of indicators includes the environmental indicators proposed by the Warsaw Stock Exchange in the publication ‘Guidelines for ESG Reporting. A Guide for Companies’ (European Bank for Reconstruction and Development & GWP in Warsaw, 2023), which are used by automotive companies that are the subject of the empirical chapter on environmental reporting when initiating communication on ESG issues with the market environment. The recommended indicators have been prepared based on relevant regulations such as CSRD and ESRS, as well as the Best Practices of WSE Listed Companies (DPNS2021). In addition, to meet the growing data needs of investors, they have also been aligned with the mandatory PAI indicators for investments in companies required by SFDR. It should be emphasised that the Guidelines do not contain an exhaustive list of indicators and topics. Rather, they aim to provide companies with a basic set of selected indicators to help them prepare for the upcoming CSRD and ESRS requirements and better meet investors' ESG data needs.

Table 1 Relevant environmental indicators of ESG reporting

Indicator	Type of indicator (expressed in units of measurement or descriptive)	Alignment with EU regulations		Alignment with other reporting framework
		European Sustainability Reporting Standards	Sustainable Finance Disclosure Regulation	Global Reporting Initiative
Environmental indicators directly linked to climate change:				
E-P1 Managing climate change issues	Descriptive	YES	NO	YES
E-P2 Greenhouse gas emissions	Tons of CO2 eq.	YES	YES	YES

E-P3 Intensity of greenhouse gas emissions greenhouse gases	CO2 eq. tons/revenue	YES	YES	YES
E-P4 Energy consumption and its sources	MWh	YES	YES	YES
Environmental indicators on environmental issues other than climate change:				
E-P5 Environmental policy	Policy description	YES	NO	YES
E-D1 Water consumption	m^3	YES	NO	YES
E-D2 Water resources management	Descriptive	YES	NO	YES
E-D3 Impact on biodiversity	Descriptive	YES	YES	YES
E-D5 Waste management	Descriptive	YES	-	YES

Source: author's work based on International Foundation for Valuing Impacts [20].

Table 2 presents the Environmental Indicators related to climate change, in terms of ESG reporting, and synthesizes the definition of each indicator and the minima of information disclosure.

Table 2 Synthesizes the key disclosures for the indicators presented

Environmental indicators directly linked to climate change:		
Indicator	**Definition**	**The minimum disclosure applies to:**
E-P1 Managing climate change issues	In preparing climate-related disclosures, companies should make use of materials such as TCFD recommendations, ESRS standard E1 Climate Change and/or IFRS S2	Climate-related disclosures that provide detailed explanations for aspects such as governance, strategy, risk management, and targets and indicators.
E-P2 Greenhouse gas emissions	Greenhouse gas emissions represent the total sum of direct and indirect greenhouse gas emissions. They can be divided into Scope 1, Scope 2 and Scope 3 emissions.	• Methods and assumptions used in calculating emissions • Scope 1, 2, and 3 emissions (if relevant) for the last 3 years to allow evaluation of the trend over time • A relevant explanation if there has been a significant change in the value of the issue (both increase and decrease). • It is recommended that companies use international standards for calculating and disclosing greenhouse gas emissions, such as the GHG Protocol or the ISO 14064-1:2018 standard.
E-P3 Intensity of greenhouse gas emissions greenhouse gases	Greenhouse gas intensity is the amount of greenhouse gas emissions per unit of economic activity.	• Methods and assumptions used in the calculations. • The ratio of greenhouse gas emissions intensity to revenue.
E-P4 Energy consumption and its sources	Energy consumption is the total amount of energy used in an organization. It includes both energy purchased from suppliers and generated internally.	• Methods and assumptions used in calculating energy consumption. • Total energy consumption in the organization (in MWh).

		• Percentage (%) of energy consumed by energy type (i.e., renewable and non-renewable sources, energy).
Environmental indicators directly linked to climate change:		
Indicator	**Definition**	**The minimum disclosure applies to:**
E-P5 Environmental policy	An environmental policy is a formal document that sets out a company's commitments and approach to managing environmental aspects	• Has the company adopted an environmental policy • Compliance with relevant environmental laws and regulations • Commitment to manage and mitigate adverse environmental impacts • Implementation of a management system for environmental issues • Monitoring of results • The company's expectations of suppliers and business partners in managing environmental issues.
E-D1 Water consumption	Water consumption means the total amount (in m3) of water used in the enterprise.	• The total amount of water used in the enterprise (in m^3). • Percentage of water recycled and reused in relation to total water withdrawal
E-D2 Water resources management	Water stewardship refers to the process a company has implemented to optimize water consumption and thereby minimize its environmental impact. It includes measures to reduce water consumption, increase water circulation (through reuse and recycling) and conserve water resources.	• Whether the company has adopted and implemented a water management program and what activities comprise it • Companies operating in water-scarce areas should also disclose how they are identifying and mitigating the associated risks.
E-D3 Impact on biodiversity	Biodiversity, according to the United Nations Convention on Biological Diversity, is defined as “a term for the diversity of life forms on Earth in their natural shape and form.” It includes species, genetic and ecosystem diversity.	• Does the company's operations negatively impact biodiversity (directly or indirectly through the supply chain) and what are the main reasons for this. • Has the company implemented a policy to protect and restore biodiversity and counter deforestation, and does it extend to suppliers.
E-D5 Waste management	Waste management refers to a range of activities to monitor, manage and reduce waste (including reuse or recycling) generated within a company.	• Amount of hazardous waste and other waste produced (in tons). • Percentage of waste (%) by disposal method (e.g., recycled, landfilled). • A description of the measures taken to manage waste and comply with relevant regulations.

Source: author’s work based on International Foundation for Valuing Impacts [20].

Companies that disclose ESG information currently use various reporting standards and frameworks, which usually include both qualitative and quantitative information. Ongoing qualitative disclosures focus on sustainability, core values and net zero goals and commitments to show how these factors create value for both shareholders and stakeholders. The quantitative information disclosed on an ongoing basis includes the indicators used for reporting and measurement, progress towards the objectives set out in the qualitative information, safety data, energy used in production, water management data, and data on air quality and greenhouse gases and energy, including scope 1, 2 and 3 greenhouse gas emissions.

4 Results and discussion

In the empirical chapter, the authors analysed 5 automotive companies listed on the Warsaw Stock

Exchange to determine whether and to what extent they disclosed ESG information in 2022-2023. In their reports, company managers emphasise their awareness of the environmental impact of their activities. The main measures taken by companies to reduce greenhouse gas emissions include the development of a climate policy, the creation of a green product range to attract customers, and the strengthening of the transparency of ESG policies.

Table 3 presents the basic financial data describing the economic and financial potential of the analysed companies, which is important due to the impact of these entities on the environment in the scope of their operations.

Table 3 Important financial data characterising the analysed companies for 2022-2023

Company	**Year's**	**Sales revenues** (in thousands of PLN)	**EBITDA** (in thousands of PLN)	**Balance sheet total** (in thousands of PLN)
Auto Partner SA	2022	2 834 701	314 218	1 570 282
	2023	3 653 384	346 228	1 793 923
Inter Cars SA	2022	15 285 101	1 197 208	8 034 046
	2023	18 030 309	1 217 522	9 271 136
Tire Company Dębica SA	2022	3 277 965	175 181	2 214 744
	2023	2 992 411	419 830	2 430 966
Sanok Rubber Company SA	2022	1 445 601	150 348	1 029 794
	2023	1 446 378	138 930	1 204 752
Wielton SA	2022	3 433 366	203 040	2 104 817
	2023	3 225 223	206 580	2 002 354

Source: author's work based on the financial statements of the analysed companies, data available on their websites [21-25].

Table 4 presents, in summary, the results of the authors' research on the reporting by the companies in the research sample of the value of environmental indicators directly related to climate change (E-P1 - E-P4).

Table 4 Values of environmental indicators directly related to climate change reported by companies in the survey sample

Company	**Year's**	**E-P1** Managing climate change issues	**E-P2** Greenhouse gas emissions CO_2 eq. tons / revenue	**E-P3** Intensity of greenhouse gas emissions greenhouse gases	**E-P4** Energy consumption and its sources MWh or GJ or BTU
Auto Partner SA	2022	YES	-	-	-
	2023	YES	-	-	-
Inter Cars SA	2022	YES	1 524 017	8,869	80 098 (GJ)
	2023	YES	1 696 548	8,611	70 247 (GJ)
Tire Company Dębica SA	2022	YES	37 000	-	5 769 (BTU)
	2023	YES	33 000	-	6 118 (BTU)
Sanok Rubber Company SA	2022	YES	39 715 235	-	487 515 (GJ)
	2023	YES	38 426 333	-	471 138 (GJ)
Wielton SA	2022	YES	374 463	16,2	215 737 (GJ)
	2023	YES	411 685	19,8	181 033 (GJ)

Source: author's work based on the ESG report of the analysed companies, data available on their websites [26-30].

In terms of disclosures regarding the management of climate change issues (E-P1), each of the companies indicated that the company's management boards take such actions internally. From the information available on websites and in the ESG reports of the companies analysed, it is possible to find statements from the management boards that managers are aware of the impact of the companies' activities on the climate, as well as the impact of climate change risks themselves on the companies' activities. Managers emphasise that they have a good understanding of stakeholders' expectations regarding the reporting of the company's environmental impact. Managers consider climate risk management to be a key element of strategic management. Company management indicates that climate-related risks are analysed in terms of both the impact of climate change on operations (business as usual) and the impact of business on climate change. Company management indicates that they are intensifying their efforts to meet regulatory requirements, including the EU Taxonomy.

In terms of greenhouse gas emissions disclosure (E-P2), only 4 out of 5 companies analysed made full disclosures for the years 2022-2023. In the case of Inter Cars SA and Wielton SA, an increase in emissions was noticeable. From the available information provided by the management boards of the companies, a number of activities that the companies undertook to reduce CO_2 emissions should be pointed out. The main activities include, among others, reducing energy and water consumption and new energy-saving investments. The reports provide information that Inter Cars SA, Tire Company Dębica SA, Sanok Rubber Company SA and Wielton SA have actively and consciously taken steps to implement the carbon footprint calculation standard.

When it comes to reporting information on greenhouse gas emission intensity (E-P3), only two companies (Inter Cars SA and Wielton SA) have disclosed full data for 2022-2023. The companies have also indicated that they will increase the share of renewable energy sources in the future. It is worrying that the other companies do not have emission data in this regard. Nevertheless, it should be noted that they were not obliged to do so during the period for which the analysis was carried out.

Regarding the scope of disclosures related to energy consumption information (E-P4), only 4 companies disclosed full information in the analysed period. In most cases, there was a decrease in energy consumption in the analysed period. This should be considered a positive aspect of the energy consumption reduction strategies implemented in these companies, among other things. With regard to Autopartner SA, although the management boards of these companies indicate that they are trying to reduce energy consumption, there is a lack of hard figures confirming this fact.

Table 5 shows, in summary, the authors' findings on the reporting of environmental information on other environmental issues by the companies in the research sample (E-P5, E-D1, E-D2, E-D3, E-D5).

Table 5 Values of environmental indicators regarding other environmental issues

Company	Year's	E-P5 Environmental policy	E-D1 Water consumption	E-D2 Water resources management	E-D3 Impact on biodiversity	E-D5 Waste management
Auto Partner SA	2022	✓	-	✓	✓	✓
	2023	✓	-	✓	✓	✓
Inter Cars SA	2022	✓	62 152	✓	✓	✓
	2023	✓	65 654	✓	✓	✓
Tire Company Dębica SA	2022	✓	-	✓	✓	✓
	2023	✓	-	✓	✓	✓
Sanok Rubber Company SA	2022	✓	336 160	✓	✓	✓
	2023	✓	325 822	✓	✓	✓
Wielton SA	2022	✓	53 938	✓	✓	✓
	2023	✓	103 081	✓	✓	✓

Source: author's work based on the ESG report of the analysed companies, data available on their websites [26-30].

With regard to the disclosure of environmental policy management (E-P5), the management of each company indicated that it had implemented such a policy. The management boards indicate that it is implemented primarily in order to meet the requirements related to environmental aspects, including legal regulations. The companies plan their development based on modern and environmentally friendly technologies. The management boards indicate that they minimise the negative impact on the environment, among others, through appropriate management in the areas of water and sewage management and air pollutant emissions, limiting the amount of waste generated. It should also be noted that criterion E-P5 is a descriptive criterion, and therefore it must be stated that the effects of the implemented strategies will only start to bring measurable benefits in a period longer than the scope of the analysed reports. Thus, the actual, measurable benefits should become apparent in the future. This information seems to be important, but it is difficult to verify at present.

Disclosures regarding water consumption (E-D1) are also important cognitive information. In the analysed sample, only 3 companies (Inter Cars SA, Sanok Rubber Company SA and Wielton SA) provided an estimate of their water consumption. In the case of the remaining companies, despite the fact that their ESG reports indicate that they follow the principle of conservation and that they monitor and optimise the consumption of water used for technological purposes on an ongoing basis, it is difficult to say unequivocally whether the described measures have actually translated into lower water consumption due to the lack of figures.

In terms of disclosures concerning water management (E-D2), each company indicated that it takes action in this area. The scope of activities described was at a general rather than a detailed level. For example, the management boards indicated that, following the principle of efficient resource management, they monitor and optimise the consumption of water used for technological purposes on an ongoing basis.

In terms of impact on biodiversity (E-D3), companies indicated that they are taking action in this area. Most companies in the research sample indicate in their ESG reports that they are actively working to preserve and develop biodiversity. Companies indicate that they are taking action to protect environmental resources. They implement a range of partnerships and their own projects to monitor, protect and develop ecosystems. The companies co-sponsor and cooperate with partners involved in nature conservation and ecology.

In the area of waste management (E-D5), company management indicated that it is taking action in this area.

Compliance with legal regulations regarding ESG reporting is also a key issue [31-33].

5 Conclusions

Reporting environmental information plays a key role for stakeholders today. A company's responsibility for the environment has become a key issue in today's world. As companies grow and expand, their impact on the environment becomes more and more significant.

The study conducted by the authors had a practical aspect of reporting environmental information by companies from the automotive sector listed on the Warsaw Stock Exchange. The study was conducted for the years 2022-2023 to determine whether automotive companies, despite the lack of mandatory regulations in the analysed period, nevertheless reported such data and whether or not the scope of disclosures was satisfactory for stakeholders. The companies in the research sample carried out ESG reporting in the analysed period.

It should be noted that the results of the research conducted in the empirical chapter indicate that the companies from the analysed research sample despite the lack of mandatory requirements for reporting environmental information and ESG indicators in 2022-2023, the vast majority of them presented such data in their non-financial reports, which should be considered a positive aspect. However, the scope of information, environmental indicators and the detail of descriptions varied.

In the case of the analysed reports, it should be noted that the scope of disclosures is at a satisfactory level. Often, in these companies' reports, despite indicating that the companies are, for example, reducing their energy and water consumption or greenhouse gas emissions, there was a lack of hard figures confirming these activities. Whether or not a company can be said to have a management approach depends on hard facts - often having environmental objectives in the adopted business strategy, developing a sustainable development strategy, assigning responsibility for sustainable development to the management board or holding management accountable.

The results of the analysis can be used by the reader to summarise the scope of disclosures in the reporting of environmental information by companies to the environment at a time when such disclosures were not mandatory. The results presented can also be used to compare the level of detail of these disclosures by companies from Poland with companies from the automotive sector from other countries.

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Enhancing logistics of intermittent demand items: optimization via simulation based stock control using empirical method

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Abstract: In this paper we examine whether empirical method can replace bootstrapping in intermittent demand stock control based on simulation. Thus, we generate artificial demand data with 30; 50 and 70 % of zero demand periods and simulate reorder point/fixed order quantity inventory control policy using past stock movement simulation and the local search to obtain the optimal trade-off between holding and ordering costs and the required fill rate for order lead time 2; 6; 12 and 18 periods. The outputs from simulation experiments prove that empirical method outperforms bootstrapping in term of the consumption of computational time while maintaining similar ability to overestimate lead time demand. Thus, empirical method can become a suitable substitute of bootstrapping in the local search. Moreover, it can be successfully used to generate an initial reorder point in a more on a one-way neighbourhood search oriented optimization. As empirical method copes both with theoretical and empirical demand distributions and does not require a deciding on number of sampling runs, an optimization of smoothing constants based on a selection of an appropriate accuracy metric, an adoption of a demand classification schemes or a data aggregation it is well predetermined to become an important part of a simulation-optimization software solution focusing on sporadic demand inventory control in large scale real life tasks.

1 Introduction

One of the most important tasks in supply chain management is inventory control. By effectively managing inventory such that total cost of ownership is kept to a minimum, the best inventory control techniques aim to lower supply chain costs. Today's market competitiveness is largely determined by a company's capacity to manage the difficulties of cutting expenses and lead times, raising customer satisfaction standards, and enhancing product quality [1]. The challenge of inventory management is to maintain a sufficient supply of a given good to satisfy an anticipated demand pattern while finding a fair trade-off between the expense of keeping the thing in stock and the potential consequences of running out [2].

Intermittent demand, characterized by sporadic demand arrivals with varying sizes and frequent periods of zero demand, poses a significant challenge in forecasting and stock control [3]. Intermittent demand is a prevalent phenomenon in various industries. Sectors like process industries, aerospace, automotive, IT, and the military often have a significant portion of their inventory value attributed to intermittent demand items, particularly in service and repair parts inventories [4]. Additionally, the after-sale industry heavily relies on items with intermittent demands, underscoring their importance in post-sales service [5].

To guarantee successful and economical operations throughout the supply chain, a variety of optimization approaches, technologies, and risk management measures must be integrated when dealing with this kind of demand pattern. In the literature, parametric time series forecasting based on single exponential smoothing (SES) is considered to represent a mainstream approach [6]. It requires to estimate mean and variance of lead time demand with help of a time-series forecasting method and subsequently use these characteristics as an input to stock management usually aimed at reaching the trade-off between a service level and inventory costs [7]. Time series forecasting techniques are widely used in practice because they are straightforward and simple to use. They mostly rely on historical data and make little effort to determine the factors driving the need for demanded items by including contextual information (e.g., expert assessments, product attributes, maintenance information). As a result, they can be easily automated using data that is readily available in ERP systems and take less work to acquire. However, the major drawbacks of the parametric techniques represent an assumption on a standard demand distribution and also perceiving demand forecasting and inventory control to be two separated stages [8].

That leads to the development of alternative data driven approaches including mainly bootstrapping [9], empirical method [10] and most recently the applications of neural networks [11]. As all these non-parametric approaches do not assume the order lead time demand to follow a particular distribution they are suitable for applications in demand forecasting of items with quite complicated and intriguing patterns. On the other hand these approaches still separate estimating order lead time demand from inventory optimization not taking into account a calculation of economic order quantity. Moreover, time consumption to obtain an estimation of order lead time demand can be excessive when compared to traditional parametric time series methods as non parametric techniques may require repeated sampling or lengthy learning about a demand pattern from historical data making the applications of these methods potentially expensive mainly when speaking about large scale real life tasks [12].

The idea of optimizing both when and how much to order as a conjunctive task represents the core of past stock movement simulation (PSMS) [8]. In PSMS a simulated period is divided into time intervals of equal length and a demanded quantity is assigned for each interval based on either historical real demand data or data derived from a generation technique. For each interval a replenishment, a direct demand satisfaction from available inventory, and an ordering is simulated under the control of a selected inventory control policy. To obtain the optimal combination of control variables for the selected inventory control policy an optimization technique is employed trying to reach the trade-off between the required service level and minimal holding and ordering costs. In the literature this procedure is called optimization via simulation [13]. Optimization via simulation (OvS) provides a versatile and effective way to address complex optimization problems in different domains by integrating simulation models with optimization algorithms to efficiently find optimal solutions [14]. More specifically in this case of multiproduct inventory management, the system design variables are discrete valued, and thus the optimization problems are discrete optimization via simulation (DOvS) problems [15]. For DOvS problems many optimization techniques are available including heuristics such as random search [16] or hill climb [17] and metaheuristics represented for example by evolutionary algorithms [18], tabu search [19] or simulated annealing [20]. In this paper, rather than on the efficient exploring of a solution space we focus on its reduction following the idea of local search (LS) proposed by [8]. These authors pointed out that supplementing PSMS with all combinations search (AC) certainly outperforms parametric forecasting methods in term of reaching lower holding and ordering costs, though it suffers from excessive consumption of computational time for time series with a high total non-zero demand (*S*). Thus, in LS, [8] underestimate order lead time demand using linear regression (R_{LR}) and overestimate order lead time demand using bootstrapping (R_B) and manage to explore significantly reduced number of R_B – R_{LR} reorder points/fixed order quantity (*Q*) combinations in (*R*, *Q*) inventory control policy bringing substantial savings of the computational time while maintaining pretty decent ability to reach the best possible holding and ordering costs (i.e. the ability to outperform parametric forecasting methods). We continue to develop the principles of LS and examine whether in the overestimating order lead time demand a replacing bootstrapping with empirical method (EM) has a potential to bring additional time savings as bootstrapping is based on tardy repetitive sampling from historical demand data. Thus, we generate artificial intermittent demand data with a different level of sporadicity (i.e. 30; 50 and 70 % of zero demand periods), simulate (*R*, *Q*) inventory control policy and compare PSMS+AC, PSMS + LS with LR and B and PSMS + LS with LR and EM in term of the consumption of computational time and trade-off between required fill rate and minimal reached holding and ordering costs for lead times ranging from 2 to 18 periods.

2 Methodology

2.1 Replacing bootstrapping with empirical method in overestimating lead time demand

As bootstrapping originally proposed by [21] requires to set a sufficient number of sampling runs (i.e. 100; 1 000; 5 000…) consisting of lead time selections of a demand from historical data to construct an empirical distribution of lead time demand it can be quite time consuming. That is why we suggest to simplify this procedure and employ empirical method by [22] which is also a way easily to understand and implement. Empirical method does not randomly sample demands from a time series, it just gradually sums up these demands according to a lead time and similarly to bootstrapping creates an empirical distribution of lead time demand. If a time series consists for example of 20 periods and order lead time is 2 periods, empirical method creates 10 sums for periods 1+2; 3+4; ….; 19+20, uses these sums to create the distribution of order lead time demands and based on a required service level the reorder point is directly set according to the distribution function. A disadvantage of this method is a potentially low number of lead time demands coming from too short time series or too long lead times and that is why we in this study examine the functionality of empirical method for different order lead times (i.e. 2, 6, 12 and periods).

2.2 Demand data characteristics

To compare the performance of bootstrapping and empirical method, we create 3 artificial demand data sets each consisting of 10 000 time series with number of zero demand periods 30; 50 and 70 %. The length of a time series is 36 periods. To generate artificial demand data, we apply the two stage process proposed by [8]. At the first stage we randomly generate non-zero demands per period uniformly distributed between 1 and 30 pieces and then we replace randomly selected non-zero demands with zeros to obtain required level of sporadicity. To classify demand patterns of a time series within the data sets we use average demand interval (*ADI*) based on equation (1):

$$ADI = \frac{36}{N_{S_t}} \qquad (1)$$

where N_{S_t} represents number of non-zero demand periods and squared coefficient of variation (CV^2) based on equation (2):

$$CV^2 = \left(\frac{\sigma_{St}}{\bar{S}_t}\right)^2 \tag{2}$$

where σ_{St} represents non-zero demand standard deviation and $\bar{S}_t$ represents non-zero demand average.

We apply a demand classification scheme described in [23] using *ADI* equal to 0.49 and CV^2 equal to 1.32 decisive values to distinguish among smooth, erratic, intermittent and lumpy demand pattern. Number of time series with the certain demand pattern displays Table 1 together with minimal (S_{min}), maximal (S_{max}) and average total demand (S_{avg}).

Table 1 Features of randomly generated demand data

	Demand pattern						
0 demand periods	Smooth	Intermittent	Erratic	Lumpy	S_{min} [pcs]	S_{max} [pcs]	S_{avg} [pcs]
30 %	0	9 632	0	368	227	547	387
50 %	0	9 414	0	586	152	419	279
70 %	0	8 996	0	1 004	69	278	170

It can be seen in Table 1 that we work predominantly with intermittent demand pattern with increasing number of lumpy time series.

2.3 Past stock movement simulation and arrangement of simulation experiments

To simulate randomly generated data we modify original PSMS+LS Excel VBA code and also original PSMS+AC Excel VBA code described in [8] in a way to measure the consumption of computational time separately for R_{LR}, R_B, and R_{EM} calculations and subsequent exploration of a solution space (Figure 1).

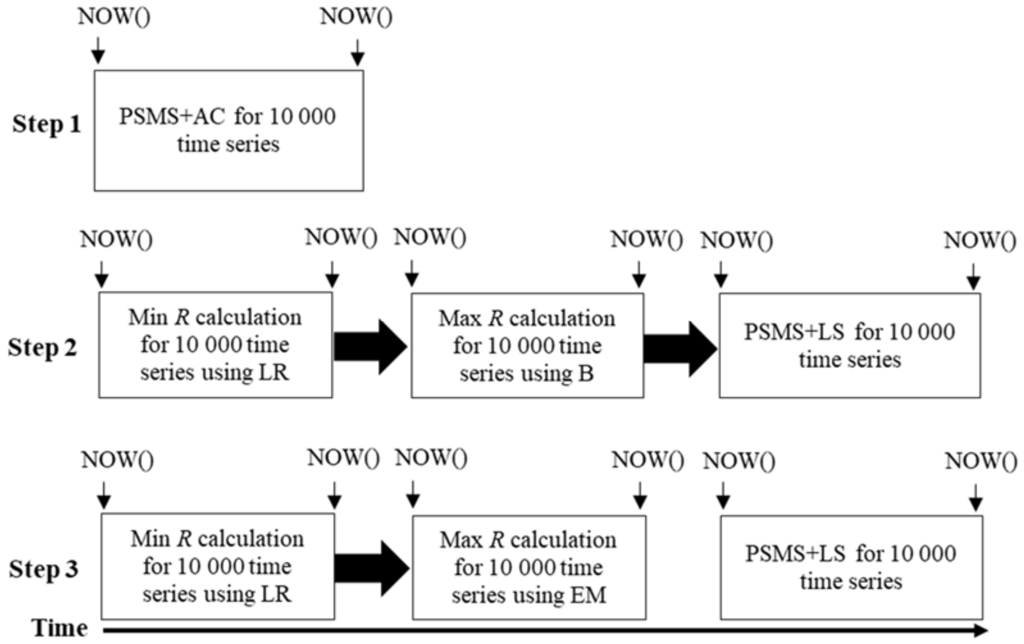

Figure 1 Arrangement of experiments for a data set

We simulate (R, Q) inventory control policy taking into account only such reorder point (R)/fixed order quantity (Q) combinations where $Q > R$. In all simulation experiments we use parameters summarized in Table 2 including holding costs (c_h), ordering costs (c_o), required fill rate (FR) and price (p).

Table 2 Parameters of simulation

c_h [% of average stock in €/period]	4%
c_o [€/1 order]	16
FR [%]	95%
p [€/piece]	70

For a time series and a simulated R, Q combination ensuring at least FR we calculate total holding and ordering costs (C_t) using equation (3):

$$C_t = AI \cdot c_h \cdot p \cdot 36 + N_o \cdot c_o \tag{3}$$

where AI represents average inventory and N_o number of orders.

In agreement with [8] there is no backordering, a partial satisfaction of demand is available and initial inventory is unified in all simulation experiments. Number of sampling runs for bootstrapping is set to be 100. Combining 3 artificial demand data sets (i.e. 10 000 time series each) with PSMS+AC for lead times equal to 2, 6, 12, 18 periods, with original PSMS+LS based on LR and B reorder points estimations for lead times equal to 2, 6, 12, 18 periods and with modified PSMS+LS replacing B with EM again for lead times equal to 2, 6, 12, 18 periods we carry out 3 · 10 000 · 3 · 4 = 360 000 simulation experiments. To execute simulation experiments in MS Excel 2016 environment we use laptop with 2,8 GHz, 16 GB RAM processor.

3 Results and discussion

First, we try to find out whether the empirical method reliably fulfil the role of overestimating order lead time demand and can be therefore an appropriate alternative to bootstrapping. Thus, for every simulated combination of the level of sporadicity (i.e. 30; 50; 70 % of zero demand periods)/order lead time (i.e. 2; 6; 12 and 18 periods) we calculate the differences among reorder points (Δ_R) for a simulated time series in the form of percentiles (Table 3) and also create distributions of reorder points connected with the best reached minimal holding and ordering costs for a simulated time series (Figure 2).

As PSMS+AC returns the best possible holding and ordering costs for a correct function of PSMS+LS based on LR and B or LR and EM we expect $R_{LR} \leq R_{AC} \leq R_B$ or similarly $R_{LR} \leq R_{AC} \leq R_{EM}$. The results in Figure 2 and Table 3 show that overestimated reorder points based on empirical method are distributed closer to the distribution of the best possible reorder points (i.e. R_{AC}s) than reorder points based on bootstrapping. For example in case that level of demand sporadicity is 30 % zero demand periods and lead time is equal to 2 periods the minimal difference R_{EM} - R_{AC} is 1 and 95 % percentile is 30 while the minimal difference R_B - R_{AC} is 4 and 95 % percentile is 32 (see Table 3, rows 4 and 6; red font values). For this combination of the level of demand sporadicity and lead time the local search proposed by [8] performs correctly for the most of simulated time series because minimal R_B - R_{LR} > 0 (see Table 3, row 5) and for at least 95 % of simulated time series R_{LR} – R_{AC} < 0 (see Table 3, row 3). This is in accordance with findings in [8] proving PSMS+LS to work efficiently for smooth/slightly intermittent demand pattern (see Table 1) and we claim also whether order lead time is relatively short. This is because with increasing order lead time the underestimating lead time demand with LR works improperly as for example in case that level of demand sporadicity is 30 % zero demand periods and lead time increases from 2 to 6 periods now for at least 20 % of simulated time series R_{LR} - R_{AC} > 0 (see Table 3, row 8). Moreover, with increasing lead time we also register an occurrence of both R_B - R_{AC} < 0 and R_{EM} - R_{AC} < 0 (see e.g. Table 3, rows 9, 11, 14, 16, 19 and 21; green font values). That brings a potential difficulty to find at least a feasible suboptimal solution with PSMS+LS because order lead time estimations based on LR, B and EM are too low and in many cases they cannot be sufficiently compensate with higher replenishment orders to reach at least required service level. Before we examine this problem closely and summarizes number of simulation experiments where PSMS+LS returns no solution (i.e. results in Table 4) we want to emphasize that the above described inability of LS to work properly continues to deteriorate with increasing level of demand sporadicity when mainly LR is unable to underestimates lead time demand. More specifically, while for the level of demand sporadicity 30 % zero demand periods and order lead time equal to 2 periods R_{LR} – R_{AC} < 0 is reached for at least 95 % of simulated time series, for 50 % zero demand periods it goes down to 90 % (see Table 3, row 23) and for 70 % of zero demands it further decreases to 80 % (see Table 3, row 43). This is mainly because the distribution of R_{AC}s is becoming more volatile and with increasing number of time series with R_{AC} = 1. On the other hand the ability of B and EM to overestimate lead time demand remains pretty decent regardless to the growing level of sporadicity and in case of B it is very stable even for higher lead times. For EM, despite R_{EM} - R_{AC} are in general lower than R_B - R_{AC} with increasing lead time more and more time series tend to R_{EM} - R_{AC} < 0 (see e.g. Table 3, rows 56 or 61) because number of lead time demands coming from time series drops (i.e. from 36/2 = 18; 36/6 = 6; 36/12 = 3 to 36/18 = 2) negatively affecting the ability of EM to build the empirical distribution of lead demand and subsequently to overestimate lead time demand for a required service level successfully.

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Table 3 Δ_R percentiles

			Δ_R - percentiles [%]													
0 demand periods [%]	**Lead time**	**B/EM**	**0**	**5**	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**95**	**100**	Δ_R
30	2	Both	-26	-19	-18	-16	-15	-14	-12	-11	-10	-8	-5	-2	11	R_{LR} - R_{AC}
		B	4	13	15	17	19	20	22	23	25	27	30	32	50	R_B - R_{AC}
			18	27	29	30	32	33	34	35	36	38	39	41	48	R_B - R_{LR}
		EM	1	10	12	14	16	18	19	21	22	24	28	30	52	R_{EM} - R_{AC}
			16	23	25	27	29	30	31	33	34	36	38	40	47	R_{EM} - R_{LR}
	6	Both	-63	-23	-19	-14	-11	-8	-6	-4	-1	2	7	12	54	R_{LR} - R_{AC}
		B	-27	22	27	32	35	38	41	44	47	51	56	62	112	R_B - R_{AC}
			20	35	38	41	43	45	47	49	51	53	57	59	80	R_B - R_{LR}
		EM	-17	10	14	18	22	25	28	31	35	39	46	53	113	R_{EM} - R_{AC}
			9	21	23	27	29	32	34	37	39	43	48	52	84	R_{EM} - R_{LR}
	12	Both	-72	-29	-21	-13	-7	-3	1	5	10	17	26	34	107	R_{LR} - R_{AC}
		B	-30	29	37	46	52	57	62	67	72	79	88	97	161	R_B - R_{AC}
			21	44	47	52	55	58	61	63	66	69	74	78	114	R_B - R_{LR}
		EM	-16	5	11	15	18	23	28	35	42	51	64	76	170	R_{EM} - R_{AC}
			5	14	17	21	24	27	30	33	36	41	48	54	112	R_{EM} - R_{LR}
	18	Both	-78	-29	-21	-12	-5	1	7	14	22	33	50	64	154	R_{LR} - R_{AC}
		B	-17	35	46	58	66	74	81	88	96	107	121	134	219	R_B - R_{AC}
			26	50	54	60	64	67	71	74	78	82	88	93	121	R_B - R_{LR}
		EM	-8	5	11	16	18	20	24	33	43	56	77	95	218	R_{EM} - R_{AC}
			-9	7	10	13	16	20	23	26	30	35	42	48	84	R_{EM} - R_{LR}
50	2	Both	-29	-20	-18	-16	-14	-12	-11	-9	-7	-5	-2	1	13	R_{LR} - R_{AC}
		B	-5	10	12	15	17	19	21	23	25	28	31	34	51	R_B - R_{AC}
			13	23	24	27	29	30	32	33	34	36	39	40	51	R_B - R_{LR}
		EM	-6	7	9	12	14	16	18	19	22	24	28	32	50	R_{EM} - R_{AC}
			14	20	21	23	24	26	28	30	32	34	37	39	49	R_{EM} - R_{LR}
	6	Both	-66	-24	-19	-13	-10	-7	-5	-2	1	5	12	19	52	R_{LR} - R_{AC}
		B	-23	18	23	29	33	36	39	43	47	51	59	65	105	R_B - R_{AC}
			27	32	36	37	40	42	44	46	48	51	54	56	65	R_B - R_{LR}
		EM	-13	7	11	16	19	23	26	29	34	39	48	57	120	R_{EM} - R_{AC}
			8	18	20	23	26	29	31	33	36	40	45	50	85	R_{EM} - R_{LR}
	12	Both	-71	-27	-20	-11	-6	-1	3	8	14	20	30	39	112	R_{LR} - R_{AC}
		B	-21	26	34	43	50	55	60	66	71	79	90	100	174	R_B - R_{AC}
			12	39	43	48	51	54	57	60	62	66	71	75	104	R_B - R_{LR}
		EM	-37	0	7	12	16	22	28	35	42	52	65	77	185	R_{EM} - R_{AC}
			0	11	14	17	20	23	26	30	33	38	45	51	96	R_{EM} - R_{LR}
	18	Both	-92	-31	-23	-13	-7	-1	5	12	20	32	49	63	147	R_{LR} - R_{AC}
		B	-33	29	39	51	60	68	75	82	90	101	116	129	208	R_B - R_{AC}
			16	45	50	55	60	63	67	70	74	78	84	90	120	R_B - R_{LR}
		EM	-9	-1	6	11	12	14	19	27	38	51	73	91	213	R_{EM} - R_{AC}
			-10	4	7	10	13	16	20	23	27	32	39	44	95	R_{EM} - R_{LR}
70	2	Both	-35	-19	-17	-14	-12	-10	-8	-6	-4	-2	1	3	13	R_{LR} - R_{AC}
		B	-16	4	6	9	12	14	16	19	21	23	27	29	50	R_B - R_{AC}
			9	18	19	21	22	23	24	25	26	28	32	35	49	R_B - R_{LR}
		EM	-8	5	7	9	11	13	15	17	19	22	25	28	52	R_{EM} - R_{AC}
			9	17	19	20	21	22	23	24	25	27	30	34	49	R_{EM} - R_{LR}
	6	Both	-53	-21	-16	-11	-8	-5	-2	1	4	9	16	21	44	R_{LR} - R_{AC}
		B	-22	14	19	24	28	32	35	39	43	48	55	61	89	R_B - R_{AC}
			12	25	27	31	33	35	37	39	41	44	48	51	70	R_B - R_{LR}
		EM	-13	4	8	12	16	20	23	27	31	37	46	54	97	R_{EM} - R_{AC}
			5	14	16	19	21	23	25	28	30	34	39	43	73	R_{EM} - R_{LR}
	12	Both	-57	-21	-15	-8	-3	1	5	10	15	21	31	39	79	R_{LR} - R_{AC}
		B	-22	23	30	38	44	49	54	59	65	72	83	91	136	R_B - R_{AC}
			9	31	35	39	42	45	48	51	54	58	63	67	92	R_B - R_{LR}
		EM	-32	-1	5	9	15	21	26	32	39	47	60	72	154	R_{EM} - R_{AC}
			-2	8	10	13	16	18	21	24	27	31	37	43	99	R_{EM} - R_{LR}
	18	Both	-71	-27	-21	-12	-6	-1	5	11	19	29	44	56	116	R_{LR} - R_{AC}
		B	-21	23	32	42	50	57	64	70	78	88	101	113	170	R_B - R_{AC}
			9	36	40	45	49	53	56	60	63	68	74	79	110	R_B - R_{LR}
		EM	-7	-1	3	6	8	9	15	23	31	45	62	79	171	R_{EM} - R_{AC}
			-10	2	4	7	9	12	15	18	21	25	31	36	72	R_{EM} - R_{LR}

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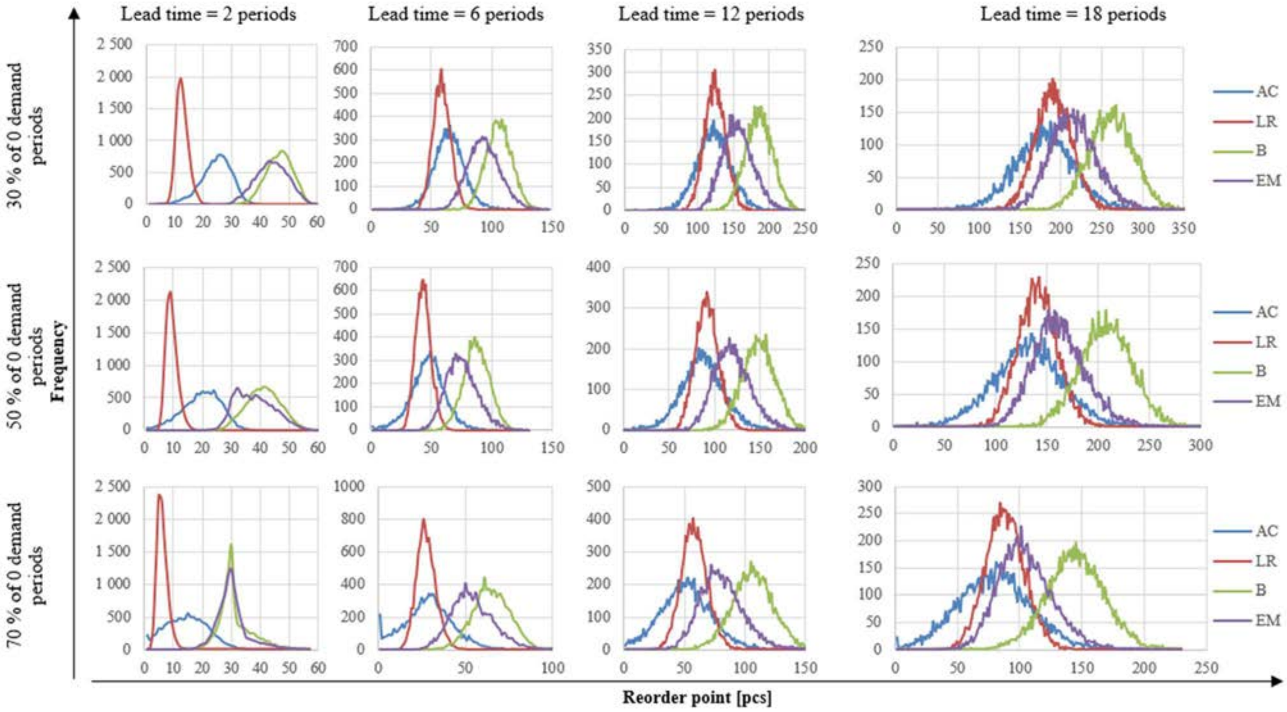

Figure 2 RAC, RLR, RB and REM distribution

Table 4 shows a number of simulation experiments where PSMS+LS returns no solution.

Table 4 Simulation experiments with no solution

0 demand periods [%]	Lead time	B/EM	No solution	No solution for R_B or R_{EM} - R_{AC} < 0	Time series with R_B or R_{EM} - R_{AC} < 0
30	2	B	0	0	0
		EM	0	0	0
	6	B	17	17	19
		EM	42	42	53
	12	B	14	14	18
		EM	161	161	231
	18	B	5	5	19
		EM	282	257	259
50	2	B	0	0	2
		EM	5	5	9
	6	B	35	35	38
		EM	113	113	134
	12	B	27	27	30
		EM	348	348	459
	18	B	4	4	39
		EM	628	530	530
70	2	B	34	34	97
		EM	21	21	49
	6	B	47	47	55
		EM	186	186	241
	12	B	25	25	29
		EM	468	467	607
	18	B	7	7	43
		EM	1 000	789	790

In general there are two reasons why PSMS+LS returns no solution. First, estimations of R_{LR} and R_B or R_{LR} and R_{EM} are both < R_{AC} and at the same time R_B or $R_{EM} \geq R_{LR}$. In this case PSMS+LS returns no solution because there is no examined R/Q combination ensuring to achieve at least the required service level. From the consumption of computational time point of view that means completely wasting time on the generation of R_{LR}, R_B/R_{EM} and also on PSMS+LS searching a fruitless solution space. Second, estimations of R_B or $R_{EM} < R_{LR}$ for example because number of sampling runs for bootstrapping is set too low or because empirical method works with too short time series or too long order lead time. This causes PSMS+LS does not examine a single R/Q combination at all and from the consumption of computational time point of view that means wasting time "just" on the generation of R_{LR}, R_B/R_{EM}. Anyway, the results in Table 4 proves bootstrapping to perform significantly better than empirical method in term of number of simulation experiments where PSMS+LS returns no solution both for increasing level of sporadicity and prolonging lead times. Moreover, empirical method suffers much more from $R_{EM} < R_{LR}$ kind of no solution mainly for too long lead times (see for example Table 4, row 9). PSMS+LS have also a certain ability to overcome low estimated lead time demand through adjusted replenishment orders for both bootstrapping and empirical method. For example for lead time equal to 6 periods from 19 time series with 30 % of zero demands PSMS+LS with B manage to find at least a feasible solution for (19 - 17) = 2 time series (see Table 4, row 4) and PSMS+LS with EM do the same thing for (53 - 42) = 11 time series (see Table 4, row 5) in situation when no $R_B < R_{LR}$ or $R_{EM} < R_{LR}$ takes place.

Besides the distribution of reorder points to compare the ability of bootstrapping and empirical method to overestimate lead time demand in PSMS+LS we also record the consumptions of the computational time separately for the generation of reorder points and to explore a solution space with PSMS+LS. This consumption is shown in Table 5.

Table 5 Consumption of computational time

0 demand periods [%]	Lead time	AC/ LS+B/ LS+EM	LR [min]	B/EM [min]	LS [min]	Total [min]	Simulated combinations	Time consumption of AC or LS [μs/combination]
30	2	AC	-	-	-	43.5	758 009 224	3.44
		LS+B	3.0	16.8	8.3	28.1	126 113 655	3.96
		LS+EM	3.0	4.2	7.8	14.9	117 305 928	3.98
	6	AC	-	-	-	44.8	758 009 224	3.54
		LS+B	3.0	17.0	9.8	29.8	147 896 555	3.97
		LS+EM	3.0	2.1	7.7	12.8	112 706 747	4.08
	12	AC	-	-	-	44.9	758 009 224	3.55
		LS+B	3.0	17.9	9.5	30.4	143 751 137	3.97
		LS+EM	3.0	1.6	5.6	10.3	79 663 608	4.25
	18	AC	-	-	-	45.1	758 009 224	3.57
		LS+B	3.0	18.1	7.9	29.0	115 987 202	4.09
		LS+EM	3.0	1.5	3.6	8.1	46 089 013	4.71
50	2	AC	-	-	-	23.0	394 192 140	3.51
		LS+B	3.0	18.0	5.9	26.8	83 484 157	4.21
		LS+EM	3.0	4.3	5.8	13.1	75 902 081	4.60
	6	AC	-	-	-	24.1	394 192 140	3.67
		LS+B	3.1	18.4	6.8	28.3	97 522 230	4.20
		LS+EM	3.2	2.4	5.3	10.9	72 853 910	4.38
	12	AC	-	-	-	23.9	394 192 140	3.63
		LS+B	3.1	22.4	6.4	32.0	92 541 546	4.18
		LS+EM	3.5	1.9	3.9	9.3	50 095 343	4.65
	18	AC	-	-	-	23.6	394 192 140	3.59
		LS+B	2.9	20.7	5.1	28.7	71 941 595	4.30
		LS+EM	3.0	1.5	2.4	6.9	27 781 994	5.19
70	2	AC	-	-	-	9.5	148 422 089	3.83
		LS+B	3.0	16.8	3.1	22.9	39 756 591	4.70
		LS+EM	3.0	4.0	3.0	10.1	38 448 406	4.72
	6	AC	-	-	-	9.3	148 422 089	3.75
		LS+B	3.0	18.4	3.8	25.1	48 451 721	4.68
		LS+EM	3.0	2.1	3.0	8.1	35 910 839	4.96
	12	AC	-	-	-	9.2	148 422 089	3.71
		LS+B	3.0	18.9	3.5	25.4	44 249 372	4.77
		LS+EM	3.0	1.7	2.2	6.9	23 579 957	5.55
	18	AC	-	-	-	9.3	148 422 089	3.75
		LS+B	2.9	18.7	2.6	24.2	31 498 299	5.03
		LS+EM	3.0	1.5	1.4	5.9	12 397 843	7.01

The difference between the consumption of computational time spent on the generation of R_B and R_{EM} is quite impressive. While in all simulation experiments R_B sampling with 100 runs takes from 16.8 to 22.4 minutes per a data set with 10 000 time series, R_{EM} needs only from 1.5 to 4.3 minutes per a data set with 10 000 time series. Furthermore, in contrary to R_B, the consumption of computational time spent on the generation of R_{EM} decreases with increasing order lead time and from the lead time 6 periods it even takes less time (i.e. from 1.5 to 2.4 minutes a data set with 10 000 time series) than the generation of R_{LR} taking constantly around 3 minutes per a data set with 10 000 time series. It follows that empirical method is not just significantly faster but also more suitable to be applied in tasks where a detailed discretization of time could be advantageous (i.e. switching from months to weeks or days). Together with the significant speeding up of generating the overestimated reorder point, the application of empirical method in PSMS+LS also further reduces an explored solution space through the closer distribution of R_{EM}s due to the distribution of the best possible reorder points coming from PSMS+AC (see Table 5, the column entitled Simulated combinations, LS+B vs LS+EM comparison). This enables to extend the use of PSMS+LS to strongly sporadic demand areas characteristic with lower total demanded quantity as the total consumption of computational time of PSMS+LS longer keeps up to be lower than PSMS+AC (see Table 5, the column entitled Total [min], AC vs LS+EM comparison).

However, the acceleration of the overestimated reorder point generation and the additional reduction of the solution space bringing the time savings must go hand in hand with a corresponding level of holding and ordering costs. That is why we for each simulation experiment calculate the difference between the best reached holding and ordering costs coming from PSMS+LS and the best possible holding and ordering costs coming from PSMS+AC (i.e. $\Delta_{Ct,best}$). These differences are in the form of percentiles displayed in Table 6.

Table 6 $\Delta_{Ct,best}$ percentiles

			$\Delta_{Ct,best}$ - percentiles [%]												
0 demand periods [%]	**Lead time**	**B/EM**	**0**	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**95**	**98**	**100**
30	2	B	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	41%
		EM	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	41%
	6	B	0%	0%	0%	0%	0%	0%	0%	0%	3%	8%	14%	22%	122%
		EM	0%	0%	0%	0%	0%	0%	0%	0%	3%	8%	14%	22%	122%
	12	B	0%	0%	0%	0%	0%	1%	4%	8%	13%	21%	29%	40%	103%
		EM	0%	0%	0%	0%	0%	1%	5%	8%	13%	21%	29%	40%	103%
	18	B	0%	0%	0%	0%	1%	3%	6%	9%	15%	23%	32%	43%	95%
		EM	0%	0%	0%	0%	1%	4%	7%	10%	15%	23%	32%	43%	95%
50	2	B	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	3%	11%	101%
		EM	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	3%	11%	101%
	6	B	0%	0%	0%	0%	0%	0%	0%	1%	7%	15%	24%	38%	116%
		EM	0%	0%	0%	0%	0%	0%	0%	2%	7%	15%	24%	38%	116%
	12	B	0%	0%	0%	0%	0%	3%	7%	12%	20%	32%	45%	60%	145%
		EM	0%	0%	0%	0%	0%	4%	8%	13%	20%	33%	46%	60%	145%
	18	B	0%	0%	0%	0%	0%	3%	8%	13%	21%	35%	47%	65%	159%
		EM	0%	0%	0%	0%	1%	4%	8%	14%	22%	35%	48%	66%	159%
70	2	B	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	9%	18%	74%
		EM	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	9%	18%	74%
	6	B	0%	0%	0%	0%	0%	0%	1%	7%	16%	30%	46%	68%	517%
		EM	0%	0%	0%	0%	0%	0%	1%	7%	16%	30%	46%	68%	517%
	12	B	0%	0%	0%	0%	2%	7%	13%	22%	34%	55%	76%	104%	368%
		EM	0%	0%	0%	0%	3%	8%	15%	23%	36%	57%	78%	105%	368%
	18	B	0%	0%	0%	0%	0%	5%	11%	21%	35%	58%	84%	112%	279%
		EM	0%	0%	0%	0%	1%	7%	13%	23%	37%	61%	86%	115%	279%

In general, it can be seen in Table 6 that mainly for longer lead times (i.e. 12 and 18 periods) bootstrapping in PSMS+LS performs slightly better than empirical method. For the level of sporadicity 30 % of zero demand periods and the lead time equal to 2 periods PSMS+LS with both B and EM reached the best possible holding and ordering costs for at least 95 % of simulated time series and the maximal difference in the total costs is up to 41 % compared to PSMS+AC. In term of total holding and ordering costs, the ability of PSMS+LS to perform similar to PSMS+AC decreases with increasing number of zero demand periods and also with the prolonging of lead times. This confirms that especially for a demand data with a higher level of sporadicity it is useful to replace the local search with a more on a neighbourhood search oriented optimization based on a generation of a single reorder point. The outputs from the simulation experiments show that empirical method is definitely the number one choice. It outperforms bootstrapping and linear regression in term of the consumption of computational time while maintaining the ability to execute one way exploration of the solution space during the optimization. This is because, similarly to bootstrapping, for the majority of generated data empirical method reliably overestimates lead time demand (i.e. the additional optimization rests in gradually decreasing the reorder point) and in a relatively stray case that the lead time demand is underestimated PSMS+LS returns mostly no solution (i.e. the additional optimization focuses on gradually increasing the reorder point).

4 Conclusions

In this paper we examine whether empirical method can replace bootstrapping in intermittent demand stock control based on simulation. Thus, we generate artificial demand data with 30; 50 and 70 % of zero demand periods and simulate reorder point/fixed order quantity inventory control policy using past stock movement simulation and local search proposed by [8] to obtain the optimal trade-off between holding and ordering costs and the required fill rate for order lead time 2; 6; 12 and 18 periods. The outputs from simulation experiments prove that empirical method outperforms bootstrapping in term of the consumption of computational time while maintaining similar ability to overestimate lead time demand. Thus, empirical method can become a suitable substitute of bootstrapping in the local search. Moreover, it can be successfully used to generate an initial reorder point in a more on a neighbourhood search oriented optimization as it potentially suffers from a less blindness compared to linear regression. Besides additional time savings, optimization via simulation based on a single reorder point generation would also enable to control the consumption of computational time more efficiently and make for example a decision whether for a certain demand data it is advantageous to apply PSMS+AC prior to the optimization. This is because number of simulated R/Q combinations in PSMS+AC is equal to $\frac{Total\ demand \cdot (Total\ demand - 1)}{2}$ and for the generated single reorder point it is then easy to decide on some additional time spent on one way neighbourhood search simply assigning a certain amount of computational time to every change of the initial reorder point. Empirical method does not require any kind of settings such as deciding on number of sampling runs in bootstrapping. It also does not require any kind of optimization of smoothing constants based on a selection of an appropriate accuracy metric which is common for SES based parametric time series forecasting methods or an adoption of demand classification schemes and data aggregation. As an assumption free and data driven nonparametric approach it also copes with both theoretical and empirical distributions of demand. This predetermines empirical method to become an important part of a simulation-optimization software solution focusing on sporadic demand inventory control in large scale real life tasks.

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Smart solutions for importing automotive components from Europe to Mexico

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Keywords: AHP technique, Weber problem, location allocation problem, exportation efficiency, consolidation centre.
Abstract: This study presents a strategic approach to optimizing the importation of automotive components from Europe to Mexico, aimed at enhancing operational efficiency, reducing costs, and ensuring timely deliveries. Using the Analytic Hierarchy Process (AHP) as a structured decision-making tool, the research evaluates and selects the optimal port of departure based on criteria such as cost, transit time, and port capacity. The Weber Location Problem (WLP) is also applied to determine the ideal consolidation center (CC) location to streamline cargo collection from multiple European suppliers. Through a Mexican automotive company case study, the research highlights the importance of integrating Full Container Load (FCL) and Less Container Load (LCL) operations to improve traceability, reduce handling errors, and optimize supply chain performance. The findings emphasize the critical role of port selection and cargo consolidation in mitigating risks associated with supply chain disruptions. The proposed methodology provides importers practical tools to strengthen their logistics strategies, offering valuable insights for enhancing global automotive supply chain competitiveness. This work contributes to maritime logistics and supply chain management, guiding importers, shipping companies, and policymakers in improving port efficiency and cross-border operations.

1 Introduction

Being efficient in importation is crucial for several reasons. Here are some key points highlighting the importance of importation efficiency: *Cost Reduction:* efficient importation processes help minimize costs associated with shipping, customs duties, and handling. Lower costs can lead to reduced consumer prices and improved business profit margins. *Timely Delivery*: importation efficiency ensures that goods are delivered promptly. It is essential for maintaining inventory levels, meeting customer demand, and ensuring that businesses can operate smoothly without delays. *Competitive Advantage:* companies that import goods efficiently are better positioned to compete in the market. They can respond more quickly to changes in consumer demand, adjust pricing strategies, and maintain a strong market presence against competitors, including parallel importers. *Quality Control:* efficient importation processes often include better quality control measures. It ensures that the products received meet the required standards and specifications, which is particularly important in industries like pharmaceuticals and electronics. *Regulatory Compliance:* efficient importation helps businesses navigate complex customs regulations and compliance requirements. It reduces the risk of delays, fines, or legal issues arising from non-compliance. *Supply Chain Optimization*, an efficient importation process, contributes to overall supply chain optimization. It allows businesses to manage logistics better, reduce lead times, and improve coordination with suppliers and distributors. *Market Responsiveness*: in a rapidly changing market environment, importation efficiency enables businesses to respond more to trends and consumer preferences. This agility can lead to better customer satisfaction and loyalty. *Sustainability*: efficient importation can also contribute to sustainability efforts by optimizing transportation routes and reducing waste. It can lead to lower carbon footprints and more environmentally friendly practices [1].

The study [2] empirically demonstrates that efficiency in importation processes, driven by key factors such as international price, product quality, product availability, customs clearance knowledge, and a company's logistics capability, significantly reduces costs and improves profit margins. Through a survey of major food processing companies in Northern Mexico and multiple linear regression analysis, the research finds that these variables collectively explain 66.4% of the variation in import volume. The findings highlight that price competitiveness and product quality are primary drivers, enabling companies to reduce procurement costs and enhance product differentiation, ultimately leading to increased competitiveness and profitability in the market.

For example, the context of the [3] is rooted in the complexities of the global soybean market, the strategic role of China as a primary importer, and the competitive dynamics that shape trade relationships among the leading soybean-producing countries. This study provides valuable insights that can help exporters, policymakers, and industry stakeholders make informed decisions, enhance competitiveness, and adapt to the evolving dynamics of the global soybean market.

The study [4] evaluates the efficiency of customs operations in 29 countries from the APEC region and other leading trading nations. Using the Data Envelopment Analysis (DEA) Network model reveals that efficient customs procedures are crucial for facilitating international trade. Countries with streamlined customs processes, such as China, Germany, and Singapore, demonstrate higher efficiency, resulting in faster cargo clearance, reduced operational costs, and improved regulatory compliance. The research emphasizes that modernizing customs infrastructure and adopting digital solutions, like electronic declarations, significantly enhance the punctuality and reliability of import processes. These improvements reduce the risk of delays and help businesses avoid penalties associated with non-compliance, fostering more competitive and resilient supply chains.

Overall, the study [5] aims to fill a gap in the literature on import retail e-commerce by providing a detailed analysis of competitive strategies and their implications for sellers operating in this dynamic market. The three major competitive strategies identified in the study are product optimization, cost leadership, and reputation priority. It also underscores the need for imported retail e-commerce sellers to be strategic and adaptive in their approaches to enhance their competitiveness in a rapidly changing market environment.

In [6], it explores developing and implementing effective marketing strategies to enhance industrial import substitution in Russia, emphasizing the necessity for Russian enterprises to adapt to a volatile competitive environment and focus on achieving competitive stability. In conclusion, the paper presents a comprehensive analysis of the marketing and operational strategies necessary for successful industrial import substitution, offering practical tools and methodologies for enhancing competitiveness in the Russian industrial sector.

The research [7] delves into the global forage trade from 1997 to 2020, focusing on the market power of forage exporters in key importing nations like Japan, China, and South Korea. By employing an extended G-K model, the authors uncover important dynamics in pricing power and market structure, highlighting the significant roles played by the United States and Australia in this sector. Some key benefits are an enhanced understanding of market dynamics, strategic planning for exporters, informed policy development, and sustainability.

The study [8] emphasizes that efficient import management is a key factor for companies in the automotive sector in Tungurahua, Ecuador, to enhance their competitiveness and adapt swiftly to international market demands. It demonstrates that firms that streamline their import processes can reduce costs, improve production planning, and ensure timely input delivery, strengthening their ability to respond to changing consumer preferences. Moreover, optimizing imports contributes to supply chain efficiency by improving inventory control, enabling better supplier relationships, and fostering innovation through access to quality materials and technologies from global markets. These advantages collectively position companies to compete more effectively both locally and internationally.

Therefore, an importation strategy is crucial for several reasons, regardless of sector. An effective importation strategy helps ensure a stable and reliable supply of essential goods. By diversifying sources and establishing relationships with multiple suppliers, countries can mitigate risks associated with supply disruptions due to geopolitical issues, natural disasters, or market fluctuations. In addition, an importation strategy enables countries to respond quickly to changes in market demand. By monitoring trends and adjusting import volumes accordingly, countries can avoid shortages or surpluses that could disrupt local markets.

1.1 Context problem

This project is focused on companies in the automotive sector in Mexico, which require processes for importing goods (production material, spare parts, auxiliary maintenance material, and machinery) from Europe. The case study is of a Mexican company that needs to establish the logistics chain for present and future projects.

The Mexican company already has a list of suppliers, and every week, an exclusive consolidated container must be sent with cargo collected from different suppliers. The company uses the LCL (Less Container Load) and FCL (Full Container Load) operations. LCL is required to collect all the goods from different European suppliers that do not fill an entire container by themselves, which is why a collection and consolidation service is needed. FCL is used to transport the necessary machinery to install production lines for which full containers of different types are required: 20 and 40 feet, dry cargo, high cube, flat rack, and open top, as well as for production materials and spare parts.

Currently, the company is responsible for collecting the components weekly from each of its European suppliers under the (Free Carrier) FCA incoterm at the plant and sending them by any available parcel service to the ports of Hamburg and/or Bremen, depending on the availability of containers. Causing more excellent staff wear in product traceability and not necessarily consolidating the containers. There are times when up to 20 partial containers have been received, generating high costs for the importing company even if the product has been lost between the parcel and the ports and delays in finding this product for shipment or restocking and shipping in the worst case.

This work aims to create an import strategy for Mexico from Europe through the Weber Location Problem (WLP) to select a Consolidation Centre (CC). Through the Analytic Hierarchy Process (AHP) method, select the port of departure that meets the time, costs, and capacity criteria to have more control over the consolidation and shipment of the products.

In Figure 1, there are 42 European suppliers of the Mexican company. These have blue markers, and in Figure 2, the ports of Bremerhaven and Hamburg have red markers.

Figure 1 European suppliers

Figure 2 Ports of Bremerhaven and Hamburgo

2 Literature review

This study applied an AHP method to select the best port. Then, it used the Weber Problem to allocate the CC that optimized the importer's time and cost and had more control over the product traceability.

On the one hand, the AHP is a structured decision-making framework used to analyze complex problems by breaking them down into smaller, more manageable parts. Thomas Saaty developed it in the 1970s, and it is beneficial in situations where multiple criteria must be considered. AHP is valued for its flexibility and ability to incorporate qualitative and quantitative factors, making it suitable for various applications, including construction management, project selection, resource allocation, and risk assessment [9].

The AHP involves several key steps to facilitate decision-making. The authors outline the following six phases in the AHP method: 1) Define the Problem, 2) Determine the Criteria and Sub-Criteria, 3) Identify the Alternatives, 4) Structure the Hierarchy, 5) Perform Pairwise Comparisons, and 6) Calculate Weights and Rank Alternatives [10].

[11] employs the AHP to investigate the criteria influencing transshipment port selection by global container carriers. Four primary criteria and twelve sub-criteria were identified through a comprehensive literature review and expert Delphi surveys. The study reveals that global carriers and port service providers share similar views on the importance of these attributes. However, their rankings differ, indicating potential areas for service providers to adapt to user priorities. The findings underscore the significance of understanding these criteria for enhancing competitive strategies in the transshipment market, ultimately aiding in effective decision-making for port operators and authorities.

Also, [12] presents an AHP model to analyze port choice in regions with multiple container ports, emphasizing its significance in international trade transportation. The model aims to simulate shipping carriers' decision-making behaviors and identify the importance of various factors influencing port selection. By applying the AHP model to five shipping companies, the research reveals the weight of each factor affecting port choices. The findings are intended to assist port managers and government agencies in developing effective operational strategies and policies to enhance port competitiveness and attract more container traffic. The study underscores the critical role of optimal port selection in reducing transportation costs.

Many studies have applied the AHP model to identify critical criteria influencing transshipment port selection by global carriers. In [13], expert surveys reveal that critical factors include handling costs, primary infrastructure conditions, and proximity to navigation routes. The findings highlight the need for ports to focus on cost reduction and infrastructure investment to enhance competitiveness. Additionally, understanding carrier preferences and addressing perception gaps between port users and operators can improve service alignment. These insights provide strategic implications for enhancing transshipment market strategies in a competitive global environment.

The study [14] introduces a decision support system (DSS) that utilizes the Analytic Hierarchy Process (AHP) to rank alternatives and support multi-criteria decision-making in port selection for maritime operators. The research emphasizes that AHP is valuable for integrating qualitative and quantitative factors, such as port efficiency, costs, infrastructure, and transit times. By systematically evaluating these criteria, AHP helps operators identify the most cost-effective and efficient route, which is crucial for ensuring business sustainability and competitiveness in the highly demanding maritime transportation.

In [13], this article applies the analytical hierarchy process (AHP) technique to analyze transshipment port selection by global carriers. It identifies primary criteria and sub-criteria influencing port choice, offering a comprehensive understanding of carriers' decision-making priorities. The study provides valuable insights into how port service providers can better align their offerings with user preferences, enhancing ports' competitiveness and attracting more significant container traffic in the global shipping market.

On the other hand, the Weber problem, introduced by Alfred Weber in his 1909 work on industrial location, generalizes the Fermat problem by considering not just the distances but also the weights of the points representing demand or supply and the costs associated with transportation. When all weights are equal, and the distances are Euclidean, the Weber problem reduces to the Fermat problem. The objective is to minimize the total weighted distance to a set of points. The Weber problem is more focused on practical applications in economics and logistics, particularly in determining optimal locations for facilities based on transportation costs and the distribution of resources [15].

The Weber Problem in logistics and service networks under congestion conditions. It analyzes how the optimal location of a facility can maximize resource utilization and minimize travel times, considering capacity constraints and demand distribution. The findings offer an updated perspective on the practical application of the Weber Problem in optimizing modern supply chains [16].

[17] This paper examines the Facility Weber Problem with Setup Costs, an advanced version of the classic Weber problem, which considers both transportation costs and the fixed setup costs associated with opening multiple facilities. The authors propose a mathematical model and develop solution methods that optimize facility location under capacity constraints. The research demonstrates that including setup costs significantly impacts the placement of facilities, leading to more realistic and cost-effective decisions. This approach is especially valuable for logistics and supply chain management, as it helps businesses minimize total costs when establishing distribution centers, warehouses, or production sites in competitive, resource-sensitive environments.

However, in the literature, many techniques can solve location problems. [18] Explores the strategic positioning of critical ports across Asia, Europe, and Oceania using a mixed-integer linear programming model; they analyzed a realistic shipping network and discovered significant hub ports, including Rotterdam and Zeebrugge in Europe, Sokhna and Salalah in Western Asia, Colombo and Cochin in Southern Asia, and Singapore and Jakarta in Southeastern Asia and Australia. This approach allowed the authors to develop a hierarchical hub location problem that distinguishes between different types of ports, specifically international hub ports, regional hub ports, main ports, and feeder ports. The model was tested through numerical experiments based on a realistic Asia-Europe-Oceania liner shipping network to evaluate its effectiveness and determine optimal port locations.

[19] presents an exciting mixed integer programming model focused on selecting a hub port along the East Coast of South America. The study evaluates a set of 11 ports to effectively meet the regional demand for container shipping, aiming to optimize logistics and enhance maritime economics. The mixed integer programming model for selecting a hub port considers several critical factors, including total system costs, port costs, shipping costs, traffic flows, and feeder ports. One of the benefits is cost efficiency, which minimizes total system costs. The model helps identify the most cost-effective hub port, lowering shipping and operational expenses for shipping companies and port authorities.

Another research delves into the complexities of port choice and hinterland dynamics, explicitly analyzing the shipment of French AOC wines to the US. By addressing the common confusion surrounding the origins of containerized shipments, the authors propose innovative solutions and introduce new variables that enhance our understanding of logistical decisions. Using a conditional logit model, they reveal vital factors influencing port selection, emphasizing the significance of inland distance. Some critical benefits highlighted in the research are the improved accuracy in shipment origin identification, the enhanced understanding of port choice factors, insights into forwarder behavior, and maritime connectivity as a competitive advantage [20].

3 Methodology

3.1 AHP method

This research will use the power method of Palacios of 2007 and the Saaty scale of 1994 [21].

The criteria used in this project are:

1. Sending costs, costs of maneuvers in the terminal, depending on the incoterm, freight costs / Terminal Handling Charges (THC) at Origin.
2. Transit time.
3. Port terminal with enough capacity. Today, the Port of Hamburg is managed by the Hamburg Port Authority, created in 2005 in a merger between the various authorities that managed responsibilities related to the port. The port handles an annual throughput of 126 million tonnes and a container throughput capacity of 8.5 million TEU, making it the largest port in the country. The Port of Bremerhaven handled almost 54.7 million tonnes of containerized cargo at over 5.4 million TEU. The Port of Bremerhaven can handle nearly 5.5 million TEU and 55 million tonnes of containerized cargo annually.

Were:

- ✓ Cost is 3 times more important than time.
- ✓ Cost is 7 times more important than capacity.
- ✓ Time is 4 times more important than capacity.

The respective weights were calculated after the experts selected this list of judgments. Thus, the positive reciprocal matrix is the following (1):

$$\begin{array}{l} \\ \textit{Criterion 1} \\ \textit{Criterion 2} \\ \textit{Criterion 3} \end{array} \begin{array}{c} \begin{array}{ccc} \textit{Criterion 1} & \textit{Criterion 2} & \textit{Criterion 3} \end{array} \\ \begin{pmatrix} 1 & 3 & 7 \\ 1/3 & 1 & 4 \\ 1/7 & 1/4 & 1 \end{pmatrix} \end{array} \tag{1}$$

The alternatives were considered by three shipping companies that can be found in both ports. Thus, there are six alternatives (2). The records of these alternatives were treated with the correct interpretation of the data in terms of priorities; that is, the method looks for the maximum argument, so the data, such as the lead time, was corrected for its correct interpretation since the maximum argument was not beneficial for the selection, on the contrary, we looked for the minimization of the transfer times, and later these data were normalized. The Consistency Radius (CR) was calculated, resulting in 3.7%, so the judgment matrix is considered unbiased.

$$\begin{array}{l} \\ \textit{Alternative 1} \\ \textit{Alternative 2} \\ \textit{Alternative 3} \\ \textit{Alternative 4} \\ \textit{Alternative 5} \\ \textit{Alternative 6} \end{array} \begin{array}{c} \begin{array}{ccc} \textit{Criterion 1} & \textit{Criterion 2} & \textit{Criterion 3} \end{array} \\ \begin{pmatrix} 0.163 & 0.250 & 0.111 \\ 0.158 & 0.227 & 0.222 \\ 0.157 & 0.250 & 0.111 \\ 0.163 & 0.253 & 0.222 \\ 0.177 & 0.250 & 0.111 \\ 0.177 & 0.246 & 0.222 \end{pmatrix} \end{array} \tag{2}$$

The global priority for each decision alternative is summarized in the column vector resulting from the priority matrix's product with the priority vector of the criteria; it was proven that the matrices are conformable; that is, they can be multiplied. Finally, a matrix of six by one or solution vector was obtained, in which the final weights of each one of the alternatives were to be selected (3).

$$\underset{\textit{Alternatives/Criteria}}{\begin{pmatrix} 0.163 & 0.169 & 0.111 \\ 0.158 & 0.153 & 0.222 \\ 0.157 & 0.169 & 0.111 \\ 0.163 & 0.171 & 0.222 \\ 0.177 & 0.169 & 0.111 \\ 0.177 & 0.167 & 0.222 \end{pmatrix}} \times \underset{\textit{Criteria Weights}}{\begin{pmatrix} 0.690 \\ 0.263 \\ 0.079 \end{pmatrix}} = \underset{\textit{Results}}{\begin{pmatrix} 0.1664 \\ 0.1673 \\ 0.1622 \\ 0.1756 \\ 0.1760 \\ 0.1842 \end{pmatrix}} \quad (3)$$

Once the results were found, the Weber method was applied to find the best location for the CC.

3.2 Weber problem

The main objective of the Fermat-Weber location problem is to find a point in $\mathbb{R}^N$ that minimizes the sum of weighted Euclidean distances to a given set of *m* points. In practical terms, these fixed points often represent locations such as customers or demands, while the determined point denotes the location of a new facility. The problem can be mathematically formulated by minimizing the function, which reduces the sum of weighted Euclidean distances to a given set of *m* points. In practical terms, these fixed points often represent locations such as customers or demands, while the determined point denotes the location of a new facility. The problem can be mathematically formulated as minimizing the function (4):

$$W(x) = \sum_{i=1}^{m} w_i \, ||x - a_i|| \quad (4)$$

Where w_i is a positive weighting constant that converts the distance between the new facility and demand point *i* into a cost, and a_i represents the known position of the *i-th* demand point.

Weiszfeld's algorithm is an iterative method for solving the Fermat-Weber location problem. The algorithm is based on the first-order necessary conditions for a stationary point of the objective function, which leads to a mapping. The convergence of Weiszfeld's algorithm is conditional on specific criteria like:

1. Non-collinearity: If the given points $a_1,\dots,a_m$ are not collinear, the algorithm will converge to the unique optimal solution for all but a denumerable set of starting points x^0.
2. Avoiding Fixed Points: The algorithm's convergence is guaranteed as long as none of the iterates in the sequence generated by the algorithm coincides with one of the fixed points a_i. If an iterate does coincide with a fixed point, the algorithm may not converge to the optimal solution.
3. Dimension of Convex Hull: The authors conclude that Weiszfeld's algorithm converges to the unique optimal solution for all but a denumerable set of starting points if the convex hull of the given points is of dimension *N*.

In summary, Weiszfeld's algorithm is a powerful tool for solving the Fermat-Weber location problem. Still, its effectiveness depends on the geometric arrangement of the given points and the choice of starting point [22].

The problem was programmed in Lingo software, and the coordinates of 42 suppliers were considered.

4 Results and discussion

The AHP method is beneficial in selecting carriers-ports for several reasons: a) it can provide a systematic framework for breaking down complex decision-making processes into manageable components, allowing decision-makers to evaluate multiple criteria and sub-criteria effectively. B) It enables identifying and quantifying the importance weights of various factors influencing port choices, such as port charges, operational efficiency, and hinterland economy. This helps in understanding which factors are most critical for shipping companies. C) It allows for including qualitative and quantitative data, incorporating the insights and preferences of top decision-makers from shipping companies, and enhancing the decision-making process's relevance and accuracy. D) The method facilitates direct comparisons between different ports based on the established criteria, making it easier to identify the most favorable options for carriers. E) AHP can be adapted to various contexts and accommodate changes in criteria or preferences over time, making it a flexible tool for port selection.

Applying the AHP method made it possible to see that alternative six was the best for sending the products, and this carrier belongs to the port of Hamburg. The worst option for sending the products is alternative three, which leaves from the port of Bremerhaven. With this solution, we can see shipping options and select the best for the importing company. The idea is only to choose one carrier and one port to negotiate better prices, without forgetting that there are alternatives for any incident. In this case, the second option with which you can also start negotiations is alternative five, the same as shown in Table 1.

Table 1 List of AHP results

Port	Alternatives	Results
Hamburg	Alternative 6	0.2052494
Bremerhaven	Alternative 5	0.19732552
Hamburg	Alternative 4	0.19714262
Bremerhaven	Alternative 1	0.18765689
Hamburg	Alternative 2	0.18669939
Bremerhaven	Alternative 3	0.1834489

We can see that alternative five corresponds to the port of Bremerhaven, so we will have to view alternative four if we want to use the same port.

Once the port of Hamburg was chosen as the best choice, not so much for capacity, but for the carrier's costs and delivery times, the Weber problem wa365egion365ded and solved. Both ports were added, and 42 clients were considered. The problem wa365egion365ded as a non-linear programming problem, and the solution to locate the new CC was the following coordinate 50.82786, 8.981236 (50°'9'40"3"N 8°'8'52"5" E) corresponding to RXHJ+4FX Kirchhain, Germany. In Figure 3, you can see the proposed CC with the green marker. The idea of having a CC is to have greater control of the processes and traceability and negotiate costs with the parcel.

Figure 3 Results of the Consolidation Centre (CC)

Location-allocation models are essential tools in logistics and supply chain management, helping organizations optimize the placement of facilities and allocation of resources to meet demand efficiently. These models consider transportation costs, customer proximity, and service levels, ensuring facilities are strategically positioned to minimize costs and improve service quality. Using location-allocation models, companies can reduce operational expenses, improve delivery times, and enhance customer satisfaction. These models are also valuable for handling fluctuating demand, accommodating growth, and mitigating risks associated with location-based disruptions. Ultimately, location-allocation models enable data-driven decision-making, leading to more resilient and cost-effective supply chain networks, especially in complex, dynamic environments where efficiency and customer satisfaction are critical for maintaining competitive advantage.

This research has many benefits for the importers and suppliers, among them are:

1. Strategic Insights for Importers: Companies importing any components can use this strategy to reduce costs and have more planned and controlled operations.
2. Strategic Insights for Exporters: Exporting companies of any components can use this strategy as a competitive advantage to be selected as a leading supplier, since if among their services they offer to handle all customs procedures and send the package to the CC, they would reduce the amount of paperwork on the part of the buyer, generating confidence in a quality shipment.
3. Market Diversification: The findings emphasize diversifying component supply sources. By recognizing the quality of the European supplier's components, importers can reduce reliance on any single market and mitigate associated risks.
4. Policy Formulation: Policymakers can use the insights from the study to develop strategies to improve the automotive industry's competitiveness in Mexico. By having a CC, it is possible to negotiate discounts with the shipping company on all incoming component packages and have reduced shipping costs. Likewise, the most convenient shipping policies can be established regarding shipping cost and time by having a single port of departure.
5. Collaboration between Importing and Exporting Countries: The findings highlight a common interest among the different suppliers of the countries analyzed. This collaboration can lead to joint marketing efforts and shared strategies to lead the sector.
6. Cost Leadership: This strategy focuses on achieving cost advantages through various means, such as optimizing logistics and reducing waiting costs, rather than relying solely on low-price suppliers. A well-planned importation strategy allows countries to negotiate better prices and terms with suppliers. By understanding market dynamics and demand trends, importers can make informed decisions that help control costs and improve profitability.
7. Sustainability Considerations: An importation strategy can incorporate sustainability goals, such as sourcing

from environmentally responsible suppliers or reducing the carbon footprint associated with transportation.

8. Strategic Port Development: Identifying key hub ports can inform the important strategic decisions regarding port development and investment for the government. Shipping companies and port authorities can focus on enhancing infrastructure and services at these critical locations to serve global trade better.
9. Feeder Allocation: The study highlights the importance of feeder ports. It can optimize the flow of containers from smaller suppliers, improving overall network efficiency and reducing transit times.
10. Improved Decision-Making: The proposal provides a structured approach to decision-making, allowing port managers and policymakers to make informed choices based on quantitative data and analysis. It can lead to more strategic investments and resource allocation.
11. Enhanced Service Quality: By focusing on port and shipping costs, the model encourages ports to improve their service offerings, enhancing customer satisfaction and attracting more shipping lines.
12. Regional Economic Growth: The proposal can improve regional economic development by optimizing logistics and enhancing container transportation efficiency. Improved port operations can facilitate trade, create jobs, and stimulate local economies.
13. Improved Accuracy in Shipment Origin Identification: The proposal recognizes shipment origins and allows for a more accurate estimation of where and when goods are actually coming from, rather than relying solely on the addresses provided in shipping documents. It can lead to better logistical planning and decision-making.

5 Conclusions

This research presents a robust methodology for optimizing the importation of automotive components, focusing on port selection and the strategic location of a consolidation center (CC). The proposed approach, which integrates the Analytic Hierarchy Process (AHP) and the Weber Location Problem (WLP), demonstrates its applicability not only to the automotive industry in Mexico but also to import operations in other countries and sectors. The methodology can be adapted to different geographical and market contexts, such as China or other regions with diverse suppliers, by adjusting the input data and criteria according to local conditions.

The findings underline the critical role of selecting an optimal port and establishing a consolidation center to improve traceability, reduce transportation costs, and enhance delivery times. These elements collectively contribute to greater supply chain visibility and operational control, enabling companies to mitigate risks associated with supply disruptions and minimize product losses during transit. The study also emphasizes the importance of negotiating long-term contracts with carriers and optimizing FCL (Full Container Load) and LCL (Less Container Load) operations to achieve cost leadership and ensure flexibility in shipping schedules.

The practical implications of this work extend beyond cost reduction; the proposed strategy supports long-term business planning by fostering resilient and sustainable logistics operations. By consolidating cargo from multiple suppliers into a single shipment, importers can leverage economies of scale, reduce handling errors, and enhance product quality assurance. This approach improves efficiency and contributes to environmental sustainability by optimizing transport routes and reducing the carbon footprint associated with fragmented shipments.

Furthermore, the research highlights the strategic value of collaboration between importers, suppliers, and shipping companies. Establishing strong partnerships and aligning logistics processes can improve service levels, predictable lead times, and better negotiation power regarding freight rates and port fees.

From a policy perspective, the study offers insights that can inform government authorities and port operators in developing infrastructure and policies that support import efficiency, particularly in sectors with complex supply chains like the automotive industry. Strengthening port capabilities and promoting consolidation services can enhance the competitiveness of logistics hubs and attract more international trade.

In summary, improving importation efficiency is essential for reducing costs, ensuring timely delivery, maintaining quality, complying with customs regulations, and increasing market responsiveness. These factors collectively enhance a company's competitiveness and long-term success in the global marketplace.

6 Future research

While this study focuses on automotive components, the proposed methodology can be extended to other industries with complex supply chains, such as electronics, pharmaceuticals, or consumer goods. Future research could explore the adaptation of this approach to different product categories and regions, as well as the integration of digital technologies like blockchain, IoT, and real-time tracking systems to enhance traceability and operational control further. Additionally, investigating the impact of trade policies, port congestion, and geopolitical factors on port selection and consolidation strategies could provide valuable insights for supply chain resilience.

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Digital marketing in logistics: how new technologies change the rules of the game

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Keywords: digital marketing, logistics, technology, efficiency.
Abstract: In the conditions of the rapid development of technologies, digital marketing in logistics undergoes significant changes. The article examines how innovative technologies - such as artificial intelligence (AI), blockchain, the Internet of Things (IoT), and automation - are transforming traditional approaches to logistics, providing improved customer interaction, supply chain optimization, and increased transparency of operations. The main goal of the research is to analyze the influence of new technologies on marketing and logistics processes, as well as to identify relevant strategies for increasing the efficiency and competitiveness of companies. The research methodology includes the use of data analysis, statistical models and examples from the practice of leading global companies. The main tasks of the article are to reveal how digital marketing contributes to the improvement of the customer experience and how technologies allow companies to adapt to modern market conditions. The main results made it possible to substantiate that the implementation of AI allows to improve the personalization of offers and increase the accuracy of demand forecasts, while the blockchain contributes to increasing trust and transparency in supply chains. IoT allows companies to track goods in real time, and automation reduces costs and speeds up order processing. On the basis of the obtained results, it is proved that the digitalization of marketing and logistics processes of modern companies contributes to the strengthening of positions on the market and creates a basis for sustainable growth in the conditions of a rapidly changing economic environment.

1 Introduction

Digital transformation has affected almost all areas of business, and logistics and marketing are no exception. Traditional logistics strategies and marketing approaches are no longer able to effectively meet the new demands of the global market. With the rapid growth of e-commerce, increased customer expectations and increased competition, digital marketing in logistics is becoming critical. The introduction of advanced technologies such as artificial intelligence (AI), the Internet of Things (IoT), blockchain and automation are changing the rules of the game, turning marketing and logistics into integrated processes aimed at increasing the speed, efficiency and transparency of supply chains. The development of technology and digitalization have led to significant changes in the structure of supply chains, which now actively include marketing elements aimed at improving the customer experience. In the digital era, customers not only expect fast and safe delivery, but also personalized offers, availability of information about each stage of the product's movement, as well as confidence in the security of their data. Therefore, studying how digital marketing in logistics is transforming business processes becomes necessary for creating more flexible and sustainable strategies. In a world where business competitiveness is increasingly determined by the speed and quality of service, this study offers valuable recommendations for companies seeking to adapt to the new reality. The benefits that company receive from implementing digital technologies are varied and extensive. The use of artificial intelligence allows us to process huge amounts of data, thereby predicting demand, personalizing customer interactions, and optimizing marketing campaigns and flow or management of information. Blockchain technologies provide transparency and reliability of data at every stage of the supply chain, which increases customer trust and reduces operational risks. IoT devices allow us to track goods in real time, which improves inventory management and minimizes losses. Secure and verifiable data also strengthens the reputation of companies that can demonstrate their responsibility to consumers and partners.

This study aims to identify the most effective digital strategies that companies can use to improve customer interactions and increase the productivity of logistics processes. The relevance of the study is due to the need to adapt logistics and marketing to the new challenges of the digital economy. In the context of globalization, increasing speed of change and the development of electronic platforms, companies that do not implement technologies risk losing competitiveness. Thus, the study of digital marketing in logistics has significant practical significance, helping businesses navigate the changing economic environment and use digital opportunities for sustainable growth. To achieve the goals and objectives of the study, specific examples of companies that have successfully integrated digital technologies into their logistics and marketing processes are substantiated. It is expected that the results of the study will be useful not only for companies that already use digital tools, but also for those who are just planning to implement innovations and technologies in their business processes.

1.1 Theory of digital marketing in logistics: argumentation of the features and specifics of the interaction of strategic management

Research on the integration of digital technologies in logistics and marketing demonstrates that technological innovations open up new opportunities to improve customer engagement, increase supply chain efficiency, and create competitive advantages. Current work highlights key aspects of technologies such as artificial intelligence (AI), the Internet of Things (IoT), blockchain, and automation, and their impact on logistics and marketing. Digital marketing plays a key role in modern logistics, helping to improve the interaction between a company and its customers, as well as to increase operational efficiency. Several studies, such as [1] and [2], highlight the importance of digital technologies in empowering logistics companies, improving customer service, and optimizing supply chains. Digital marketing tools, including data analytics, automation, artificial intelligence (AI), and the Internet of Things (IoT), help companies respond more quickly to changing customer needs and manage operations efficiently [3].

It is worth noting that digital technologies have also changed the approach to managing the interaction between marketing and logistics. The integration of technologies such as IoT and blockchain allows companies to offer customers more transparent and personalized services, as well as manage their expectations [4]. The study by [5] shows that IoT in logistics helps track goods and improves supply chain transparency. Thus, the integration of digital tools and data from logistics into marketing allows for better customer service at every stage of the purchasing process, which increases their loyalty. Strategic management of digital marketing in logistics is becoming an important factor for sustainable business growth. Due to the growing importance of digital technologies and data, companies must build strategic management based on data. Works such as [6] emphasize the need for a strategic approach to the implementation of digital solutions, which allows companies to improve demand forecasting and optimize logistics processes. These studies highlight the need for companies to adapt their strategy to new technologies in order to remain competitive in the market. The use of AI and big data in digital marketing improves forecasting accuracy, which significantly reduces storage and transportation costs, and improves customer service [7]. In turn, this allows companies to create personalized offers and respond to changes in demand in a timely manner, which is especially important in unstable conditions. Systematization of data within the supply chain allows companies to provide customers with accurate information about the status of their orders in real time [8]. While the benefits of applying digital marketing in logistics are obvious, such as improving customer experience, cost optimization, and increasing data accuracy, there are also some challenges. For example, studies by [9] and [10] note that digital transformation requires significant financial investments and can cause difficulties in change management. The shortage of skilled workers and cybersecurity issues are also significant challenges that require a careful approach to strategic management. In today's environment, companies need to develop digital marketing strategies in logistics based on the implementation of advanced technologies to ensure effective customer engagement and adapt to market changes. To successfully implement technologies, companies must consider both the benefits and potential challenges associated with digital transformation. The review shows that further research in the field of digital marketing in logistics should focus on creating accessible and adaptable technologies that can support the sustainable development of companies in the long term.

Conceptually, it should be noted that digital marketing and logistics research shows that new technologies such as artificial intelligence (AI), the Internet of Things (IoT), blockchain and big data are significant game changers in both logistics and marketing. However, a critical analysis of existing works reveals several important aspects that require further improvement and more in-depth research. Current research in digital marketing and logistics confirms the importance of implementing innovative technologies to improve the efficiency of business processes. However, despite numerous achievements in these areas, there is a significant gap in the scientific literature regarding the full integration of these technologies into logistics and marketing strategies. According to research [8], the use of AI and big data analytics has high potential to create a personalized experience for customers, but so far not all companies have realized these opportunities in practice. In turn, [7] notes that many companies face challenges in implementing digital solutions, such as the high cost of technology and a lack of qualified personnel. Although the implementation of technologies such as IoT and blockchain do contribute to improving transparency and accuracy in logistics, as claimed by [10], in practice these solutions require a high level of integration with existing business processes. This may be associated with additional complexities, such as the need to revise management strategies and organizational structure. Therefore, more in-depth research is needed to analyze different models of technology implementation in a company, as well as to create clear recommendations for their effective use. In addition, insufficient attention is paid to studies aimed at analysing the impact of new technologies on the interaction between logistics and marketing departments. As noted by [1], successful integration of these technologies requires synergy between different departments. It is important to note that the literature review found contradictions in the studies regarding the application of AI in marketing and logistics, and more work is needed to understand how these technologies can work in tandem to improve the overall business process. Many studies confirm the effectiveness of digital technologies in isolation, but there is a lack of work that would examine their integration at the business level. Particular attention should be paid to the synergy models between marketing and logistics, as well as the need for strategic management of technology implementation. Critical need to rethink strategies. Technologies such as AI and blockchain are indeed changing the landscape in both logistics and marketing, but companies must be prepared for significant internal changes before these technologies can deliver real value. Existing research does not sufficiently take into account the challenges that companies face when implementing digital solutions. Therefore, there is a need to further explore methods for evaluating the effectiveness and profitability of these implementations in a practical context.

1.2 Theoretical aspects of assessing the impact of technology on changing the management of digital marketing and logistics

Digitalization in marketing and logistics is crucial for the growth and efficiency of modern companies. Modern technologies such as artificial intelligence (AI), the Internet of Things (IoT), big data, blockchain and machine learning are actively used to improve all stages of customer interaction and optimize logistics processes. With these technologies, organizations can increase efficiency, decision-making accuracy and improve service quality. However, there are a number of theoretical aspects related to their implementation and impact on overall business strategies. Arguing attention to theoretical aspects and scientific approaches in the field of determining the impact of technologies on the digital marketing and logistics of companies, it is necessary to note the following directions:

– Artificial Intelligence in Marketing and Logistics. The use of AI in marketing allows companies to create personalized offers for customers, predict needs, and optimize advertising campaigns. AI in logistics helps improve demand forecasting processes, automate inventory management, and optimize delivery routes. The impact of AI on digital marketing and logistics is estimated through increased forecast accuracy, improved customer experience, and reduced costs [11].

– Big Data and Analytics. The use of big data in marketing and logistics helps organizations collect and analyze information about customer behaviour and production processes. With the help of analytics, it is possible to accurately predict consumer behaviour and optimize the supply of goods. However, the critical point is the processing and protection of data, which requires significant resources and knowledge [12].

– Internet of Things (IoT). IoT is used to track goods, monitor transport in real time, and automate processes. The benefits of the technology include improved supply chain visibility, minimized human intervention, and increased efficiency. However, the implementation of IoT requires a high degree of integration with existing systems [13].

– Blockchain in logistics and marketing. Blockchain will provide security, transparency and trust in logistics. It allows for lower transaction costs, improved product tracking and fewer errors. However, its implementation is associated with high technological barriers and the need for standardization at a global level [14].

In stating the main results of the presented research, the following advantages and disadvantages should be highlighted:

– Increased efficiency. Current research shows that technology can significantly improve business processes in marketing and logistics, increasing their efficiency and reducing costs.

– Adaptation to change. The introduction of new technologies allows companies to respond more flexibly to market changes and customer needs, making them more competitive.

– High implementation costs. Many studies highlight that the implementation of technologies such as AI or blockchain requires significant investment, which can be a challenge for small and medium-sized enterprises.

– Complexity of integration. The challenges of integrating new technologies into existing business models remain relevant, especially for companies using legacy systems.

Ongoing changes in the technology landscape require businesses to constantly adapt and improve their processes. In a globalized and increasingly competitive environment, companies must be prepared for innovations that can significantly improve their productivity and efficiency. The need for research on the implementation of new technologies is due to their importance for ensuring long-term success and sustainability in a rapidly changing world. Undoubtedly, technologies such as AI, blockchain and big data play a key role in changing the management of digital marketing and logistics of modern companies. Despite the high costs of implementation, they provide significant benefits in the form of increased operational efficiency, improved customer experience and data security.

However, companies must be prepared for the difficulties associated with the integration of technologies and the adaptation of existing business processes. Continued research in this area is necessary to identify optimal strategies for the implementation of technologies and increase their availability to a wide range of companies.

2 Methodology

2.1 Peer review process

The penetration of technology into marketing and logistics is having a profound impact on the way we do business, improving efficiency and speeding up processes. This phenomenon is happening thanks to the introduction of new technologies such as artificial intelligence (AI), blockchain, the Internet of Things (IoT), big data and cloud technologies. Based on the above, it should be noted that assessing the impact of technology on digital marketing and logistics and changing the rules of the game in the global market is an important tool for companies looking to improve their processes and adapt to a rapidly changing environment. Let's look at some reasons why this is necessary:

– Optimization of business processes: Technologies such as artificial intelligence, blockchain and the Internet of Things (IoT) have the potential to significantly improve processes in marketing and logistics, including supply chain management, personalization of offers and real-time product monitoring. Assessing their impact helps companies determine how to optimize processes, reduce costs and increase productivity.

– Prediction of future changes: Assessing the impact of technology allows you to not only understand current changes but also make predictions for the future. Forecasting allows companies to adapt their marketing and logistics strategies in advance, which is critical for their sustainability in a competitive market.

– Risk Management: Implementing new technologies always comes with risks. These may include technical difficulties, high initial investments, problems with employee training, or even possible legal issues. Assessing the impact of technology helps identify such risks and develop strategies to minimize them.

– Competitive Advantage: Assessing the impact of technology on marketing and logistics helps companies respond faster to changes in the industry. Technologies such as automation and machine learning can provide a competitive advantage to a company by speeding up decision-making and improving customer interactions. Companies that do not conduct such assessments risk falling behind more technologically advanced competitors.

– Innovation and Customer Experience Improvements: Technology affects not only internal processes but also customer interactions. Assessing its impact helps identify which innovations will improve customer experience.

– Reduced Costs and Increased Efficiency: Implementing new technologies, such as automated logistics processes and personalized marketing, can significantly reduce operating costs and increase efficiency. Impact assessments help identify which technologies are best suited for specific business goals, ensuring the highest return on investment.

– Strategic Planning: Assessing the impact of new technologies helps organizations make more informed decisions when planning strategically. Understanding which technologies are best suited to meet company goals allows resources to be focused on areas that will have the greatest impact.

Assessing the impact of technology on digital marketing and logistics enables companies to make more informed decisions, anticipate potential changes, and adapt their strategies to remain competitive in a rapidly changing marketplace. This not only reduces risks and improves business processes, but also increases customer satisfaction by streamlining operations and improving their interaction with the brand. To assess the impact of technologies on digital marketing and logistics, real data from world-class companies in the field of digital marketing and logistics will be taken as a basis, using the principal component analysis (PCA). Principal Component Analysis (PCA) is a statistical technique used to reduce the dimensionality of data and identify the main factors that explain the most variation in a data set. It is a powerful tool for analyzing the relationship between multiple variables and can be used to assess the impact of technology on digital marketing and logistics [15-16].

PCA reduces a large number of correlated variables to a smaller number of independent variables called principal components. Each principal component is a linear combination of the original variables and explains part of the total variance in the data. The main goal of this method is to reduce the dimensionality of the data while preserving as much information as possible. This is especially useful when you need to analyze complex relationships in the data, such as in digital marketing and logistics, where many factors can interact with each other. The principal component analysis includes the following key steps:

1) Data standardization (1):

$$Z = \frac{X-\mu}{\sigma} \tag{1}$$

where: X -is the original data, μ - is the mean, and σ is the standard deviation.

2) Calculating the covariance matrix C for standardized data (2):

$$C = \frac{1}{n-1} X^t X \tag{2}$$

3) Finding the eigenvalues and eigenvectors of the covariance matrix. The eigenvectors (principal components) determine the directions of maximum data dispersion.

4) Formation of the transformation matrix and projection of the initial data onto the principal components (3):

$$Z = X * W \tag{3}$$

where, W - is the matrix of eigenvectors and Z is the transformed data.

It is important to note that in order to analyze and evaluate the impact of technologies such as artificial intelligence, blockchain, IoT and big data on digital marketing and logistics, it is important to consider many factors, including economic, technological and operational aspects. Principal component analysis (PCA) is a powerful tool for data analysis in digital marketing and logistics, allowing to identify key factors that influence efficiency and process optimization. Using PCA enables companies to adapt their strategies, increase the efficiency of supply chains and improve marketing results. However, for the accuracy of the analysis, it is important to consider the possible limitations of the method, such as linearity and complexity of interpretation.

3 Results and discussion

Digitalization and the introduction of advanced technologies are radically changing the landscape of logistics and marketing. In the context of globalization and rising customer expectations, companies in the logistics sector are looking to adopt innovative approaches to improve efficiency, meet customer needs and remain competitive. The issues of implementing digital marketing in logistics and flow or management of information are becoming central, as traditional models no longer provide the required level of flexibility and efficiency. Digital marketing in logistics is becoming one of the key aspects of strategic management today, allowing companies to adapt to rapidly changing market conditions and strengthen their competitiveness. The interaction of marketing and logistics occurs through the integration of digital technologies that optimize supply chain management, improve customer experience and increase operational efficiency. Digital marketing in logistics is a direction that focuses on the use of digital technologies to improve customer interactions, optimize supply chains, and strengthen the brand. It combines marketing methods and tools with technological solutions in logistics, allowing companies to adapt to rapidly changing market demands and ensure high levels of customer satisfaction.

The theory of digital marketing in logistics is based on the integration of modern technologies into logistics processes to improve their efficiency, speed and customer satisfaction. The combination of digital marketing and logistics allows companies to optimize the delivery of goods, improve supply chain management, and provide customers with a personalized experience. Based on the above, it should be argued that intensive digitalization and globalization processes are key triggers that significantly change the current rules of the game in the marketing and logistics market worldwide. Together, they not only transform the processes themselves, but also provide new business opportunities, allowing companies to create more efficient, flexible and adaptive systems of interaction with customers, as well as optimize their operations. Undoubtedly, the emergence of new technologies and their penetration into the marketing and logistics management systems of companies play an important role and require a serious approach to management and operational application. Given the active penetration of technologies into digital marketing and logistics of companies, it is necessary to consider the periodization of the development of technologies and their penetration into the marketing and logistics system of companies, which are presented in Table 1.

Table 1 Periodization of the development and penetration of technologies into the marketing and logistics of companies

STAGE	PECULIARITIES OF PENETRATION INTO THE MARKETING AND LOGISTICS SYSTEM OF COMPANIES
PRE-DIGITAL ERA	Initially, logistics and marketing were completely autonomous and solved their own problems, with minimal automation of processes. Logistics was mainly responsible for storing and transporting products, and marketing was responsible for promotion and sales using traditional methods (printed materials, television, radio). Logistics and marketing rarely interacted directly, which led to data fragmentation and limited opportunities for coordination.
AUTOMATION AND EARLY DIGITALIZATION (1980-1990)	With the advent of information systems, automation began in logistics and marketing. ERP and supply chain management systems (SCM) made it possible to track product flows, optimize stocks, and improve accuracy and efficiency. In parallel, marketing began to use databases for customer segmentation, which contributed to the growth of targeted marketing. The interaction of logistics and marketing remained limited, but some processes began to integrate.
THE INTERNET AND E-COMMERCE (2000)	The introduction of the Internet has changed both marketing and logistics, giving rise to new tools such as CRM systems, online platforms, and marketplaces. Segmentation has become more precise, and personalization has emerged. Logistics has become integrated with marketing to service online orders, which has created unified information flows and the need for data coordination.
THE ERA OF BIG DATA, ANALYTICS, AND ARTIFICIAL INTELLIGENCE (2010)	The emergence of big data, analytics, and artificial intelligence has led to the creation of new strategies for marketing and logistics. Logistics began to forecast demand and optimize routes using analytics, and marketing began to use consumer behavior prediction. The synergy between logistics and marketing has increased thanks to omnichannel approaches and real-time data management.
CURRENT TRENDS (2020)	Modern technologies continue to transform marketing and logistics. Internet of Things (IoT) technologies help track goods, warehouses, and transportation. Blockchain provides transparency in supply chains, promoting customer trust. Artificial intelligence helps to forecast demand and manage personalized marketing. Sustainability has also become a priority, increasing the demands for transparency and environmental friendliness in logistics processes [17-18].

Clearly, modern technologies and their penetration into the digital marketing and logistics management systems of companies significantly transform their business processes at the global level. The penetration of technologies into marketing and logistics opens up new horizons for companies, providing opportunities to increase efficiency, optimize processes and improve customer experience. However, the successful implementation and use of these technologies requires significant effort, investment and competent risk management. Given that technologies continue to evolve rapidly, companies must be prepared for constant change and adaptation in a dynamic market. Features of technology penetration and their specificity in digital marketing and logistics of modern companies are consolidated and presented by the author in Table 2.

Table 2 Consolidation of features and specificity of technology penetration in digital marketing and logistics of modern companies

TECHNOLOGIES	TECHNOLOGY PENETRATION	
	DIGITAL MARKETING	LOGISTICS
ARTIFICIAL INTELLIGENCE (AI) AND MACHINE LEARNING (ML)	Artificial intelligence helps analyze customer behavior data, automate personalized advertising campaigns, and improve the accuracy of demand forecasting. For example, machine learning algorithms can recommend products based on individual user preferences or automatically optimize marketing campaigns across platforms, which reduces costs and increases conversion.	In logistics, AI and ML are used to optimize delivery routes, predict arrival times, and manage inventory. AI algorithms help improve warehousing, reduce order processing times, and reduce operating costs. This is especially useful for large companies with extensive supply chains, where automation and precise planning provide a competitive advantage.
INTERNET OF THINGS (IOT)	IoT technologies allow the collection and analysis of data from smart devices and sensors that consumers carry. This gives marketers information about how, when, and where products are used, allowing them to better tailor marketing strategies to customer needs.	IoT is actively used to track goods in real time, improve warehouse management and control transportation conditions. With the help of smart sensors and tags, IoT allows you to track the location and condition of goods, which is especially important for perishable or high-value goods. This helps to minimize losses, reduce risks and increase customer satisfaction.
BIG DATA AND ANALYTICS	Big data allows marketing departments to analyze a huge amount of information about customers and the market. Customer segmentation, predictive analytics and real-time behavior analysis are all made possible by big data technologies, which allow companies to make more informed decisions.	In logistics, big data helps analyze historical data, forecast demand and optimize the supply chain. This allows companies to better plan their resources, prevent shortages and manage risks associated with changes in demand and supply in the market [19].
BLOCKCHAIN	Blockchain technologies help build consumer trust as they provide transparency and data protection. For example, blockchain is used to verify the authenticity of goods, especially in areas such as fashion and pharmaceuticals, where customers want to be sure of the quality and origin of products.	In logistics, blockchain is used to track and protect data on the origin and routes of goods. This is important for companies with global supply chains, as the technology helps improve transparency, reduce the number of intermediaries and speed up the document management process.
AUTOMATION AND ROBOTICS	Automation helps marketers speed up processes such as advertising campaigns, collecting and analyzing data, communicating with customers through chatbots. Robotics of marketing operations allows you to quickly respond to customer requests and increase engagement.	Automation of warehouse processes, using robots and automated storage systems, significantly speeds up order processing and reduces personnel costs. Robots can perform routine tasks such as packing, sorting and transporting goods within the warehouse, freeing up employees for more complex tasks.
CLOUD AND SAAS	Cloud platforms allow you to manage marketing campaigns and interact with customers from anywhere in the world, providing access to data in real time. This is especially important for companies with international operations, where a single database and centralized management help maintain brand and marketing message consistency.	Cloud technologies in logistics are used to manage supply chains and interactions between all participants in the process - from suppliers to distributors. This helps reduce IT infrastructure costs, improve process flexibility and quickly respond to changes in supply conditions [20].

In considering the presented strategic goals, it should be noted that the implementation of technologies in marketing and logistics and flow or management of information is not only a way to increase efficiency and reduce costs, but also a necessity to maintain competitiveness in the global market. Technologies open up new opportunities for personalizing services, improving logistics processes and increasing business flexibility in a dynamically changing external environment. However, the implementation of these technologies requires serious investments, a well-thought-out strategy and readiness to quickly respond to new challenges. The penetration of technologies into the digital marketing and logistics system ensures the implementation of a number of strategic goals, which are presented in Figure 1.

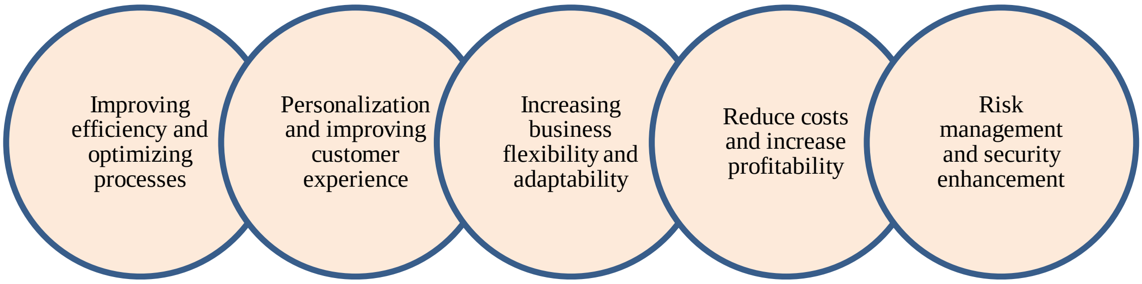

Figure 1 Strategic goals, the implementation of which in digital marketing and logistics depends on technologies

Technology enables marketers and supply chain management to increase efficiency, reduce costs, improve customer interactions, and minimize risks. However, its implementation is associated with a number of challenges, such as the need to scale and adapt to business needs, maintain data security, and train qualified personnel. Clearly, the penetration of technology into marketing and logistics leads to the fact that data becomes the main strategic resource for a company, and the integration of technologies requires constant updating of strategies and adaptation to new market conditions. Based on this, it is conceptually necessary to formalize the advantages and disadvantages of technology penetration into digital marketing and logistics, thereby changing the rules of the game in global markets, which are presented in Table 3.

Table 3 Formalization of the advantages and disadvantages of technology penetration into digital marketing and logistics, which affect the change in the rules of the game in global markets

TECHNOLOGY PENETRATION	CHARACTERISTICS OF TECHNOLOGY PENETRATION IN MARKETING AND LOGISTICS
ADVANTAGES	
COST REDUCTION	Automation and optimization of processes can significantly reduce operating costs.
INCREASE IN SPEED AND ACCURACY	Technologies speed up processes in logistics, allowing for faster delivery of goods, and in marketing – more accurate targeting of the audience.
IMPROVED CUSTOMER EXPERIENCE	Personalized offers and improved service with the help of technologies increase customer satisfaction.
INCREASED COMPETITIVENESS	The use of modern technologies helps companies stay on the cutting edge of development and offer more efficient and innovative solutions.
TRANSPARENCY AND SECURITY	Technologies such as blockchain increase the level of trust and security in supply chains and data management [21].
DISADVANTAGES	
HIGH INITIAL INVESTMENT	Implementing new technologies requires significant capital investment in hardware, software, and staff training.
CYBER THREATS AND DATA SECURITY	With the increase in digital solutions comes the risk of data leaks and attacks on systems, which can lead to a loss of trust with customers and partners.
DEPENDENCY ON TECHNOLOGY	Complete reliance on automated systems can lead to serious disruptions in the event of technical problems or failures.
NEED FOR SKILLED LABOR	Effective use of technology requires highly skilled personnel, which can be a challenge for some companies, especially in the context of IT talent shortages.
INTEGRATION CHALLENGES	Integrating new technologies with existing systems can be complex and expensive, especially in larger organizations with legacy infrastructures [22].

The use of technology in digital marketing and supply chain management offers enormous opportunities to optimize processes, improve customer experience, and increase competitiveness [23]. However, each technology also carries risks that can affect the safety, reputation, and efficiency of companies. The structuring of key risks caused by the penetration of new technologies into digital marketing and logistics, which radically changes the rules and conditions of the game in the global market for modern companies, is presented in Figure 2.

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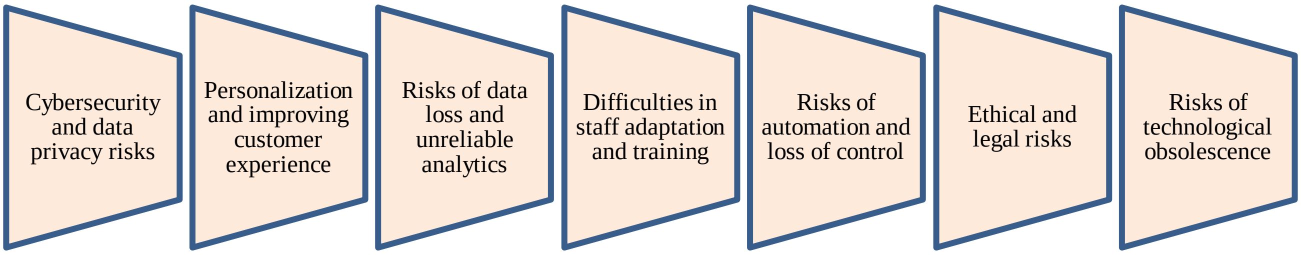

Figure 2 Structuring of key risks caused by the penetration of new technologies into digital marketing and logistics, which radically changes the rules and conditions of the game in the global market for modern companies

The risks associated with the penetration of technology into marketing and logistics are becoming increasingly significant as companies seek to integrate digital solutions to improve efficiency and customer engagement. At the same time, significant challenges arise related to data security, dependence on digital platforms and other factors that can affect the stability and sustainability of the business [24-25]. The risks associated with the implementation of technologies in marketing and logistics must be taken into account in strategic planning. A systematic approach to risk assessment and management will help companies maximize the benefits of digitalization while minimizing potential threats to their reputation, sustainability, and competitiveness. Conceiving the presented, it should be noted that there is a global and intensive digitalization of the modern economy, which is caused by the penetration of new technologies into all sectors of companies' activities and the transformation of the rules of the game in the markets. Based on this, it is necessary to determine the main indicators of development trends and dynamics of technology penetration into digital marketing and logistics of companies, which are presented in Figure 3.

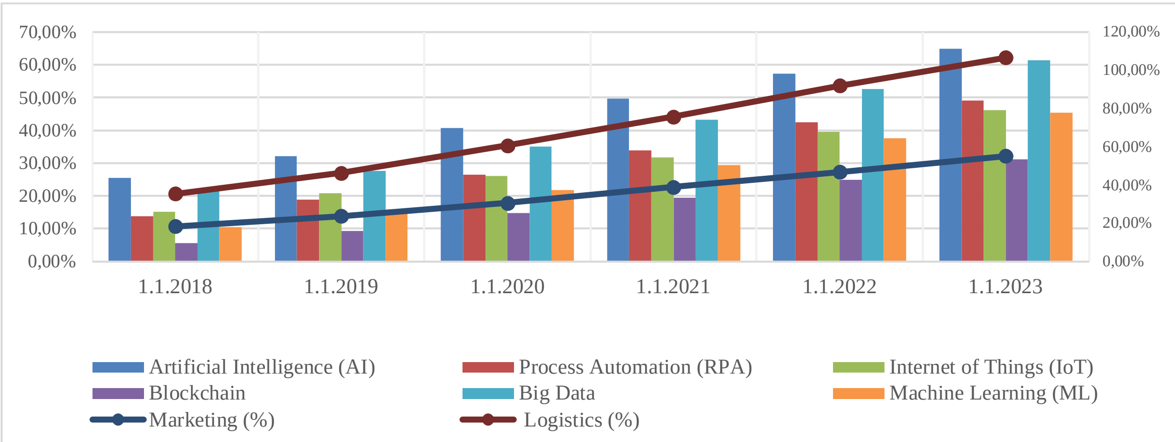

Figure 3 Main development trends and dynamics of technology penetration into digital marketing and logistics of companies, which radically change the rules of the game in the market

It is definitely worth noting that the use of AI in marketing and logistics is growing by 8-9% annually, indicating its significant impact on the processes of analysis and personalization. Automation is growing faster in logistics than in marketing, especially in warehouse and transportation management. The growth in 2023 was about 7% compared to the previous year. In logistics, IoT is actively used for real-time monitoring and supply chain management. In marketing, this technology is used to analyze customer data. Despite the low growth rate, blockchain is finding application in logistics to ensure supply chain transparency. In marketing, its use is associated with data protection and transaction security. Big Data and machine learning (ML) are technologies that provide deep analytics of customer data, helping companies predict demand and improve the accuracy of personalized marketing [25-27]. Growing rates of advanced technology adoption indicate that companies are looking to integrate digital solutions to improve service quality and increase operational efficiency in marketing and logistics.

In arguing the presented, it should be noted that in order to identify all hidden dependencies and trends in the data, highlighting the main factors and components that have the greatest impact on processes in marketing and logistics and change the key rules of the game in the markets, it is necessary to implement the Principal Component Analysis (PCA) method. To assess the impact of technologies on digital marketing and logistics of modern companies using the principal component analysis (PCA) method, it is necessary to complete several key steps:

– Formulation of the problem and selection of variables. Determination of how technologies (automation, use of AI) affect key business indicators of modern companies in the digital marketing and logistics system. The variables used are technology implementation metrics: degree of automation, use of AI. Logistics indicators: delivery time, data processing speed. Business results: revenue growth, customer satisfaction.

– Collection of data on key metrics from real companies through open sources (annual reports, studies). Checking data for gaps, anomalies, as well as their normalization. Technological indicators: automation, use of AI, implementation of IoT. Market: market share, revenue growth. Logistics: order processing speed, delivery time.

– Data Standardization. Before conducting PCA, the data is standardized so that each variable has the same impact on the result. Build a covariance matrix. The covariance matrix shows the relationship between variables.

– Calculate eigenvalues and eigenvectors. Eigenvalues show the proportion of variance explained by each principal component. Eigenvectors determine the direction of the principal components.

– Project data onto principal components. Data is projected onto new axes (principal components) using matrix multiplication.

– Analysis of results. Proportions of explained variance: determine how important each component is. Projection values: allow you to compare companies with the impact of technology.

– Conclusions and recommendations. Which technologies have the greatest impact on company results. Where companies are losing efficiency. How key indicators can be improved using technology [26-27].

Clearly, the use of the PCA methodology allows us to identify which technological factors (automation, AI, blockchain, and others) have the most significant impact on the rules of the game in the digital marketing and logistics market. To substantiate the role and sorption of the influence of technologies on changes in the rules of the game in the digital marketing and logistics management markets [28], the following initial data were determined, using the example of world-class companies, which are presented in Table 4.

Table 4 Structuring of initial data for assessing the impact of technologies on changes in the rules of the game in the digital marketing and logistics market of modern companies

COMPANY	AUTOMATION (%)	PROCESSING SPEED (MIN)	AI USAGE (SCORE)	DELIVERY TIME (HOURS)	REVENUE GROWTH (%)
AMAZON	95.00	45.00	9.00	2.10	22.00
WALMART	85.00	60.00	8.00	3.20	15.00
ALIBABA	90.00	50.00	10.00	2.50	20.00
FEDEX	80.00	70.00	7.00	3.80	12.00
DHL	88.00	55.00	8.00	3.00	18.00

Standardization of data for assessing the impact of technologies on changing the rules of the game in the digital marketing and logistics market of modern companies is presented in Table 5.

Table 5 Standardization of data for assessing the impact of technologies on changing the rules of the game in the digital marketing and logistics market of modern companies

COMPANY	Z (AUTOMATION)	Z (PROCESSING SPEED)	Z (USE OF AI)	Z (DELIVERY TIME)	Z (REVENUE GROWTH)
AMAZON	1.48	-1.28	0.59	-1.40	1.29
WALMART	-0.53	0.46	-0.39	0.48	-0.68
ALIBABA	0.48	-0.70	1.57	-0.72	0.73
FEDEX	-1.52	-1.63	-1.37	1.51	-1.52
DHL	0.08	-0.12	-0.39	0.14	0.17

Based on this, projections were calculated through matrix multiplication of standardized data by eigenvectors, which are presented in Table 6.

Table 6 Projections of matrix multiplication of standardized data by eigenvectors for assessing the impact of technologies on changing the rules of the game in the digital arctic and logistics market of modern companies

COMPANY	PC1	PC2	PC3	PC4	PC5
AMAZON	-2.73	-0.59	-0.11	-0.04	~0.00
WALMART	1.14	0.08	-0.12	0.12	~0.00
ALIBABA	-1.84	0.92	0.04	-0.02	~0.00
FEDEX	3.38	0.00	-0.03	-0.09	~0.00
DHL	0.06	-0.41	0.22	0.03	~0.00

In conceptualizing the presented, it should be noted that the application of the principal component method tools is characterized by its significance, which is determined by the following:

– Multidimensionality of data: Modern digital marketing and logistics cover many metrics (automation, delivery speed, AI). PCA allows you to reduce a large number of variables to a smaller number of key factors.

– Reduction of dimensions: Reducing the number of variables without losing meaningful information simplifies analysis and allows you to identify the main drivers of changes in the market.

– Identification of hidden dependencies: PCA helps to reveal complex relationships between technologies and business results that are not obvious in traditional analysis [29].

The PCA results show that process automation and AI implementation have the greatest impact on company metrics, including processing speed, delivery time, and revenue growth. This is supported by the fact that the first principal component (PC1) explains 94% of the data variation, reflecting the importance of these technologies for business. Clearly, advantages for companies with high technological maturity: companies such as Amazon and Alibaba actively use automation and AI technologies, which allows them to achieve high performance in all key indicators: processing speed, revenue growth, and customer satisfaction. The role of logistics and its relationship with technology: Although logistics also has an impact on business metrics, its effect is limited without the support of technology. Delivery time and order processing speed play an important role, but these factors acquire significance only in the context of integration with high technologies. Therefore, innovation changes competitive strategies: The implementation of advanced technologies such as automation and AI is a game changer in the market. Companies that actively implement these technologies gain competitive advantages in terms of speed, accuracy, service quality and, as a result, revenue growth [30]. Lagging behind the technology race brings risks: Companies that do not take technological changes into account may face difficulties related to insufficient logistics and marketing efficiency. For example, companies with low levels of automation (e.g., FedEx and DHL) risk falling behind competitors unless they implement new technologies to optimize their operations. Diversify approaches depending on the industry: Technologies have different levels of impact in different markets (e.g., e-commerce, logistics and retail). For example, in e-commerce (Amazon), automation and AI play a decisive role, while in logistics (FedEx, DHL), a combination of technology and traditional operational efficiency is important. Companies that want to remain competitive must continue to invest in process automation and AI development. The use of AI for demand forecasting, route optimization and improving customer experience will play an increasingly important role. The PCA results highlight the need for agility in business strategy. To keep up with technological changes, companies must actively monitor trends and adjust their business processes accordingly. With the development of the Internet of Things (IoT), 5G, autonomous vehicles, and blockchain technologies, changes in logistics will occur much faster. These technologies will allow for even more automation of processes, increase their transparency, and speed up delivery. Based on the results of the study, it should be argued that the main recommendation for companies is to actively invest in technologies that can improve their logistics and marketing processes. This will not only increase efficiency, but also provide better conditions for revenue growth and improved customer service. It is important to create strategies that can be adapted to rapidly changing market conditions. Understanding how technology can change the process will give the company flexibility in decision-making.

4 Conclusions

Digital marketing and logistics have become central elements of modern business strategies, and their integration with new technologies forms the basis for competitive advantages in the global marketplace. Recent years have seen a sharp increase in the implementation of advanced technologies in these areas, which has increased the need to analyze them and understand their impact on business success. It is argued that the introduction of technologies such as artificial intelligence (AI), process automation and the Internet of Things (IoT) radically changes the way companies interact with customers and manage logistics processes. The transition to more automated and intelligent systems allows for a significant reduction in order processing time, increased forecast accuracy and improved service quality. It is substantiated that in conditions where technologies are rapidly changing the market, companies need to promptly respond to these changes and adjust their strategies. Without the introduction of modern technologies, one can expect a loss of competitiveness. It is stated that in order to ensure business sustainability in the long term, it is important not only to effectively integrate technologies into operational processes, but also to take into account their impact on consumer preferences and market trends. This creates new challenges for businesses, including the need to fine-tune marketing and logistics strategies.

The principal component analysis (PCA) method was chosen to analyze the impact of technologies on digital marketing and logistics because it allows for the efficient processing of complex multivariate data and the identification of the most significant factors that determine changes in the market. According to the PCA results, technologies such as automation and artificial intelligence have the greatest impact on business results. The implementation of these technologies can significantly improve key metrics such as data processing speed, delivery efficiency, and revenue growth.

The results of the analysis show that logistics itself is an important aspect of business, but its efficiency increases many times when integrated with advanced technologies. Companies that have not adopted advanced technologies such as AI or automation face the risk of reduced efficiency. An example of this would be companies with highly efficient logistics but without modern technologies, which could lead to a loss of competitiveness in the future. With the development of new technologies such as 5G, blockchain and autonomous systems, the future of digital marketing and logistics looks even more dynamic. The integration of these technologies will not only speed up processes, but also create new opportunities to improve service quality and personalize offers. In the coming years, we can expect a significant increase in the use of AI to predict customer needs, as well as the use of autonomous vehicles and robotics to optimize logistics operations.

Companies must invest heavily in new technologies, such as automation and AI, to remain competitive and drive revenue growth. Implementing these technologies will improve logistics and marketing efficiency, improve customer service, and reduce costs. To successfully adapt to market changes, companies must be prepared to continually update their strategies in response to technological changes. This requires flexibility and speed of decision-making.

Synergy between technology and operational efficiency will allow not only to implement new technologies, but also to integrate them into the company's existing operational processes. Combining innovation with traditional management methods will allow achieving maximum efficiency. However, the implementation of technologies requires significant investment and adaptation of business strategies. One of the challenges remains the problem of the high cost of switching to new systems, as well as the need for staff training. In addition, with increasing dependence on technology, the risk of cyber-attacks and data leaks increases. Therefore, it is necessary to find a balance between innovation and risk to ensure sustainable growth and business security.

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Route analysis of waste transportation vehicles in urban areas using the saving matrix method

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Keywords: waste transportation, vehicle capacity, tangkasaki truck, route optimization, saving matrix.
Abstract: The increase in population in Indonesia, particularly in the city of Makassar, will be followed by an increase in the volume of waste generated. Tamalate District, as part of Makassar City, has a waste generation volume of 583 m^3/day, requiring waste management to be addressed through waste collection services to handle the amount of waste produced. This study identifies the existing conditions of tangkasaki truck service routes to obtain data on service locations, number of vehicles, travel distance, travel time, and operational costs. The identification shows that there are 37 waste disposal sites served by 11 trucks at night, but the waste transportation is considered inefficient due to the underutilization of vehicle capacity. This study aims to optimize waste transportation routes with using the saving matrix method by maximizing vehicle capacity. The saving matrix method is used to evaluate fleet requirements on existing routes by considering vehicle capacity, working time, and predetermined fuel consumption. The research results show that proposed routes with the implementation of the saving matrix method can reduce the number of tanker truck fleets from 11 units to 9 units. The efficiency of travel distance is 21.7%, previously 294.4 km/day reduced to 230.4 km/day. The efficiency of travel time is 8.9%, previously 2,063 minutes/day reduced to 1,880 minutes/day by maximizing the working time of each service route and operational cost efficiency within one month of service is 22.6%, previously IDR 99,330,000.00 reduced to IDR 76,900,320.00.

1 Introduction

The swift expansion of urbanization and population, coupled with industrial and material transformations, has led to a crisis in urban solid waste management, particularly in developing countries, as a major challenge to sustainable developmen [1]. South Sulawesi Province is ranked 9th as the province with the largest population in Indonesia. Tamalate District is one of the sub-districts in Makassar City [2]. According to data from the Makassar City Environmental Service, Tamalate District is the sub-district with the second highest volume of waste generation (583 m3/day). In implementing the waste problem, the number of facilities and infrastructure for transporting waste in Tamalate District can be said to be sufficient to overcome the volume of waste generated every day. From the results of observations, the number of waste transportation fleets in Tamalate District is divided into several types of vehicles and different service assignment routes. Tamalate District has a fleet of 99 VIARs, 15 tangkasaki trucks, 10 barge trucks and 11 waste container units. This research focuses on the Tangkasaki truck .

Planning efficient waste transportation routes and schedules is the most important thing in improving the waste transportation system. Selecting a vehicle route will determine the total distance traveled by the fleet. So, the optimal route is the goal of determining the waste collection route by getting the shortest possible route from WDS (Waste Disposal Site) to FDS (Final Disposal Site) with as few obstacles as possible. In its implementation, considering the real conditions in the field, there are many factors that can influence the waste transportation process so that it is not optimal [3]. Several factors that influence the waste transportation process include inefficient use of working time, inappropriate use of vehicle load capacity, inefficient transportation routes, the volume of waste piled up at each WDS, the behavior of officers , and poor accessibility [4].

Waste collection heavily relies on route optimization, which demands substantial investments in capital, labor, and variable operational expenses. As collection routes become more efficient, both costs and environmental impacts decrease [5]. Traditional waste management systems, which typically follow fixed schedules and predetermined routes, often suffer from inefficiencies. This method may cause collection vehicles to make unnecessary trips to bins that are not yet full, leading to increased traffic congestion and higher operational expenses. Moreover, these inefficiencies contribute to greater fuel consumption and higher greenhouse gas emissions [6].

One method to obtain the shortest route with maximum waste the capacity is determined using the saving matrix method combined with the nearest neighbor approach. This method involves identifying the sequence of distribution routes to be followed and determining the number of transport vehicles required based on their capacity. A key feature of the saving matrix method is its ability to schedule a limited number of vehicles while considering the maximum capacity of both similar and different types of vehicles. Additionally, this method applies merging points in a single step and takes vehicle capacity into account throughout the process [7].

This research focuses on determining the existing condition of the waste transportation service route in Tamalate District based on vehicle capacity and the number of tangkasaki truck fleets as well as determining the optimal transportation route and number of fleets on the waste transportation service route in the Tamalate District area based on route determination using the method of saving matrix.

2 Literature review

2.1 Route optimization

Traditional methods for optimizing freight delivery routes mainly focus on minimizing costs based on distance. Newer approaches, however, also aim to minimize time as an objective. Despite this, the relationship between time and distance is not always straightforward, and the trade-off between the two can be complex [8]. Waste transportation is one of the several benefits of optimal routes, which is why they are necessary. Waste collection is an essential part of the waste management system, and the costs involved in this procedure account for a large amount of the total cost of disposing of waste [9]. The primary goals of optimizing waste collection routes are to minimize the total route length by selecting the shortest path that covers all destinations, reduce travel time to visit all locations, and keep costs as low as possible to maximize overall benefits [10]. Many site selection techniques have evolved alongside research on waste collection routes and solution algorithms. To maximize the efficiency of the waste collecting operation, an algorithm is needed rather than following a predetermined path [11].

The optimal route is closely linked to vehicle routing problems. The Vehicle Routing Problem (VRP) is a crucial problem in combinatorial optimization that entails determining the optimal set of routes a fleet of vehicles should travel in order to serve a particular customer group [12]. Significant advancements have been made in the techniques used to model and solve both standard and capacity VRPs, as well as their various variants. Researchers and practitioners have developed more efficient and precise solution algorithms, along with improved models, enabling them to address large-scale problems more effectively [13].

The relationship between time and distance is not always straightforward. It's evident that relying solely on distance or time functions doesn't yield the most realistic or optimal outcomes. When there is no traffic congestion, distance and time are perfectly correlated. In such cases, the route optimized for distance will also be the same as the one optimized for time, and both will match the route where all costs are minimized. However, when factors like congestion, fluctuating demand, accidents, or road repairs come into play, the results from these different optimization methods will diverge [8]. This limited coordination has been a factor for inefficient planning of services and infrastructure which includes facility location, allocation of communities, medical referrals, and land transportation [14].

2.2 Nearest neighbour

Using a random example, the performance of the Variable Neighbourhood Search (VNS) method is assessed in relation to our problem [15]. Neighbor set models are designed to handle incomplete, imprecise, and uncertain data. These models have found applications in various fields, including anomaly detection and data classification. However, many existing neighbor models struggle with inappropriate neighborhood radius selection and lack of adaptability. To address this, an improved k-nearest neighbor model is proposed, where the distance serves as the k-nearest neighborhood radius, leading to more accurate granulation results and a more effective anomaly detection model [16].

Nearest neighbor-based approaches are well-established strategies that continue to be used because of their effectiveness [17]. The customer nearest to the first one visited is the next one on the route, and so on, until every customer is on the path [18]. The following steps are involved in applying the Nearest Neighbour algorithm: To ensure that the total number of requests in the current route does not exceed the vehicle's capacity (Q), we start at the depot and visit exactly one client (vertex) from each cluster. The procedure is repeated from the depot and the closest unvisited client from any unvisited cluster is selected next if the total number of requests in the current route above the vehicle capacity. This keeps going until every cluster has been visited; after then, the algorithm stops. The end result is a collection of routes, each of which has precisely one client from every cluster in the order that they were accessed [19]. The Nearest Neighbor algorithms are straightforward to implement and fast to execute, but their greedy approach can sometimes result in missing shorter, more optimal routes. The specific steps of the Nearest Neighbor algorithm are detailed in [20]:

1. A starting vertex will be selected at random.
2. The edge that joins the current vertex to an unvisited vertex with the smallest weight will be chosen.
3. Vertex V represents the current vertex V.
4. Vertex V has a visited mark.
5. After visiting every vertex in the domain, the procedure will end.

2.3 *Saving Matrix*

One method for determining the best paths for product delivery to marketing regions is the Saving Matrix. In order to ensure the shortest routes and reduce transportation costs, it entails figuring out the necessary routes and the number of vehicles based on their capacity. The deployment of vehicles from facilities with different maximum capacity is also planned using the Saving Matrix approach [21]. Steps for using the saving matrix method:

1. Constructing the distance matrix can be done using Google Earth application, Google Maps, or manual calculations with a speedometer.
2. Creating the savings matrix involves merging two potential WDS into a single truck to optimize distance, time, and transportation costs. If S(x,y) represents the distance saved—such as in a route from the central starting point → point x → 14 point y → back to the center—then the equation to determine the savings amount is:

$$S(x,y) = Dist(Pusat,x) + Dist(Pusat,y) - Dist(x,y) \qquad (1)$$

3. Allocate WDS to a transportation route. The first step is that each WDS is allocated to a different truck or route. The second step is to combine the two routes based on the largest distance savings obtained using equation (1) and checking whether the combination is feasible or not. It is said to be feasible if the total shipments that must be passed via that route do not exceed the capacity of the transport equipment. Route combinations are focused on saving the greatest distance in order to obtain distance efficiency, so that the time traveled will be faster. Checking the total amount of shipments via a route is done by looking at the distance between the largest savings. What is done after selecting the distance with the greatest savings is to add up the WDS pairs that have the greatest savings so that it can be seen that the route is less than or equal to the capacity of the transport equipment.
4. Sorts WDS on a route, at this stage the aim is to minimize the travel distance that each means of transport must travel. To obtain optimal transportation routes, two stages can be carried out, namely determining the initial delivery route for each vehicle using the Nearest Neighbor procedure and making improvements to routes that are not feasible.

3 Methodology

This research is a quantitative research utilizing historical data. The time of the research was carried out in October - November 2023 and the object of this research was the waste transportation service route in Tamalate sub-district, Makassar City. The data sources consist of both primary and secondary data.. Primary data is data obtained directly from observations and interviews with parties involved in waste transportation service activities in Tamalate District, Makassar City to formulate research problems. In contrast, secondary data refers to information not directly collected by the researchers but obtained through intermediaries or documentation related to waste transportation service activities in the Tamalate District, Makassar City.

3.1 *Service route tangkasaki truck*

The problems that exist in transporting waste in the Tamalate District area, especially on the Tangkasaki truck service route. The main cause of determining existing service routes that are not optimal is due to the large number of service location points and not maximizing vehicle capacity on each route based on the transport volume of each truck. This causes the total distance traveled, total travel time and operational costs to be high. So we will determine the optimal route and evaluate the needs of the Tangkasaki truck fleet using a combination of saving matrix and nearest neighbor methods. The use of the saving matrix method begins by determining the distance matrix that connects the FDS and each WDS. Next, the largest savings value is calculated and it will be allocated to a new route taking into account vehicle capacity. Allocation into a route will be combined with the nearest neighbor procedure to get a more optimal solution from the previously formed route by prioritizing the closest neighbors on the route to be visited. The proposed route using the saving matrix method is known to provide work and service efficiency in the waste transportation process in the Tamalate District area. The first step is determine the location of WDS use the coordinates of the existing Tangkasaki truck route as in Table 1.

Table 1 The coordinates of the existing Tangkasaki truck route

Truck number	Route	WDS Code	Coordinate *Latitude*	Coordinate *Longitude*	Volume WDS (m^3/day)	Total (m^3/day)
011	I	A1	5°10'21.51"S	119°25'54.86"E	3.04	8.10
		A2	5°10'4.09"S	119°25'54.46"E	1.89	
		A3	5°10'6.56"S	119°25'46.70"E	1.49	
		A4	5°10'18.93"S	119°25'43.63"E	0.96	
		A5	5°10'24.20"S	119°25'47.37"E	0.72	
023	II	B1	5°10'19.63"S	119°25'38.21"E	1.02	10.04
		B2	5°10'21.86"S	119°25'14.37"E	2.77	
		B3	5°10'14.54"S	119°25'7.57"E	3.18	
		B4	5°10'5.90"S	119°25'15.84"E	3.07	
148	III	C1	5°10'2.73"S	119°25'11.11"E	2.06	10.95
		C2	5°10'1.11"S	119°25'7.60"E	0.78	
		C3	5°10'10.80"S	119°25'2.91"E	2.89	
		C4	5°10'15.55"S	119°24'50.35"E	1.59	
		C5	5°10'9.92"S	119°24'48.39"E	1.56	
		C6	5°10'6.27"S	119°24'59.90"E	2.07	
047	IV	D1	5°10'24.81"S	119°24'56.82"E	3.67	8.51
		D2	5°10'39.06"S	119°24'49.65"E	1.32	
		D3	5°10'30.74"S	119°25'0.08"E	3.52	
012	V	E1	5°10'52.51"S	119°24'57.47"E	1.96	12.22
		E2	5°10'52.33"S	119°24'46.55"E	2.47	
		E3	5°10'54.41"S	119°24'34.00"E	1.77	
		E4	5°10'43.86"S	119°24'44.40"E	2.56	
		E5	5°10'48.91"S	119°25'0.79"E	2.51	
		E6	5°10'54.84"S	119°25'7.85"E	0.95	
156	VI	F1	5°10'42.41"S	119°24'24.42"E	3.39	8.24
		F2	5°10'39.85"S	119°24'19.15"E	2.85	
		F3	5°10'46.74"S	119°24'21.53"E	2.00	
167	VII	G1	5°10'7.38"S	119°24'5.00"E	3.78	6.77
		G2	5° 9'59.14"S	119°24'17.04"E	2.99	
021	VIII	H1	5°10'58.15"S	119°26'25.20"E	5.98	5.98
		X1	5°10'57.72"S	119°25'57.82"E	10.5	10.50
166	IX	I1	5°11'13.85"S	119°25'52.26"E	5.74	5.74
		X1	5°10'57.72"S	119°25'57.82"E	10.5	10.50
074	X	J1	5°11'11.98"S	119°25'32.28"E	1.74	8.70
		J2	5°11'24.14"S	119°24'51.06"E	3.56	
		J3	5°11'5.50"S	119°24'51.27"E	3.40	
054	XI	K1	5°11'4.33"S	119°25'21.17"E	3.18	8.07
		K2	5°10'41.91"S	119°25'35.03"E	4.89	

The volume of waste generated at the WDS in each Tangkasaki truck service route is based on the results of observations of the average waste generation per service route. So it can be assumed that the volume of waste generated every day at each WDS is the same. Meanwhile, determining the size of the waste volume from each waste source at the WDS is the result of brainstorming between the author and the head of the cleanliness section of Tamalate District as in table 1. Based on the coordinate data of 37 WDS points shown in table 1, it will be visualized into 11 service routes marked with different colors using Google Maps. The existing route of the Tangkasaki truck in Tamalate District is shown in Figure 1.

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Figure 1 Existing Route of Tangkasaki Truck

Mileage is calculated based on the total distance from the depot (FDS) to each service route (WDS) and back to the depot (FDS). Calculation of distance traveled using the get directions feature on Google Earth. Based on the results of the interview, the route that must be taken from the FDS back to the FDS must be within the Makassar City area. Data on the distance traveled from the existing Tangkasaki truck route in Tamalate District is shown in the Table 2. The fuel consumption of Tangkasaki trucks can also be seen in Table 2 with the assumption that the average fuel consumption of each truck can reach 5 km/liter. The fuel allowance is given because the average actual fuel consumption per truck is 7.5 liters/day. In providing services, each Tangkasaki truck is given a fuel allowance of 7.5 liters/day. So, in one day of service the total fuel consumption of all Tangkasaki trucks in Tamalate District is 82.5 liters/day. If it is assumed that the price of diesel is IDR 6,800.00 per liter, then the fuel costs are IDR 561,000.00 per day or IDR 16,830,000.00 per month assuming 1 month, namely 30 days.

3.2 Distance traveled and fuel consumption on existing route

Mileage is calculated based on the total distance from the depot (FDS) to each service route (WDS) and back to the depot (FDS). Calculation of mileage using the get directions feature on Google Earth. Based on the results of the interview, the route that must be taken from the FDS back to the FDS must be within the Makassar City area. Data on the distance traveled from the routes of Tangkasaki trucks in Tamalate District is shown in Table 2.

Fuel consumption on the existing Tangkasaki truck route in Tamalate District is known based on the results of interviews with truck drivers. The average fuel consumption of each truck can reach 5-6 km/liter, which is because during service the truck engine must remain idling or in conditions such as stop and go and is also influenced by the weight of the waste load. So, it can be assumed that the fuel consumption of a Tangkasaki truck is 5 km/liter. Actual fuel consumption is obtained from the total distance traveled by each truck divided by fuel consumption per liter. This has absolutely no effect on the fuel allowance given because the average actual fuel consumption per truck is <7.5 liters/day and it shown in Table 2.

Table 2 Distance traveled and fuel consuption on the existing Tangkasaki truck route

Truck Code	Route	Route Flow	Mileage (km/day)	Fuel Consumption (liters/day)
011	I	FDS -A1-A2-A3-A4-A5-FDS	24.8	4.96
023	II	FDS -B1-B2-B3-B4- FDS	22.2	4.44
148	III	FDS -C1-C2-C3-C4-C5-C6- FDS	25.4	5.08
047	IV	FDS -D1-D2-D3- FDS	24.3	4.86
012	V	FDS -E1-E2-E3-E4-E5-E6- FDS	27.0	5.4
156	VI	FDS -F1-F2-F3- FDS	27.9	5.58
167	VII	FDS -G1-G2- FDS	30.7	6.14
021	VIII	FDS -H1-X1- FDS	28.2	5.64
166	IX	FDS -I1-X1- FDS	27.2	5.44
074	X	FDS -J1-J2-J3- FDS	28.7	5.74
054	XI	FDS -K1-K2- FDS	28.0	5.6
Total			**294,4**	**58.88**

Travel time is calculated based on two aspects, namely the total time during the journey from and back to the landfill and the time required for loading and unloading the waste from the landfill into the truck. Travel time greatly influences the working time of workers (drivers and maids) which has been set at 4 hours (240 minutes). Working hours are determined outside of the time for waste disposal at the landfill due to the large queue of rubbish trucks so it takes a long and uncertain time. Travel time data from the existing route for each tangkasaki truck in Tamalate District is shown in the Table 3.

Table 3 Travel time on the existing Tangkasaki truck route

Truck Code	Route	t_{bm}	$t_{FDS-WDSa}$	$t_{WDSt-FDS}$	t_{total}
011	I	98	26	31	155
023	II	127	27	25	179
148	III	186	29	29	244
047	IV	115	29	28	172
012	V	149	32	30	211
156	VI	126	34	34	194
167	VII	63	38	36	137
021	VIII	153	32	29	214
166	IX	95	32	29	156
074	X	175	35	35	245
054	XI	93	32	31	156
Total					**2063**

t_{bm} : Loading and unloading time (minutes/day)
$t_{FDS-WDSa}$: Travel time from FDS /landfills to WDS /temporary shelter (minutes/day)
$t_{WDSt-FDS}$: Travel time from WDS /temporary shelter to FDS /landfills (minutes/day)
t_{total} : total time (minutes/day)

Based on the travel time data for the existing route shown in table 3, it is known that the Tangkasaki trucks with codes 148 and 074 exceeded the specified working time limit. This is because the condition of WDS C4 and C6 on the route served by the Tangkasaki 148 truck has to reach the last road section that borders Mamajang District, so the truck has to turn around and continue to WDS C5.

3.3 Operational costs of existing route

The operational costs of Tangkasaki trucks in Tamalate District are divided into fuel costs (diesel) and workers' salaries (drivers and maids). From the results of the interview, each truck received a fuel allowance of 15 liters for two days of transportation service. So it is assumed that one day each truck gets 7.5 liters of fuel. Meanwhile, workers' salaries are divided into basic salary and daily wages for the driver and two garbage collector. The calculation of the total costs incurred in one month for workers' salaries is an assumption if in one full month (30 days) all workers have carried out their duties and obligations Salary data for Tangkasaki truck workers in Tamalate District is shown in table 4. One truck have one driver and 2 garbage collector.

Table 4 Salaries of existing route

Type of Worker	Amount	Basic salary (per month)	Daily salary (per month)	Total (per month)
Truck Driver	11	IDR1,000,000.00	IDR 50,000.00	IDR 82,500,000.00
Garbage collector	22			

From the calculation results between worker salaries and fuel costs incurred, the expenditure for operational costs in one month can be seen in Table 5, which shows a total cost of IDR 99,330,000.00 per month.

Table 5 Total cost

Cost	Total Cost (per month)
Salaries	IDR 82,500,000.00
Fuel	IDR 16,830,000.00
Operasional Cost	**IDR 99,330,000.00**

4 Results and discussion

4.1 Savings matrix proposed route

Data processing is carried out using the saving matrix method and combined with the nearest neighbor algorithm to obtain a more optimal solution from the existing route as in Table 6. The result of using a saving matrix is to combine two routes based on saving the distance from the largest until all points have been combined. It can be calculated using equation (1) and checking the feasibility of the combination so that it does not exceed the truck capacity.

Table 6 Allocation of WDS to truck routes

Truck	Route Combine	*Saving*
1	A1B2	19.1
1	A1A5	18.8
1	A1B1	18.1
1	A1A2	18
1	A1A3	18
1	A1A4	18
2	H1I1	8.8
3	G1G2	4.6
4	C1C2	3.9
5	F1F2	3.7
5	F1F3	3.7
4	C1C3	3.3
6	J2J3	3
4	B3B4	2
7	D1D2	1.7
7	D1E4	1.6
7	D1E1	1.6
7	D1E2	1.5
8	E5E6	1.5
8	J1K1	1.5
6	J3K2	1.2
3	C4C5	1.1
3	C4C6	1.1
5	E3F1	1
8	D3J1	0.5

The final step is to sort the WDS that have been combined on a route. In ordering WDS hat have been merged, you can use the nearest neighbor procedure to determine the initial transportation route at each WDS. Apart from considering vehicle capacity, when sorting routes, travel time (<=240 minutes) and fuel usage (<=7.5 liters) will also be considered. The following is a proposed route for a combination of saving matrix and nearest neighbor which is shown in Table 7.

Table 7 The proposed route is a combination of saving matrix and nearest neighbor

Rute	Alur Rute	WS	DT	TT	FC
I	FDS-A1-A2-A3-A4-A5-B1-B2- FDS	11.89	24.4	216	4.88
II	FDS -I1-H1- FDS	11.72	24.0	235	4.80
III	FDS -C4-C5-C6-G2-G1 - FDS	11.99	30.4	197	6.08
IV	FDS -C1-C2-C3-B3-B4- FDS	11.98	23.0	229	4.60
V	FDS -E3-F1-F2-F3- FDS	10.01	27.1	207	5.42
VI	FDS -K2-J2-J3- FDS	11.85	26.5	237	5.30
VII	FDS -D1-D2-E1-E2-E4- FDS	11.98	25.5	207	5.10
VIII	FDS -D3-E5-E6-K1-J1- FDS	11.90	26.3	238	5.26
IX	FDS -X1- FDS	10.50	23.2	114	4.64
Total		**103.82**	**230.4**	**1880**	**46.08**

WS = Waste volume (m3/day),
DT = Distance traveled (km/day),
TT = Travel time (minutes/day),
FC = Fuel consumption (liters/day).

The calculation results show that the waste transportation service routes in Tamalate District can be eliminated into 9 routes. Each route will be served by one truck, so there is a reduction of 2 trucks from the existing route of 11 trucks to 9 trucks on the proposed route. This of course takes into account the volume of waste transportation which must not exceed the capacity of the vehicle, the travel time which must not exceed the specified working hours of 4 hours (240 minutes) and the fuel consumption which must not exceed the daily allowance (<7.5 liters/ day).

4.2 Distance traveled and fuel consumption on route saving matrix

Based on the results of data processing, a proposed route is obtained with a total distance that can be reduced linearly with a reduction in fuel consumption. The following is a table of distance traveled and reduction in fuel consumption for the proposed route using the saving matrix shown in Table 8.

Table 8 Distance traveled and fuel consumption

Truck Code	Route	Mileage (km/day)	Fuel Consumption (liters/day)
I	FDS -A1-A2-A3-A4-A5-B1-B2- FDS	24.4	4.88
II	FDS -I1-H1- FDS	24.0	4.80
III	FDS -C4-C5-C6-G2-G1- FDS	30.4	6.08
IV	FDS -C1-C2-C3-B3-B4- FDS	23.0	4.60
V	FDS -E3-F1-F2-F3- FDS	27.1	5.42
VI	FDS -K2-J2-J3- FDS	26.5	5.30
VII	FDS -D1-D2-E1-E2-E4- FDS	25.5	5.10
VIII	FDS -D3-E5-E6-K1-J1- FDS	26.3	5.26
IX	FDS -X1- FDS	23.2	4.64
Distance Total		**230.4**	**46.08**

Actual fuel consumption for the route proposed by the saving matrix method is 46.08 liters/day. This shows that the average truck fuel consumption does not exceed the allotted allowance of 7.5 liters/day. So, fuel costs can follow the proposed actual fuel consumption. If it is assumed that the price of diesel is IDR 6,800.00 per liter, then the fuel costs are IDR 313,344.00 per day or IDR 9,400,320.00 per month assuming 1 month, namely 30 days.

Table 9 Travel time on the existing Tangkasaki truck route

Route	t_{bm}	$t_{FDS-WDSa}$	$t_{WDSt-FDS}$	t_{total}
I	164	22	30	216
II	186	27	22	235
III	132	28	37	197
IV	178	27	24	229
V	146	30	31	207
VI	182	25	30	237
VII	151	27	29	207
VIII	179	28	31	238
IX	62	26	26	114
Total				**1,880**

t_{bm} : Loading and unloading time (minutes/day).
$t_{FDS-WDSa}$: Travel time from FDS / landfills to WDS /temporary shelter (minutes/day).
$t_{WDSt-FDS}$: Travel time from WDS /temporary shelter to FDS /landfills (minutes/day).
t_{total} : total time (minutes/day).

4.3 *Operational costs of route saving matrix*

The reduction in the number of trucks also has a positive impact on operators and drivers, thereby reducing costs. Previously, 11 trucks were used and the final result of the proposed route was 9 units. This is linear with the number of workers and fuel consumption. The fewer vehicles used, the less labor costs must be paid, and the fewer waste transport vehicles used, the less fuel used. Salaries and total cost can be seen in Table 10 and Table 11, which show the total operational costs consisting of salary costs and fuel costs. The total operational cost for the optimized 9-truck route is IDR 76,900,320.00 per month, which is a reduction from the previous operational costs.

Table 10 Salaries of existing route

Type of Worker	Amount	Basic salary (per month)	Daily salary (per month)	Total (per month)
Truck Driver	9	IDR1,000,000.00	IDR 50,000.00	IDR 67,500,000.00
Garbage collector	18			

Table 11 Total cost

Cost	Total Cost (per month)
Salaries	IDR 67,500,000.00
Fuel	IDR 9,400,320.00
Operasional Cost	**IDR 76,900,320.00**

4.4 *Comparison of existing routes and proposed saving matrix routes*

The proposed route using the saving matrix method will compare the existing route with the proposed route in terms of fleet number, distance traveled, travel time and operational costs. The following is a comparison table of the total distance traveled by Tangkasaki truck waste transportation services from the existing route and the proposed route using the saving matrix method. Comparison of existing routes and proposed saving matrix routes in terms of fleet number, distance traveled, travel time and operational costs is shown in table 12 below.

Table 12 Comparison of existing routes and proposed saving matrix routes

	Existing Route	Proposed Route	Difference	Efficiency
Number of truck (unit)	11	9	2	18.0%
Distance Traveled (km/days)	294.4	230.4	64	21.7%
Travel time (menit/days)	2063	1880	183	8.9%
Operasional Cost (per month)	IDR 99,330,000.00	IDR 76,900,320.00	IDR 22,429,680.00	22.6%

The comparison between the existing route and the proposed route showcases the efficiency gains achieved through route optimization. As shown in the Table 12, the number of trucks required is reduced from 11 to 9, representing an 18.0% efficiency improvement. The distance traveled per day also decreased by 64 km, a 21.7% reduction, while the travel time decreased by 183 minutes per day, an 8.9% improvement.

The most significant impact is seen in the operational cost, which decreased from IDR 99,330,000.00 per month for the existing route to IDR 76,900,320.00 per month for the proposed route, a 22.6% reduction. This cost savings can be attributed to the decreased number of trucks, reduced fuel consumption, and lower labor costs associated with the optimized route.

The findings from this analysis demonstrate the substantial benefits that can be achieved through the implementation of the saving matrix method for optimizing waste transportation routes in urban areas. Management should consider adopting this approach to enhance the efficiency and cost-effectiveness of their waste management operations. By reducing the number of trucks, distance traveled, and travel time, companies can not only achieve significant cost savings but also contribute to reduced environmental impact and improved resource utilization. The insights gained from this study can guide managers in making informed decisions about fleet management, route planning, and resource allocation to drive operational excellence and maximize the overall performance of their waste transportation systems

5 Conclusions

Comparison of existing routes and proposed routes using the saving matrix method. The number of Tangkasaki truck fleets was successfully reduced by maximizing vehicle capacity from 11 trucks to 9 trucks. The total distance travelled for the proposed route using the saving matrix method produces an efficiency of 21.7%. The total travel time results in an efficiency of 8.9%. The results of the proposed route using the saving matrix succeeded in reducing travel time disparities and maximizing the working time set by the sub-district, namely 4 hours (240 minutes). The operational costs of the proposed route using the saving matrix method produce an efficiency of 22.6%. Operational costs can be streamlined due to a reduction in the truck fleet which has an impact on reducing the workforce, namely 2 drivers and 4 maids. Apart from that, fuel costs were successfully reduced because the actual fuel consumption of each Tangkasaki truck was obtained.

Future research potential can be concentrated on developing predictive models to optimize waste transportation routes by considering variables such as varying waste volumes and external factors such as traffic congestion. In addition, the application of big data and artificial intelligence technologies can be explored to improve operational efficiency in predicting fleet needs and vehicle capacity utilization in real-time. Research can also include environmental impact analysis of optimized routes, including the potential for carbon emission reduction in waste management in urban areas.

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Mitigating the effects of Russia's invasion of Ukraine on global food security – does the transit of Ukrainian cereals through Poland matter?

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Abstract: The article presents the results of empirical research, which constitutes a case study focused on the route through Poland as an alternative export channel for Ukrainian grain, developed under the conditions of the Russia-Ukraine war. It employs analytical methods and statistical description. By analyzing the volume, dynamics, structure, and geography of the transit, the significance of this route in unleashing Ukraine's export capabilities and its role as a substitute for traditional routes during periods of disruption is assessed. It was established that almost exclusively corn and wheat are transited (in a quantitative ratio of 2:1). The railway crossings in Dorohusk, Medyka, and Hrubieszów are of key importance, as rail transport dominates in land transport, handling over 4/5 of the total mass of transited goods. More than half of the transited grain is transported by rail and road in scattered European directions, and only less than half reaches Polish Baltic ports, mainly Gdańsk (over 3/5) and Szczecin (almost 1/5). The degree of containerization exceeds 1/4. Practically all container cargo reaches the terminal in Gdańsk, while the port in Szczecin is the leader in bulk transport. The volume of Ukrainian grain transited through Poland is relatively small compared to Ukraine's export potential, and intercontinental transport concerns only a tenth of the grain transited through Poland. It was concluded that the route through Poland primarily serves as a new export channel for Ukrainian grain to the European market and only marginally substitutes traditional routes.

1 Introduction

The war in Ukraine has significantly impacted global agricultural markets, particularly the grain market [1]. Ukraine exports large volumes of this commodity (a key component in food and feed production), mainly to North Africa and the Near and Far East countries. According to 2021 data, just before the Russian invasion, Ukraine was among the leading producers of corn (42.11 million tonnes), barley (9.44 million tonnes), and wheat (32.18 million tonnes), ranking 5th globally for corn and barley production and 6th for wheat [2].

The war has reduced Ukraine's agricultural production capacity and limited its ability to agricultural products export [3,4]. The blockade of Ukrainian Black Sea ports disrupted the continuity of supply chains and led to a sharp rise in global food prices [5–7]. In response, alternative export routes for Ukrainian agricultural products were developed with the support of the European Union (EU), aiming to mitigate the negative impact of the Black Sea port blockades on global food security. The EU's "solidarity corridors" have partially offset the disruption of traditional export routes for Ukrainian grain; however, various logistical and infrastructural constraints limit their efficiency. EU initiatives aimed at expanding the Trans-European Transport Network have helped increase the capacity of transit routes [8], facilitating the reconfiguration of existing logistics links within global supply chains in pursuance of changing geopolitical conditions.

Due to its proximity to Ukraine and relatively well-developed transport infrastructure, Poland has become an important transit country (second only to Romania) for Ukrainian agricultural products [9]. Nevertheless, there remains a need for further modernization and expansion of transport and supporting infrastructure, especially in light of increasing goods flows in relations with Ukraine [10]. The smoothness of transit is particularly hindered by the insufficient capacity of border crossings between Ukraine and Poland [9,11]. Additional barriers to the development of the transit route through Poland include the limited transport capacity of Polish railways and the insufficient handling capacity of Polish seaports [12]. Despite these limitations, Poland's role as an intermediary enables the redirection of relatively large volumes of goods from Ukraine to Western and Northern European countries, as well as to non-European markets. However, the route through Poland, compared to the route via Ukrainian Black Sea ports, involves a significantly longer land segment and, given the geographic location of Ukraine's traditional grain importers, often a much longer maritime segment.

The aim of this study is to determine the role and significance of the transit route for Ukrainian agricultural products passing through Poland, based on an analysis of the volume, dynamics, structure, and geography of the transit.

2 Materials and methods

This study utilized source data provided by the Polish Ministry of Finance, extracted from the New Computerized Transit System (NCTS), which records transit operations conducted within the EU territory. The data cover the transit of five main types of grain (corn, wheat, barley, rye, and oats) from Ukraine through Poland during the period from 1 January 2022 to 31 August 2024 (2 years and 8 months, with just over 2.5 years falling within the period of the war in Ukraine).

The research is empirical and constitutes a case study concerned with the route through Poland as an alternative export channel for Ukrainian grain, focused on key findings from the point of view of logistics, in particular management of material flow and optimization of transport processes. It employs analytical techniques and statistical description methods:

- structural analysis – concerned with the commodity structure of transit (the share of individual types of cereals in the mass of transported grain) and the structure of transit by type of transport (rail and road);
- spatial analysis – allows to determine the importance of individual border crossings and seaports in handling transit, and the importance of individual importing countries as target markets;
- temporal analysis – allows to recognize the variability of the flow of goods in a monthly breakdown, which was the basis for assessing the stability of transit flow;
- statistical analysis – was the starting point for assessing the size, dynamics, structure, and geographical distribution of Ukrainian grain transit through Poland.

Diagrams and infographics were used to visualize the information obtained as a result of processing the source material.

3 Results

Between 1 January 2022 and 31 August 2024, Poland served as a transit country for nearly 4 million tonnes of Ukrainian grain. The average annual volume of transit was therefore 1.5 million tonnes. Considering Ukraine's export potential, this is a relatively small amount, given that in 2022 alone, despite the ongoing war, Ukraine exported over 38.6 million tonnes of grain [2].

The volume of Ukrainian grain transited through Poland was significantly smaller than the volume of grain exported from Ukraine to Poland. Data from NCTS indicate that the transited volume amounted to 0.71 million tonnes in 2022 and 2.04 million tonnes in 2023. In contrast, according to the latest data provided by the Food and Agriculture Organization of the United Nations [2], the volume of exports to Poland in 2022 reached 2.74 million tonnes. In 2023, temporary deviations from the trade liberalization measures introduced in June 2022 between the EU and Ukraine [13] were in place. Notably, the Polish government imposed controversial in terms of legality unilateral import bans on certain Ukrainian agricultural products, and at the EU level, regulations temporarily allowed only transit through member states located close to Ukraine, including Poland. In 2022, when duty-free, unrestricted trade with Ukraine was possible throughout almost the entire second half of the year, the volume of grain imported by Poland was nearly four times greater than the volume transited. These data indicate the scale of the load on the transport system, in particular the border crossings between Ukraine and Poland, with individual flows of goods (imported and transited).

The dominant grain transited through Poland was corn (65.8%), which, together with wheat (32.4%), made up almost the entire volume of transit. Barley, the third most significant grain, accounted for only 1.7% of the transited mass of grains. The share of other grains was negligible (below 0.1%). The structure of transited cereals by type is shown in Figure 1.

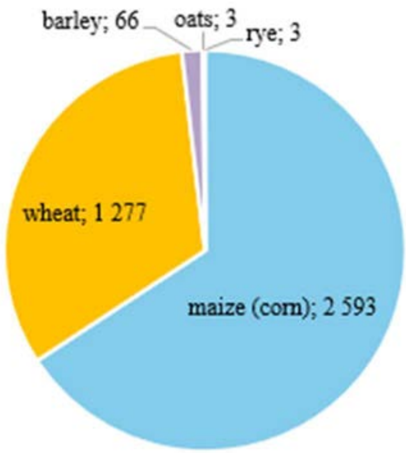

Figure 1 Structure of Ukrainian grain transited through Poland from 1 January 2022 to 31 August 2024 (data in a thousand tonnes)
Source: Own study based on NCTS data provided by the Polish Ministry of Finance.

The grain entered Poland through five border crossings: Dorohusk (rail and road crossing), Medyka (rail and road crossing), Hrubieszów (rail crossing), Hrebenne (road crossing), and Korczowa (road crossing). 82% of the grain mass was transported by rail, while the remaining 18% was transported by road.

Almost half of the total flow (49.3%) passed through the Dorohusk crossing (39.5% by rail and 9.8% by road).

The Medyka crossing accounted for 27% of the transit (26.3% by rail and 0.7% by road), and the Hrubieszów rail crossing contributed 16.1%. The road crossings at Hrebenne and Korczowa handled 4.2% and 3.4% of the grain mass, respectively. The importance of each border crossing in the transit of Ukrainian grain is illustrated in Figure 2.

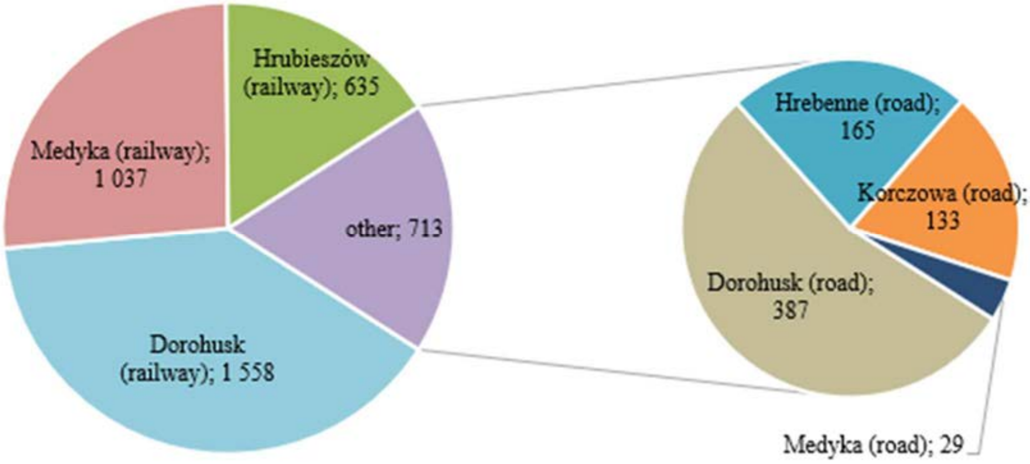

Figure 2 Significance of border crossings in the transit of Ukrainian grain through Poland from 1 January 2022 to 31 August 2024 (data in a thousand tonnes)
Source: Own study based on NCTS data provided by the Polish Ministry of Finance.

The share of each transport mode in the transit of Ukrainian grain through Polish territory was identical to the share observed at the border crossings, with rail transport handling 82% of the total grain mass and road transport handling 18%. Although detailed records tracking individual shipments were not available, the consistent proportions in the types of transport used at both the border entry points and throughout the Polish transit route suggest that the same transport mode was maintained across the entire land journey.

A total of 51.8% of the transited grain, amounting to over 2.04 million tonnes, was distributed via land transport to various European destinations. The remaining 48.2% (just under 1.9 million tonnes) was shipped to Polish Baltic Sea ports, with Gdańsk receiving the largest share (30.7%), followed by Szczecin (9.5%), Gdynia (3.3%), Świnoujście (2.5%), and Kołobrzeg (2.1%). This distribution is visualized in Figure 3.

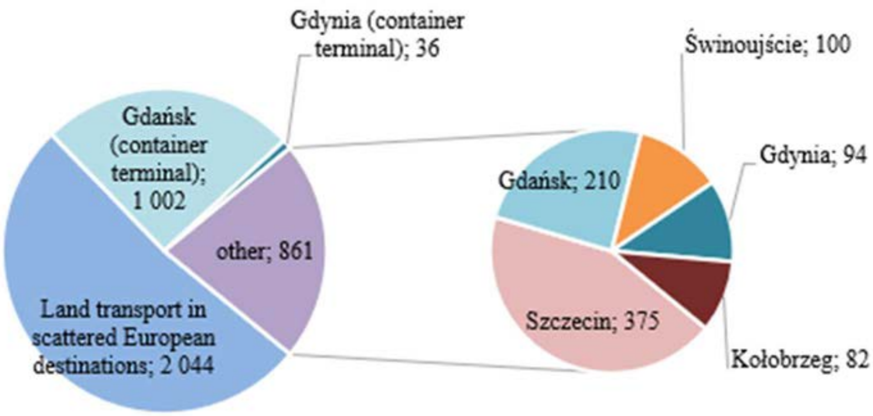

Figure 3 The role of maritime transport in the export of Ukrainian grain transited through Poland and its structure by ports and transport methods from 1 January 2022 to 31 August 2024 (data in a thousand tonnes)
Source: Own study based on NCTS data provided by the Polish Ministry of Finance.

Considering that both the characteristics of the goods in transit (homogeneity, high natural, technical, and economic transportability) and the very poorly diversified type structure of the grain in transit (as shown in Figure 1) favor mass transport, the degree of containerization of transport can be considered high. As much as 1.06 million tonnes of grain were transported by land – both to the border crossings and through Polish territory – in

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containers, accounting for 27% of the total transited grain mass.

Nearly all container shipments (1.04 million tonnes, or 97.6%) reached Polish seaports (as visualized in Figure 3), and then almost always the transport continued (by sea) in containers. The container terminal in Gdańsk dominated container transport, handling over 1 million tonnes of Ukrainian grain, which represents 94.2% of the grain transited in containers. The container terminal in Gdynia received 3.3% of the containerized grain mass, while the remaining 2.5% was distributed via land transport across various European destinations or loaded in various Polish seaports into the holds of bulk carriers.

Unlike land transport, maritime transport was predominantly container-based. The share of containerized transport in maritime operations was 54.7%, more than double the share in land transport (27%). Meanwhile, the key role in the mass transport of Ukrainian grain was played by the port in Szczecin, with transshipment exceeding 375 thousand tonnes.

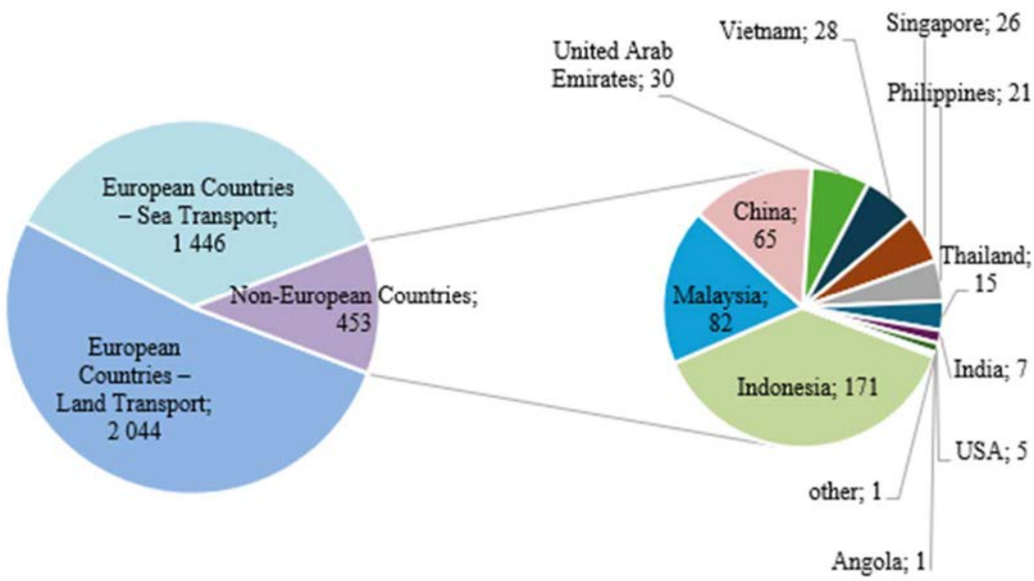

Figure 4 Geographic structure of exports of Ukrainian grains transited through Poland from 1 January 2022 to 31 August 2024, with emphasis on intercontinental exports (data in a thousand tonnes)
Source: Own study based on NCTS data provided by the Polish Ministry of Finance.

Analysis of Figure 4 reveals that nearly 3.5 million tonnes out of the slightly more than 3.9 million tonnes of transited grain (i.e., 88.5%) were destined for European countries, predominantly EU member states. Apart from the EU member states, the United Kingdom was a significant European recipient (over 115,000 tonnes). Intercontinental maritime transport accounted for just under 453,000 tonnes of grain, representing 23.8% of the total grain volume that passed through Polish seaports, and only 11.5% of the total mass of Ukrainian grain transited through Poland. This means that the route leading through Poland primarily serves supplies to the EU internal market. Its role as an alternative route for the export of Ukrainian agricultural products to traditional sales markets is marginal.

Among the non-European destinations, only Indonesia received more than 100,000 tonnes (171,000 tonnes). While notable, this volume is small considering Indonesia's large population and the fact that the data spans a period of over 2.5 years. The high degree of containerization in maritime transport facilitated dispersed deliveries, resulting in a wide range of smaller, fragmented end recipients.

In summary, the transit of Ukrainian grain through Poland predominantly supplies the EU internal market, with minimal engagement in long-haul exports to traditional markets in Africa, the Middle East, and Asia.

From the point of view of ensuring the permeability of the transport system, it is important how transport is distributed over time. According to Figure 5, following the liberalization of trade relations between the EU and Ukraine in June 2022, the monthly transit volumes ranged from 50,000 to 261,000 tonnes. The peak volume recorded in a single month is equivalent to the cargo load of approximately 120 standard 600-meter-long freight trains. This means that even if the entire volume was transported exclusively by rail, handling the transit would only require 4 freight train sets per day. Given that the key border crossing for the transit of Ukrainian grain in Dorohusk has the capacity even for a dozen pairs of freight trains daily, it becomes evident that the transit of Ukrainian grains places a relatively low demand on the capacity of the Polish transport system.

In conclusion, while the transit volumes have shown significant variability, the absorption of these flows by

Poland's rail and road networks does not appear to strain the existing infrastructure excessively. Instead, the bottlenecks are primarily at the border crossings rather than throughout the broader transport system within Poland.

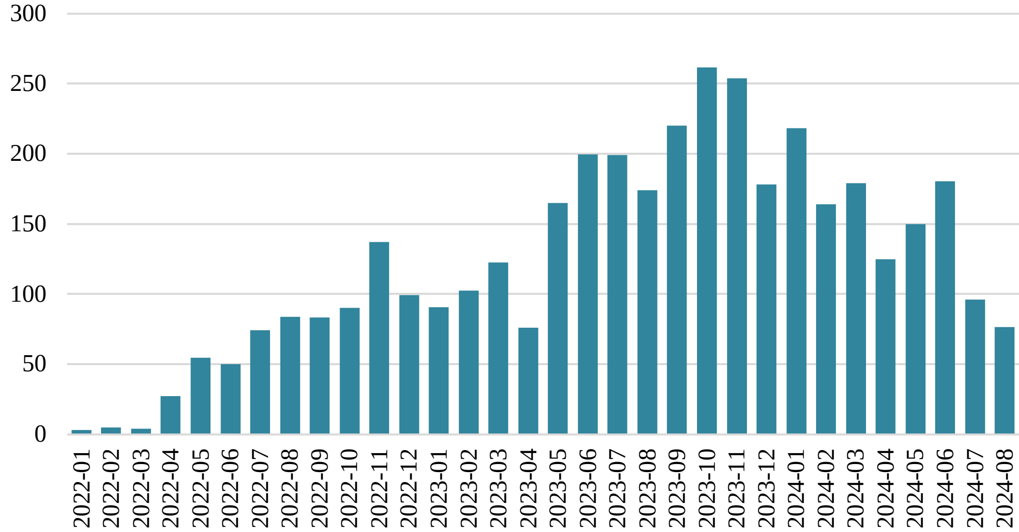

Figure 5 Monthly distribution of transit shipments of Ukrainian grains through Poland from 1 January 2022 to 31 August 2024 (data in a thousand tonnes)
Source: Own study based on NCTS data provided by the Polish Ministry of Finance.

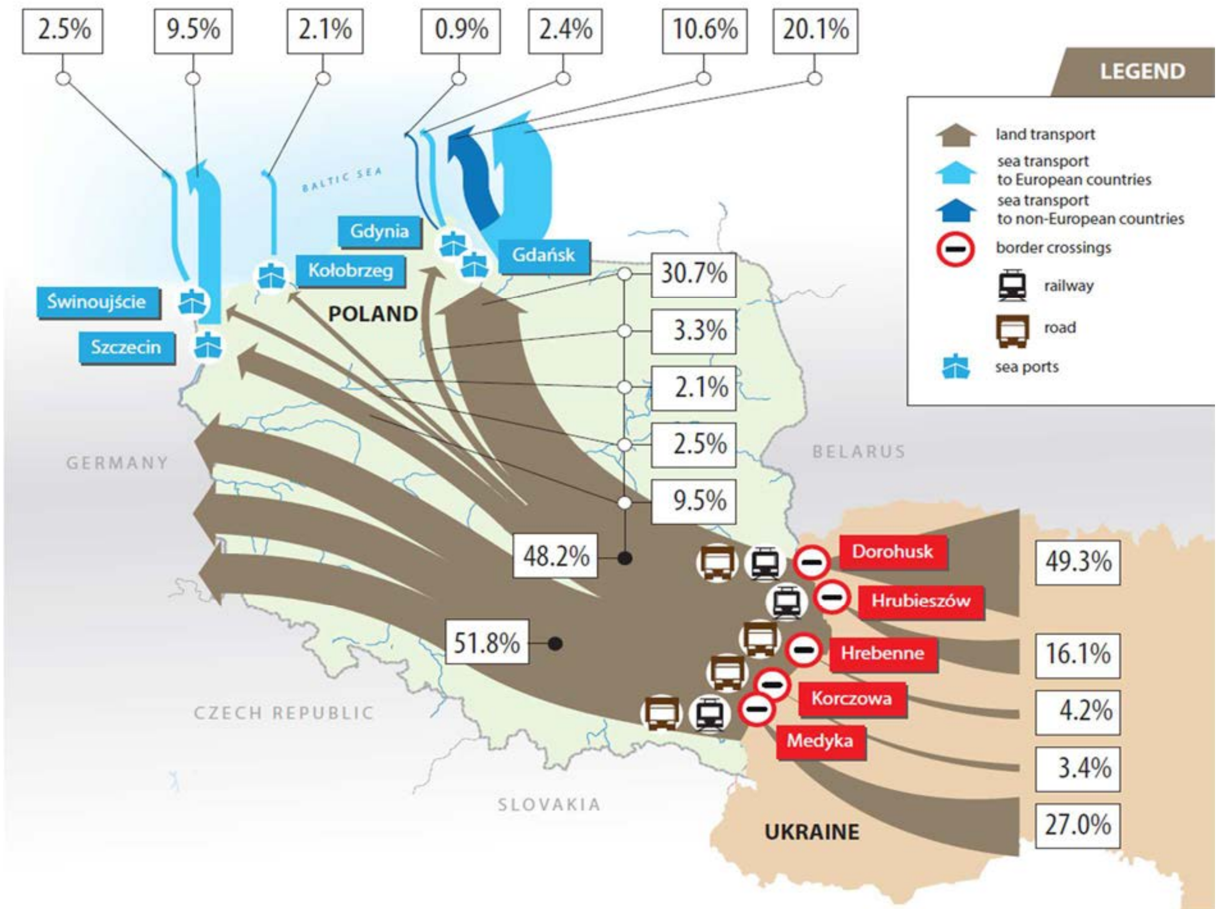

Figure 6 Schematic diagram of Ukrainian grain transit through Poland (1 January 2022 – 31 August 2024)
Source: Own study based on NCTS data provided by the Polish Ministry of Finance.

Figure 6 visually represents the key transit routes for Ukrainian grain passing through Poland during the analysis period. The diagram consolidates significant details from earlier considerations into a single graphic overview. The thickness of the arrows is proportional to the mass of the transported grain, and the accompanying percentage values indicate what proportion of the total mass of transited grain was transported via a given route.

4 Discussion

The directions and intensity of trade flows between countries are significantly influenced by geopolitical factors, as exemplified by the global reconfiguration of logistical links between countries following Russia's invasion of Ukraine [14], including the shifts in the streams of grain exports from Ukraine [15]. The issue of exporting Ukrainian agricultural products (mainly grains and oilseeds) during the Russian-Ukrainian war is frequently addressed in economic research, which focuses particularly on formulating recommendations useful for economic policy and business practices – specifically, indicating actions that should be taken to increase the efficiency of transit. This line of research concentrates on identifying bottlenecks in the transport system and optimizing logistical processes [11,16-18]. Another research focus is the implications of exporting Ukrainian goods via alternative, roundabout routes, including the quantification of the increase in negative environmental externalities associated with transport (due to the inability to use traditional export routes). The use of alternative roundabout routes requires higher energy consumption, which not only leads to increased transportation costs due to higher fuel consumption but also results in greater emissions of pollutants [19].

Studies examining changes in the volume of Ukrainian exports and their geographical structure focus on measuring the trade creation and trade diversion effects [20]. In EU member states located near Ukraine, much attention is paid to establishing the economic consequences of increased imports of agricultural products from Ukraine (in periods when free trade between the EU and Ukraine was possible) and transit leakage (in periods when imports of some agricultural products were not allowed). Due to the non-competitiveness of exports via roundabout routes through EU countries to traditional markets compared to exports to the EU, there was an influx of Ukrainian agricultural products into the EU internal market, which led to a drastic drop in prices [10]. The resulting agricultural market crisis triggered farmer protests. The serious problems associated with this prompted researchers to measure the scale of the influx of Ukrainian agricultural products and assess the impact of increased imports on domestic agricultural markets [21]. This represents a local dimension of agricultural market turbulence, paradoxically caused by excessive supply [22] (resulting from the liberalization of trade relations between the EU and Ukraine), while from a global perspective, the core of the grain crisis lies in the difficulty of supplying traditional recipients of Ukrainian agricultural products during the war in Ukraine [23], i.e., insufficient supply. The issue of declining global food security due to the war in Ukraine, including the problem of the expanding geographical scope of hunger and malnutrition, draws attention from researchers [24-27]. Another important aspect of research is food safety during wartime when the quality of agricultural products declines [28,29].

5 Conclusions

The volume of Ukrainian grain transiting through Poland (approx. 1.5 million tonnes per year) is relatively small compared to Ukraine's export potential, which, even under wartime conditions, amounts to around 40 million tonnes annually. Almost exclusively, corn and wheat are transited (in a 2:1 ratio). Ukrainian grain declared for transit enters Poland via five border crossings, of which the railway crossings in Dorohusk, Medyka, and Hrubieszów are of key importance. The transit of Ukrainian grain across Polish territory is dominated by rail transport, which handles over four-fifths of the total mass of transited goods. The same proportions apply to deliveries to border crossings, indicating that there is no change in the type of transport used for transit across Poland. More than half of the transited grain is transported by rail and road to various dispersed European destinations. The remaining portion goes to five Polish Baltic ports, mainly to Gdańsk (just under 65%) and Szczecin (almost 20%). Poland's largest grain port, located in Gdynia, plays a minor role in the transit. Although grain is a bulk commodity, intermodal transport, combining different transport modes (road, rail, sea) using containers as the cargo unit, plays a significant role in its transit through Poland. More than a quarter of Ukrainian grain is transited in containers. Almost all containerized cargo goes to the terminal in Gdańsk. Long-distance maritime transport concerns a tenth of the grain transited through Poland and is dominated by the port in Gdańsk (with a small share handled by the port in Gdynia).

This means that the route through Poland primarily serves as a new export channel for Ukrainian grain to the European market and only marginally substitutes traditional routes, supplying previous recipients whose food security – unlike European countries – is highly sensitive to disruptions in the continuity at moderately priced supplies.

The development of the transit route through Poland as an alternative export route for Ukrainian grain depends on various factors, including the military situation in Ukraine, the availability of traditional routes, geopolitical conditions, the extent of the EU's involvement in developing solidarity corridors, the scope and intensity of cooperation between Ukraine and Poland, and progress in investment and organizational improvements (including in the area of harmonizing trade procedures between the EU and Ukraine). Given the need to ensure a high level of global food security, efforts should be made, in particular, to ensure that the route through Poland primarily serves as an alternative supply channel for traditional recipients of Ukrainian agricultural produce, i.e., poorer countries of the Global South, rather than as a channel for expansion into the markets of wealthy European countries. Strongly increased export to the EU destabilizes local markets, which, in turn, prompts authorities to introduce additional financial aid measures for farmers. This results in a paradoxical situation where the openness of the EU market to agricultural products from Ukraine is accompanied by ad hoc support instruments for local producers, justified by the need to compensate farmers for the drop in agricultural product prices due to the increased influx of these products from Ukraine.

Author contributions

Conceptualization, A.S.; methodology, A.S.; formal analysis, A.S., P.W.-A. and J.Z.; investigation, A.S.; data curation, A.S.; writing, A.S. (sections 1–5), P.W.-A. (section 1) and J.Z. (section 4); visualization, A.S.; supervision, A.S.; funding acquisition, A.S., P.W.-A. and J.Z.

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Evaluating the efficiency of consulting officers in managing the implementation of engineering construction projects in Iraq

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Keywords: consulting project factors, TOPSIS, AHP, quality criterion, Delphi method.
Abstract: This research examined the engineering projects supervised by Iraqi internal management teams and evaluated the role of consulting firms in this area. The principal elements evaluated in analyzing engineering project execution management tools, methodology, objectives, resources, and success rates were time, cost, quality, and project scope. This research aims to create a detailed inventory of the services, functions, and requirements of the technical control and engineering consulting sectors in relation to national and international standards. This work utilized pertinent data and expert opinions to analyze the operations of consulting companies in Iraq via the Delphi method. The preliminary phase, considering workplace variations, was the creation of a related matrix utilizing local data to determine the relative significance of each component. After evaluating the second phase's data utilizing the Excel-based TOPSIS methodology, the factor ratings were calculated. The AHP-TOPSIS method assessed the ability to reason and resolve difficulties, handle conflicts, additional project expenditures, cost differences across four orders, and financial flow. In assessing variables, here is where the outcomes truly excelled. The research further concludes that the efficiency of consulting officers plays a pivotal role in overcoming the challenges of project execution in Iraq. Their ability to address time, cost, and quality issues directly influences the overall success of engineering construction projects.

1 Introduction

Engineering construction projects are one of the main pillars supporting Iraq's economic and social development. Under the current circumstances, where the country is facing significant challenges in the construction sector, the importance of assessing the efficiency of the consultant, which is a vital part of the project management process, is increasing [1,2]. The consultant assumes multiple responsibilities, including planning and design. In addition, the consultant supervises the implementation of work on-site. Factors management is also essential to his role, as the consultant identifies potential factors during the project stages and provides appropriate solutions to deal with them [3]. Evaluating the consultant's efficiency requires considering several main criteria. First, technical expertise is a basic factor. The performance record is also an important indicator, as it helps in reviewing previous projects managed by the consultant and their success in achieving the specified goals. Also, the consultant's ability to communicate effectively with different parties, such as the owner and the contractor, plays a crucial role in the success of the cooperation. In addition, the consultant must demonstrate the ability to manage time and costs, to ensure that the project is delivered on time and within the specified budget [4]. However, assessing consultant competence in Iraq faces several challenges. Among these challenges are economic instability that can negatively impact project budgets, as well as knowledge and skill gaps that some consultants may suffer from. Furthermore, the multiplicity of stakeholders and different interests can complicate decision-making and impact the effectiveness of joint work [5,6].

Quality is the state of conformity of the previously set requirements within the product/service [7]. Fraser [8] defined quality as "the ability to satisfy the needs at the time of purchase and during the usage at the best cost while reducing losses and increasing competitiveness." This definition points out the cost factor and loss reduction and improving competitiveness. Assaf and Al-Hejji [9]said that "quality, in general, is a set of activities that are carried out for the purpose of setting performance standards, monitoring and improving performance to make the provided service effective and efficient and also safe." This definition sets itself apart by combining performance requirements with quality. Quality is a collection of administrative procedures to provide clients the most accurate service possible. Rezaee [10] noted that despite that there is no universal concept agreed upon for quality, it can be enumerated certain elements that are shared in quality definitions as follows: Quality aims at satisfying customer’s expectations or more, applying quality could be generalized to commodities, services, operations, and individuals, and quality is marked by continuity of change, as what is acceptable today may not be acceptable later. When these factors are taken into account, quality is defined by dynamic change rather than stability. It is connected to goods, services, people, and the environment in accordance with or even beyond what clients and management may anticipate. This definition is broad because it emphasizes that quality encompasses not only the caliber of goods but also the caliber of people and services. The concept also emphasizes continuity, which is seen as a crucial component of quality. The only definition that focuses on this idea is this one. For this reason, it is regarded as the finest option overall.

Upon closer inspection, the Joiner [11] concept is among the most thorough explanations of Total Quality Management. The following is their explanation of each word in the phrase Total Quality Management: Management: the preservation and organizational growth with the goal of consistently raising the standard. Quality is defined as satisfying the beneficiary's or client's demands and expectations while going above and beyond. Total: comprises putting into practice the idea that quality should be sought in every work, beginning with determining the beneficiary's requirements and concluding with the client's evaluation of whether or not they are happy with the goods and services they received. Ahcom [12] defines it as "a cultural revolution on the method that is used by the management on improving quality. It is a field of expressing more common sensation in management practices and the importance of statistical measures. It is a continuous change by the administration in view of the results through the management that understands and manages the operations to accomplish the goals. It is the outcome of management practices and the analytical methods that help in the process of continuous improvement, hence the cost reduction".

2 Literature review

In the literature, there are several research groups that deal with management quality. The study by Suwanda [13], "Assessing the Management Elements Affecting the Construction Project Delays." The research was carried out in Qatar. Examining the importance and influence of management elements on construction project performance in terms of project completion time is the aim of this research. Surveying a sample of project managers in consulting firms and construction businesses was the approach used. The study concluded that: a) There is a statistically significant effect on the time it takes to complete construction projects for leadership competence with its aspects (manpower selection, leadership talents, and leadership skills). b) There is a statistically significant influence on the time it takes to complete construction projects related to management efficiency and its dimensions (creating teams and knowing the contractor's internal environment). c) The influence of scientific and cognitive efficiency, including its dimensions of legal skills, scientific abilities, and human resource management, on the time it takes to complete building projects has been statistically shown. Nonetheless, the research has made a number of noteworthy suggestions, which include: a) The board of directors and the founders of construction enterprises should exercise caution when choosing the employees who will run their businesses. b) establishing corporations and partnerships between various domestic and foreign construction enterprises in order to carry out large-scale projects. As a result, it will facilitate experience exchange and education on the most recent scientific developments in project management. c) Expand academic professional training in order to equip personnel working in the construction sector with scientific, theoretical, cognitive, and professional experiences. Developing Internal Audit's Functions in the Light of the International Quality Standards Requirements (ISO 9000) is the title of the previous study. The International Quality Standards, or "ISO," 9000, were to be shown and examined in this research. Additionally, as its execution guarantees the provision of the proper environment for growing and enhancing Total Quality Management, it sought to examine and analyze the standards of the intellectual and philosophical frameworks of Total Quality Management. Nonetheless, the research findings suggest that the conventional internal audit approach has shortcomings and inadequacies when compared to the more sophisticated and contemporary ideas of Total Quality Management and International Quality Standards. Additionally, the study made clear how critical it is to update the conventional internal auditor framework, broaden the purview of financial auditing, and assess compliance with laws, rules, and policies in favor of a framework that is better suited to the concepts of audit quality systems [14,15]. Khalid [16] article is headed "Introduction to Total Quality Management to Enhance Internal Audit Management's Efficiency and Effectiveness." The goal of the research was to determine if the international quality certificate-holding organizations' internal audit management applies the principles of total quality management at the level of each variable or the overall level of the variables' performance. It also sought to determine whether the internal audit management effectively uses its human and material resources and whether the challenges it faces call for implementing Total Quality Management to help it overcome those challenges and increase effectiveness. The private enterprises in the Arab Republic of Egypt that possess an International Quality Certificate comprised the study's sample. There were 106 firms that participated in the study. The researcher made use of SPSS.

The study recommended the following recommendations: a) extending the reach of internal audit services to cover senior management and the company's many divisions with advisory services. b) concentrating on enhancing internal auditors' abilities and acquainting them with contemporary management techniques. c)It is essential that internal auditors get training and strengthen their statistical techniques abilities in order to effectively carry out their duties. d) advancements in the use of Total Quality Management in internal audit departments, especially in businesses that have obtained ISO 9000 certification. Ameed Fathi's [17] assessing the Effect of Applying Total Quality Concepts on Construction Project Execution in the Arab Countries and How It Relates to Engineering Code is the title of the study. The study's most significant conclusion is that, in order to improve the quality of construction project implementation, it is necessary to achieve integration with the Engineering Code and strengthen the application of Total Quality Management concepts in the environment of construction project execution. Al-zwainy and Mustafa [18] The principles of total quality and their effect on achieving the competitiveness priorities in factories. According to the report, manufacturers must use contemporary total quality management practices and modify their tenets in order to meet competitiveness objectives. Miozzo and Ivory [19] examines how long construction projects take to complete when there is inadequate planning. Project managers were included in the study's sample. The study's most significant discovery, however, is that construction firms' lack of understanding of the value of management and engineering planning is the primary cause of the delays in the completion of engineering projects management of total quality and exceptional performance [20]. The research's most important conclusion is that, in order to apply total quality, the scientific method must be modified. Additionally, enterprises must take all necessary steps to ensure that the principles of Total Quality are implemented correctly. Sweis et al. [21] enhancing the quality of construction project execution in Iraqi government contracting firms. The study included the project managers employed by the Iraqi Ministry of Construction and Housing. Nonetheless, one of the study's most important conclusions is that the most important variables influencing the standard of project execution are compensation and incentives [22]. The implications of recent advancements in projects and technology on restriction in the British construction industry. All parties engaged in construction—contractors, consultants, sole contractors, and suppliers—were included in the sample of the British research, which included questionnaires. The goal of the research was to draw attention to the administrative aspects of the building projects. The investigation found a substantial correlation between these elements in terms of [22]: a) How the stakeholders engaged in the building process interact with one another. b) The techniques used in project design tendering, project management, supervision, implementation, and funding at each stage. c)The usage of modern technologies that help the project outputs (cost, time, quality). However, the research suggested using contemporary technology to manage and plan building projects throughout every stage, from project conception to project delivery and investment. Through this study, the researcher has been able to better comprehend the components of building projects and identify strategies for maintaining harmony among all parties involved [23]. A Framework for Comparing Contractors' Project Management Components in Saudi Arabia. The research was carried out in the Kingdom of Saudi Arabia, where it included interviewing engineers and project managers from construction businesses and consulting firms that are in charge of managing certain government projects. Its goal was to create a model that construction companies might follow to enhance their administrative capabilities. It was shown that the causes of building project delays are closely tied to cost increases, which may be decreased by [23]: a) The project's appropriate and superb planning. b) The ongoing oversight of the project plan by the project management. c)The contractor's cooperation with other external project participants, such as suppliers and independent contractors, among others. d) The harmony among teamwork members. e) adherence to guidelines and laws issued by the government. f) The contractor's pledge is to supply highly productive cadres, competent workers, and premium materials on schedule. The report advised the contractor to assemble teams of highly skilled workers with a variety of specializations and to oversee efficient coordination, careful planning, and constant monitoring throughout the project's duration. However, the researcher benefited from this study by using many of the points as a standard for his own research, particularly in relation to planning and how it relates to the project execution time.

This work provides an extensive analysis of the variables, risks, and uncertainties in engineering, along with methods for their classification and mitigation. The aim of this work is to present a systematic approach to evaluating infrastructure development projects. A comprehensive literature review revealed the obstacles associated with infrastructure initiatives. Infrastructure projects are famously challenging to estimate because of the inherent difficulties in precisely evaluating site conditions. A study of the challenges related to the efficiency evaluation of consultants that have led to many factors. In this work, the essential factors will be selected and the main independent computational methods will be selected. The research will present the modern effective factors and combine two computational methods for evaluating and ranking the factors.

3 Methodology

The research procedure commences with the formulation of an extensive questionnaire designed to collect data on pertinent factors. These components are delineated and articulated comprehensively to guarantee a lucid comprehension of the elements influencing the investigation. A broad questionnaire is thereafter disseminated to gather preliminary replies. Two multi-criteria decision-making (MCDM) methodologies are employed to examine the data: the Analytic Hierarchy Process (AHP) and the Technique for Order Preference by

Similarity to Ideal Solution (TOPSIS). The Analytic Hierarchy Process (AHP) is initially employed to ascertain the relative significance of each element, followed by the application of the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) to rank these factors according to their proximity to an ideal solution. The integrated findings of AHP and TOPSIS elucidate the most significant elements affecting the outcome. Expert comments are subsequently solicited to authenticate the findings. Should the expert comments indicate that the outcomes are inadequate, the procedure will iterate by reassessing and enhancing the effective components. This recurrent feedback loop persists until the outcomes achieve the requisite degree of satisfaction, hence ensuring precision and pertinence in the identified factors. Upon achieving satisfactory outcomes, the process terminates

This section will describe the sequence of the methodology as shown in Figure 1.

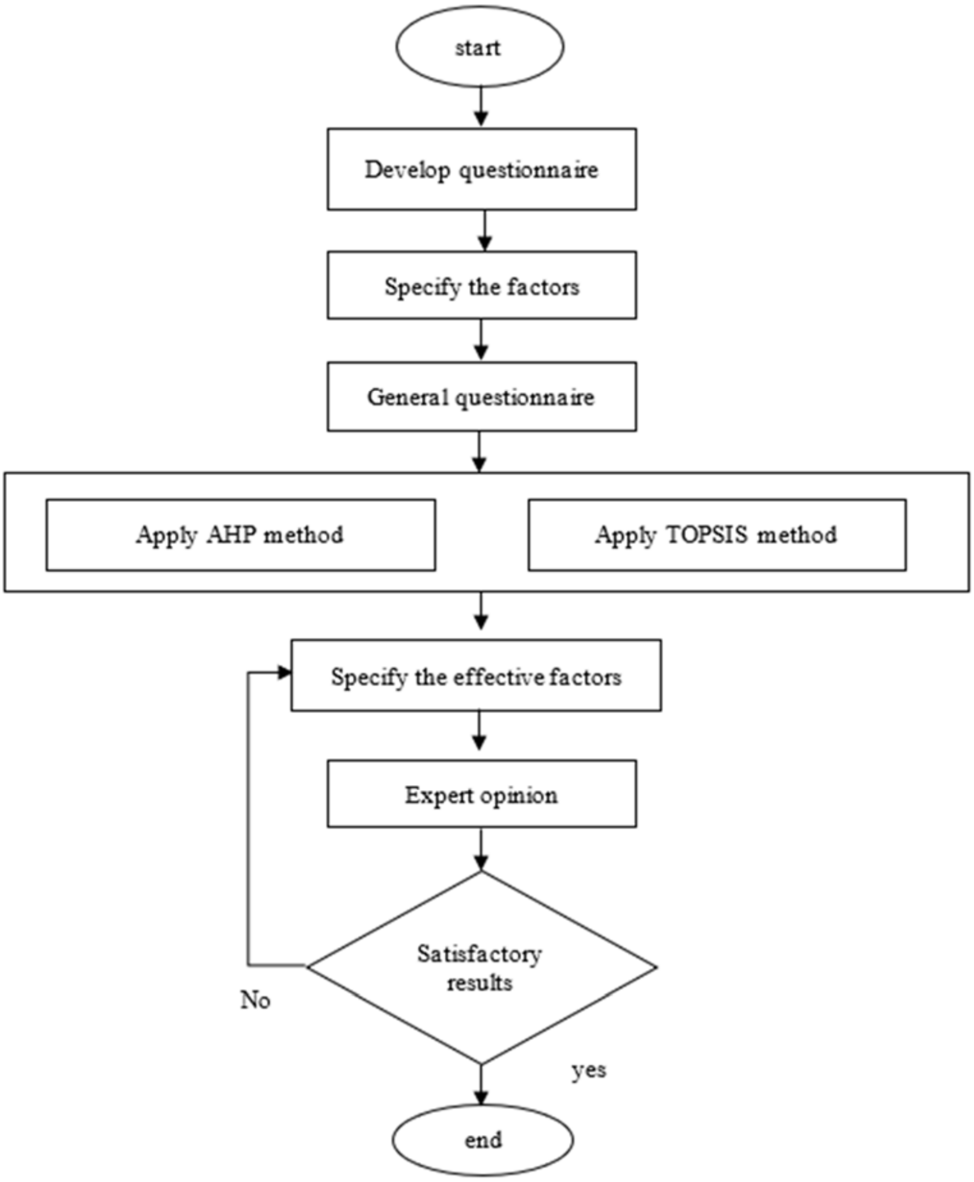

Figure 1 The Research Methodology

3.1 Developing the project questionnaire

The research articulates the primary concept prior to exploring the interview questions and subjects. The methodology portion of the article delineates the techniques employed to investigate the roles of project managers in Iraqi building projects. Employing certified architects and engineers is a customary practice in construction projects. These efforts may require the assistance of architects and general contractors. A little, uncomplicated consulting office assignment demands less time and work than a substantial, intricate one. Constructing in compliance with ranking system requirements is customary; this approach yields documentation and proof of adherence. The resistance of a structure or its components is evaluated using a comprehensive scoring system throughout the whole process, including design, construction, manufacturing, and erection. The prompt and economical completion of a project relies on the proper oversight and management of several elements, including the grading system, credit registration and documentation, stakeholder communication, and the responsibilities of team members.

3.2 Target groups

Factors included in the study include company size and level, job title, experience, and years of working on projects.

3.2.1 Type of company

Table 1 displays the employment distribution of the respondents: three organizations were contracted with the government, and four organizations used subcontractors. This competency is found in all areas, although it is evaluated most thoroughly in the project planning and initial cost estimation portions. Understanding how to put together the parts and calculating the final cost quickly follows. The majority of responses coming from contracting firms rather than consultancy firms can be explained by the increase in contracting businesses in Iraq.

Table 1 The Distribution of Questionnaires by Firm Type.

No.	Company types	No. of companies
1	government companies	4
2	subcontractors	6

3.2.2 Job title

Table 2 demonstrates that the study involves individuals from several engineering specializations. The team was distributed as project managers, as the highest-ranking members of the team, have access to all financial data relevant to the project, as illustrated in this example.

Table 2 The Distribution of Questionnaires by Job Title.

No.	Job title	No. of engineers
1	Consultant engineers	26
2	Project managers	24
3	Planning engineers	15
4	Site engineers	8

3.2.3 Years of consulting offices activities project experience

The subjects' professional background is displayed in Table 3. Most respondents demonstrated sufficient expertise in consulting offices activities to identify the primary factors influencing project costs.

Table 3 The distribution of questionnaires based on the number of years of experience

No.	Experience time	Years of experience
1	High experience	20
2	Moderate experience	10-20
3	junior engineers	5-10

It was discovered that a large percentage of them had strong experience in the construction area and hold advanced positions in their jobs, which adds to the logic and reality of the survey results to some extent.

3.3 Developing the question aire

Surveys are a good technique to collect and arrange data for assessment and getting the best outcomes. However, researchers frequently abuse the process by using questionnaires to conduct field surveys in order to select a certain assignment under investigation or trial. They're also utilized to identify and assess changes by measuring the difference between the 'before' and 'after' states. The design of the questionnaire may be broken down into three parts:

a. Research and plan the questions that will be asked.
b. Choosing the right words for each situation.
c. Create an appropriate design for the question sequence.

To determine the research objectives, the researcher creates and executes a major connection connecting the research objectives and the specific questions. Questions and a combined process of exploring creative thinking may be used to identify goals and how to attain them. Different sorts of questions can be utilized, such as open-ended versus closed-ended questions, and replies can be single versus numerous, or grouped in a certain way. Analyzing, encoding, entering, and reviewing data using open vs closed questions is a way of analyzing, encoding, entering, and assessing data. To analyze the data and measure the prediction, an Excel application was created. In all cases, data may be entered directly or through other tools like Excel, and it's usually organized on the computer as a spreadsheet, with each row indicating a "case," or a single respondent. Each column represents a single variable, with data for that variable for all of the cases in question.

3.4 Ranking the factors

The primary objective of this study is to identify the most critical and crucial factors for infrastructure projects. We require a staff that is both proficient and trained to do the evaluation. The Delphi approach offers researchers a versatile and adjustable instrument for data collection and analysis. Several justifications for employing the Delphi approach include the following:

a. While precise analytical methods are not required, accumulated subjective evaluations may prove beneficial.
b. Individuals needed to occupy these positions will possess diverse backgrounds and areas of expertise.
c. In contrast to in-person gatherings, which may encounter issues such as interpersonal disputes and dominating speakers, the Delphi method is a qualitative approach for achieving group consensus. The Delphi technique was selected primarily because to the expert panel's composition, which predominantly includes persons with decision-making authority.
d. In contrast to a cautious institutional approach, experts may express their opinions more openly inside the Delphi method, facilitating the sharing of more personal perspectives.

The validity of the results is contingent upon maintaining the individuals' heterogeneity. This necessitates extreme prudence in exhibiting evidence of authority derived from mere force of character or numerical superiority. In summary, the Delphi procedure is one of the most used methods of forecasting in the technological domain and across many industries. Over 90% of all technical forecasts and analyses stem from it. The investigation started with the formulation, evolution, and execution of the Delphi method, emphasizing subject selection and timeframes as its primary focuses. Further measures must be implemented to prevent a diminished response rate, inadvertent influence on responses, and to address panelists on their insufficient competence on the topic rather than soliciting their expert opinions. The Delphi approach was employed in this investigation for the following reason:

a. Assemble a team to supervise the execution of a Delphi assessment of the prevailing issue.
b. Designate one or more specialists in the relevant field to participate in the panel.
c. Develop the inaugural Delphi survey.
d. Amend the questionnaire to guarantee accurate phrasing.
e. Distribute the preliminary questionnaire to the panelists to collect their information.
f. Evaluate the responses from the initial round and articulate your insights into the panel.
g. Request all panel members to evaluate and provide feedback on the initial questionnaire. The poll has now entered its second and concluding stage.
h. Kindly elucidate the findings of Questionnaire. The analytical group's report will convey the results of the activity.

Continue reading to evaluate the performance of the second set of responses.

3.5 The independent research factors

This section delineates the assumptions of the independent research variables on the many performance factors' viewpoints on the importance of project management, accompanied with the rationale for each factor's standpoint as explain in Tables 4-8. The below categories delineate the predominant factors identified as influential in the investigations undertaken by [1,24,25]:

Table 4 The first group of factors

Group 1	**Consultant management skills**
F1 1	Communication skill
F1 2	Motivation skill
F1 3	Conflict management skill
F1 4	Negotiation skill

Table 5 The second group of factors

Group 2	**Consultant Leader skills**
F2 1	Decision making and problem-solving skills
F2 2	Delegation skill
F2 3	Planning and goal-setting skill
F2 4	Team building skill

Table 6 The third group of factors

Group 3	**Manpower effect**
F3 1	Project labor cost
F3 2	project control system
F3 3	Project overtime cost
F3 4	Motivation cost

Table 7 The forth group of factors

Group 4	**Planning and scheduling effect**
F4 1	Material and equipment cost
F4 2	Cost of rework
F4 3	Cost of variation orders
F4 4	Escalation of material prices

Table 8 The fifth group of factors

Group 5	**Finance factors effect**
F5 1	Cash flow of project
F5 2	Profit rate of project
F5 3	Project design cost
F5 4	Regular project budget update

3.6 AHP-Topsis Method

In reality, the challenges will unavoidably be required to make a decision. The subject of how to make the optimal option by evaluating the relevant elements remains constant, whether choosing a product or determining a strategy. Currently, multifactorial decision-making is prevalent throughout several domains, including but not limited to business, commerce, and healthcare. Decision-making instruments such as AHP streamline complex issues into manageable tiers by creating a hierarchical structure comprising goals, criteria, sub-criteria, and options. The Analytic Hierarchy Process (AHP) encompasses complex, unstructured decision-making that involves several attributes. These criteria do not define judgments linearly; instead, they involve a synthesis of physical and psychological elements. The Analytic Hierarchy Process (AHP) provides a method to quantify the subjective judgments of decision-makers. To evaluate and choose suitable stations for the development of cost systems, it is essential to create a mathematical and computational model. The Analytical Hierarchy Process (A.H.P.) model provided a systematic and rational method for organizing and prioritizing decision-making issues. The AHP paradigm is founded on four guiding principles. Figure 2 illustrates the AHP process flow diagram for material selection in construction.

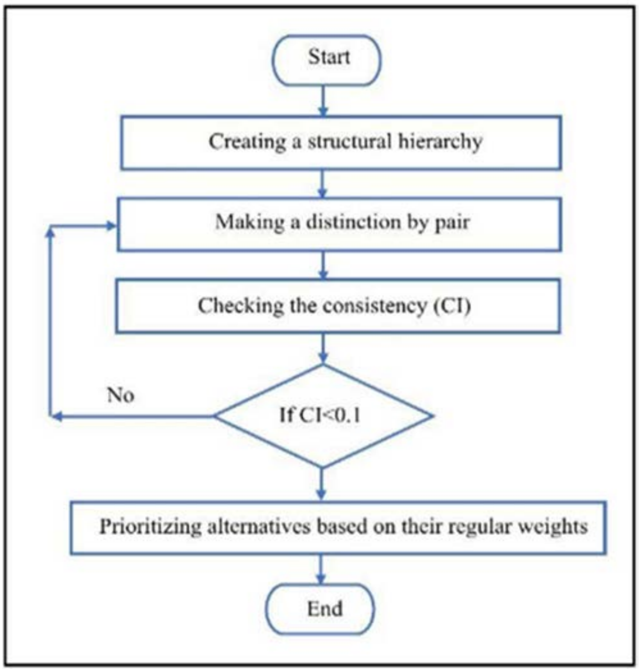

Figure 2 AHP method

For that, the priority AHP method was developed and applied to specify the required stations in the stages:
Stage 1: establishment of the pairwise comparison matrix, shown in equation (1),

$$AHP = \begin{bmatrix} a_{11} & a_{12} & \cdots\cdot & a_{1n} \\ a_{21} & a_{22} & \cdots\cdot & a_{2n} \\ a_{n1} & a_{n2} & \cdots\cdot & a_{nn} \end{bmatrix} \tag{1}$$

Stage 2: calculation of the weights of the criteria presented in equations (2)-(7).

$$AHP_{sum\_1} = \left| \sum_{i=1}^{n} i1 \quad \sum_{i=1}^{n} i2 \quad \sum_{i=1}^{n} in \right| \tag{2}$$

$$AHP = \begin{bmatrix} a_{11} & a_{12} & \cdots\cdot & a_{1n} \\ a_{21} & a_{22} & \cdots\cdot & a_{2n} \\ a_{n1} & a_{n2} & \cdots\cdot & a_{nn} \end{bmatrix} \times \left| \sum_{i=1}^{n} i1 \quad \sum_{i=1}^{n} i2 \quad \sum_{i=1}^{n} in \right|^{-1} \tag{3}$$

$$AHP_m = \begin{bmatrix} AHP_{m\_11} & AHP_{m\_12} & \cdots\cdot & AHP_{m\_1n} \\ AHP_{m\_21} & AHP_{m\_22} & \cdots\cdot & AHP_{m\_2n} \\ AHP_{m\_n1} & AHP_{m\_n2} & \cdots\cdot & AHP_{m\_nn} \end{bmatrix} \tag{4}$$

$$AHP_{sum\_2} = \begin{vmatrix} \sum_{j=1}^{n} j1 \\ \sum_{j=1}^{n} j2 \\ \sum_{j=1}^{n} jn \end{vmatrix} \tag{5}$$

$$AHP_{prio} = \frac{AHP_{sum\_2}}{\sum AHP_{sum\_2}} \tag{6}$$

$$AHP_{prio} = \prod_{St=1}^{n} St \tag{7}$$

This is the most important step in the procedure, and the outcomes are similar to a method of selection. The eight key modules were distributed among other variables referred to as "secondary" and "sub-factors." To ensure a comprehensive collection of necessary components, a statistical population consisting of specialists primarily engaged in Building Management Systems (BMSs) was selected. Quality environment modules are eight essential criteria used to evaluate IBs that impact the whole building life cycle. The TOPSIS approach was initially introduced by Yoon and Hwang in 1981. The basic concept (Figure 3) is that the selected solution needs to be close to optimal while being as distant from suboptimal as possible.

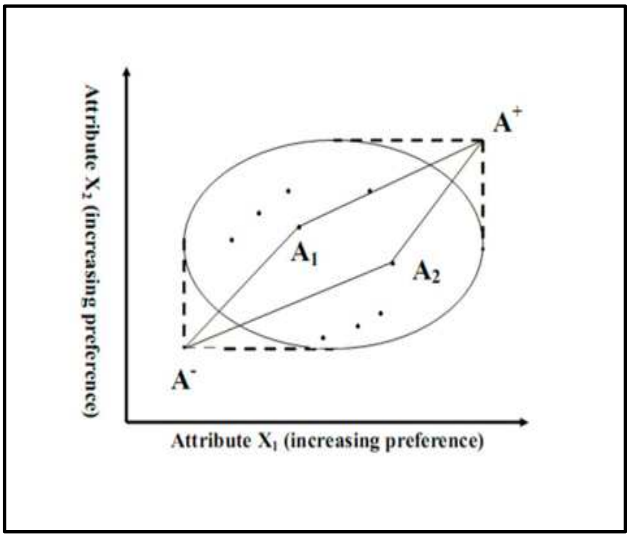

Figure 3 Basic concept of TOPSIS method

Fuzzy TOPSIS adheres to a procedure akin to the traditional method, as delineated by Chen's approach, which may be succinctly defined as follows:

a. Compile the normalized choice matrix: In a fuzzy environment, simplified equations are employed to transform many criterion scales into a unified scale, therefore circumventing the intricate normalizing calculations utilized in conventional TOPSIS.

The linear scale transformation (1) is depicted in equation (8):

$$\tilde{r}_{ij} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*}\right), c_j^* = max_{ij} \tag{8}$$

Jahanshhaloo et al.formula (2) is depicted in equation (9):

$$\left(\tilde{r}_{ij} = \left(\frac{a_{ij}}{\sqrt{\sum_{i=1}^{n}\left((a_{ij})^2+(c_{ij})^2\right)}}, \frac{b_{ij}}{\sqrt{\sum_{i=1}^{n} 2b_{ij}}}, \frac{c_{ij}}{\sqrt{\sum_{i=1}^{n}\left((a_{ij})^2+(c_{ij})^2\right)}}\right)\right) \tag{9}$$

where $\tilde{x}_{ij} = (a_{ij}, b_{ij}, c_{ij})$ are the elements of the decision matrix.

b. Calculate the relative closeness to the ideal solution using equation (10), (11).

$$A^+ = \{\tilde{v}_1^+, \tilde{v}_2^+, \dots \tilde{v}_m^+\} \tag{10}$$
$$A^- = \{\tilde{v}_1^-, \tilde{v}_2^-, \dots \tilde{v}_m^-\} \tag{11}$$

where $\tilde{v}_1^+ = (1,1,1)$ and $\tilde{v}_1^- = (0,0,0)$, $j = 1,2, \dots m$.

c. Rank the preference order using equation (12)-(16).

Ideal separation

$$S_i^+ = \sum_{j=1}^{m} s(\tilde{v}_{ij,}\tilde{v}_j^+) \qquad i = 1,2, \dots n \tag{12}$$

Negative-ideal separation

$$S_i^- = \sum_{j=1}^{m} s(\tilde{v}_{ij,}\tilde{v}_j^-) \qquad i = 1,2, \dots n \tag{13}$$

Where $s(\tilde{v}_{ij,}\tilde{v}_j^{+})$ and $s(\tilde{v}_{ij,}\tilde{v}_j^{-})$ are distance measurements calculated with the vertex method:

$$d(\tilde{X}_{ij,}\tilde{Y}_{ij}) = \sqrt{\frac{1}{3}\left[\left(x_{ij}^1 - y_{ij}^1\right)^2 + \left(x_{ij}^2 - y_{ij}^2\right)^2 + \left(x_{ij}^3 - y_{ij}^3\right)^2\right]} \tag{14}$$

$$\tilde{x}_{ij=} \left(x_{ij}^1, x_{ij}^2, x_{ij}^3\right) \tag{15}$$

$$\tilde{y}_{ij=} \left(y_{ij}^1, y_{ij}^2, x_{ij}^3\right) \tag{16}$$

d. Calculate the relative closeness to the Ideal Solution using equation (17).

$$C_i^* = \frac{S_i^-}{(S_i^+ + S_i^-)}, \qquad 0 < C_i^* < 1,\ i = 1,2,\ldots,n \tag{17}$$

Where:
$C_i^* = 1$ if $A_i = A^+$
$C_i^* = 0$ if $A_i = A^-$

e. Rank the preference order as figure (Figure 4):

```
Algorithm TOPSIS

Input: Wind turbine criteria values x_ij
       Weight of each criterion w_j
Output: Best T    //T is the best tradeoff solution

Create a decision matrix D

//Calculate normalized decision matrix
FOR x_ij in D do
  Calculate n_ij
ENDFOR

//Calculate normalized weighted decision matrix
FOR n_ij in D do
  Calculate v_ij = w_j n_ij
ENDFOR

//Determine the positive and negative ideal solutions
FOR v_ij in D do
  Calculate S+ and S-
ENDFOR

//Calculate separations from S+ and S-
FOR v_ij in D do
  Calculate d_i+ and d_i-
ENDFOR

//Determine R_i
FOR v_ij in D do
  Calculate R_i
ENDFOR
```

Figure 4 Basic concept of TOPSIS method

A novel ranking method that considers the relative significance of each option inside a collection is now accessible. This strategy is predicated on the assumption that each criteria in the decision matrix exhibits a monotonically rising or decreasing utility. A decision matrix is necessary with n possibilities and m criteria, each with specific weights. When articulating a conclusion that cannot be quantified mathematically, the most suitable approach for its quantification must be utilized.

4 Results and discussion

It is expected that construction projects that use consulting companies would be finished on schedule and under budget. Projects related to transportation are notorious for having erratic schedules and budgets. Claims, cost escalations, and schedule delays in civil infrastructure development projects can result from a variety of potential causes. Change orders commonly result in additional costs for transportation projects. In construction projects, every change, no matter how little, might lead to disputes and lawsuits. This analysis's main goal is to pinpoint the causes of claims, rework, and budget overruns. The topics of cost overruns and claims in civil construction projects—including those involving buildings, consulting firms, tunnels, hydropower, or water infrastructure—are covered in a plethora of books and articles. Only a small number of research works have focused on claims, modification orders, and cost overruns that can be linked to Iraq. This study looks at pavement construction projects in the consulting sector with an emphasis on modification orders and claims. Six typical factors are covered by the management strategies used in consulting offices' construction operations, which begin with the feasibility study and continue through the maintenance phase with the goal of attaining efficient factor management. Three fundamental pillars support the factors-driven method: well-designed foundations, prompt and adequate site assessments, and efficient foundation construction supervision. A basic need of quality assurance is the systematic and thorough documentation of the whole factors management process. This paperwork attests to the investigation's correct execution. Important findings suggested steps for factor control, and an explanation of the study's methodology and data sources must all be included in the documentation. It is clear that there are benefits to characterizing probability and outcomes statistically. Concerns about the quality and sources of the data might make quantitative analysis challenging. In this case, a thorough qualitative investigation with comparable specificity would be suitable. This study provides a useful and practical method for assessing the risks associated with consulting office operations during building projects. In factor management, it is usual practice for the person with the best qualifications and competence to manage factors to take on that role. We can protect the project from potential dangers or lessen their effects by assigning certain of its tasks to a single entity. Due to differences in soil and working circumstances, this chapter began by defining the study area in the northern parts of Iraq using the Delphi method, pertinent research, and expert insights. Using regional data, an AHP for prospective changes was developed in the final phase. The factors' ratings were determined by using the TOPSIS technique to evaluate the data collected in the third phase. You will keep all of your AHP data when you switch to TOPSIS. Based on the analysis of variables, we determined and evaluated the variables that affect consultant projects.

4.1 The weight of factors results

The purpose of AHP is to construct a data-friendly matrix that can be used to calculate the appropriate cost factor weights. Using the geometric mean of individual assessments, this approach allows for collective decision-making by consensus. AHP is a multi-objective algorithm that generates value scales using pairwise comparisons and ratings. The situations were created in two phases. After all of the information has been acquired, the following step is to rate the expenses using the AHP method. The ability of AHP to check and reduce the inconsistency of expert perspectives is its primary benefit. The first step is to identify significant value differences that may be used to prioritize cost components. Several questionnaires and interviews with Iraqi managers and engineers were conducted to arrive at this conclusion. Decision-makers employ their judgments about the relative worth of the elements in the comparison process. The AHP method starts with describing the problem and assessing the knowledge needed to solve it. The aim is at the top of the decision hierarchy, followed by consulting office activities objectives, intermediate levels (criteria for subsequent portions), and finally, the lowest level (typically a set of choices). The weighting of the priorities at the level below is based on the priorities generated from the comparisons. The researcher then utilized the AHP approach to quantify the influence of cost on project costs. The most challenging aspect of this project is determining how to handle such vast amounts of data. The researcher organizes and classifies the data in order to provide a good representation of existing practices. AHP is used in cost-group decision-making when a group of decision-makers employs pair-wise comparisons to evaluate the expert's responses to questionnaires (comparing items to one another two at a time). In terms of priority, each piece is given the same weighting. The weighted values of each element in the level below are combined together to produce the overall or global priority. Continue to weigh and add until the researcher has determined the ultimate. The pairwise of first-fifth groups of factors are shown in Tables 9-13, the weighted result is plot in Figure 5, and the numerical weight results of all groups of factors are stated in Table 14.

Table 9 The pairwise of first group of factors

	Project cost criterion	**Project implementation quality criterion**	**Project completion time criterion**	**Project profit return criterion**
Project cost criterion	1	0.2	0.2	0.33
Project implementation quality criterion	5	1	0.33	0.2
Project completion time criterion	5	3	1	3.03
Project profit return criterion	3	5	0.33	1

Table 10 The pairwise of second group of factors

	Project cost criterion	**Project implementation quality criterion**	**Project completion time criterion**	**Project profit return criterion**
Project cost criterion	1	0.333	0.2	0.333
Project implementation quality criterion	3	1	0.143	0.143
Project completion time criterion	5	7	1	0.111
Project profit return criterion	3	7	9	1

Table 11 The pairwise of third group of factors

	Project cost criterion	**Project implementation quality criterion**	**Project completion time criterion**	**Project profit return criterion**
Project cost criterion	1	0.33	0.2	0.33
Project implementation quality criterion	3	1	0.2	0.11
Project completion time criterion	5	5	1	0.33
Project profit return criterion	3	9	3	1

Table 12 The pairwise of forth group of factors

	Project cost criterion	**Project implementation quality criterion**	**Project completion time criterion**	**Project profit return criterion**
Project cost criterion	1	1	0.11	0.2
Project implementation quality criterion	1	1	0.2	0.33
Project completion time criterion	9	5	1	0.33
Project profit return criterion	5	3	3	1

Table 13 The pairwise of fifth group of factors

	Project cost criterion	**Project implementation quality criterion**	**Project completion time criterion**	**Project profit return criterion**
Project cost criterion	1	0.143	0.2	0.2
Project implementation quality criterion	7	1	0.143	0.143
Project completion time criterion	5	7	1	1
Project profit return criterion	5	7	1	1

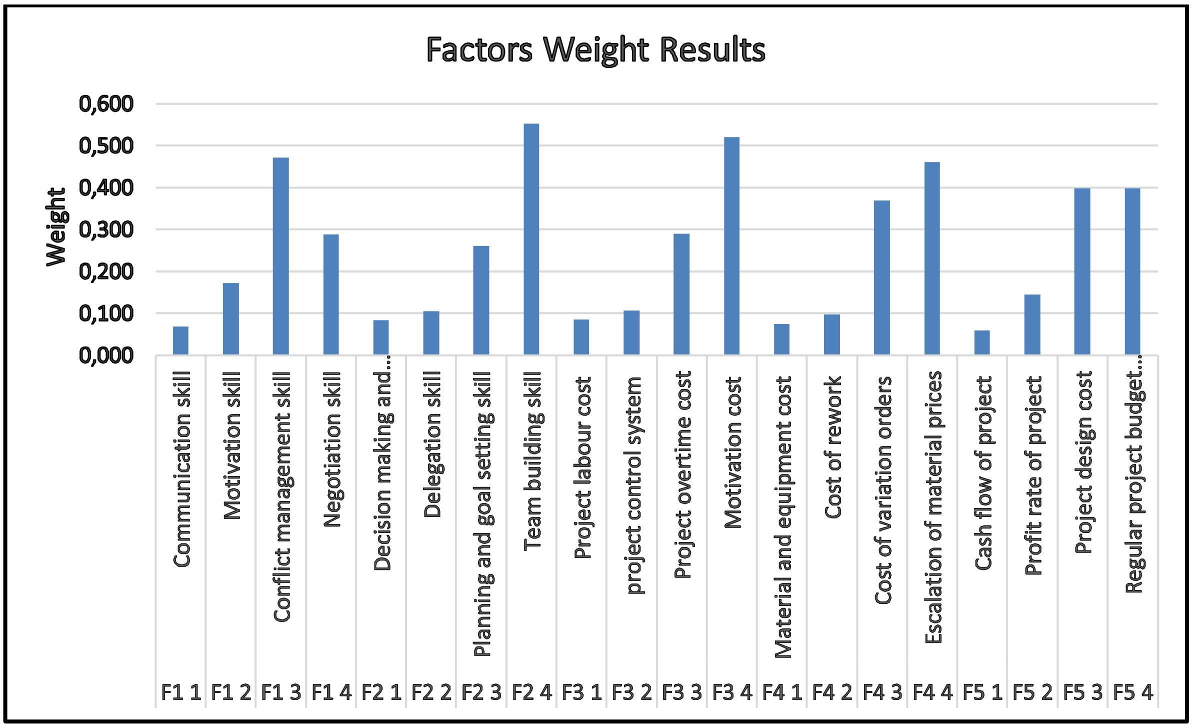

Figure 5 The weight results plot

Table 14 The numerical weight results of all groups of factors

	factor	Weight
F1 1	Communication skill	0.068
F1 2	Motivation skill	0.172
F1 3	Conflict management skill	0.471
F1 4	Negotiation skill	0.288
F2 1	Decision making and problem-solving skill	0.084
F2 2	Delegation skill	0.105
F2 3	Planning and goal setting skill	0.260
F2 4	Team building skill	0.552
F3 1	Project labour cost	0.085
F3 2	project control system	0.106
F3 3	Project overtime cost	0.289
F3 4	Motivation cost	0.520
F4 1	Material and equipment cost	0.074
F4 2	Cost of rework	0.097
F4 3	Cost of variation orders	0.368
F4 4	Escalation of material prices	0.461
F5 1	Cash flow of project	0.059
F5 2	Profit rate of project	0.144
F5 3	Project design cost	0.398
F5 4	Regular project budget update	0.398

An empirical survey's data was used to demonstrate the suggested AHP paradigm. The consultant factors impacting the project's success are depicted using a consultant-centric hierarchy. The project's consulting team had an impact on the development of the three-tiered organizational structure. The matrices make it easier for the expert to compare two hierarchical members at the same time. Microsoft Excel may be used to see the preference score of the model. Below is a thorough summary of the AHP analysis's findings. The outcomes of the AHP analysis are shown in tables for each category. The consultant's assessment of the effects revealed that the five categories that were chosen had very high priority levels. The project variables were ascertained by computing the AHP for every consultant component. These qualities were ranked according to the AHP results.

4.2 Final ranking results

The outcomes of the AHP-TOPSIS analysis are detailed in the subsequent section. Presented below are tables elucidating the results of the AHP-TOPSIS investigation for each specified reason. The ranking findings indicated that the 20 selected parameters were very pertinent to the evaluation of infrastructure projects, derived from the outcomes of construction activities conducted by consulting firms. A connection exists between the AHP weight and TOPSIS results in the initial group. The prevalence indicates a significant response in the processes.

Group 1:

Table 15 The questionnaire results of first group of factors

	Project cost criterion	Project implementation quality criterion	Project completion time criterion	Project profit return criterion	sum
F1 1	22	6	21	24	73
F1 2	27	21	15	10	73
F1 3	2	2	37	32	73
F1 4	13	27	24	9	73

Table 16 The matrix results of first group of factors

	Project cost criterion	Project implementation quality criterion	Project completion time criterion	Project profit return criterion
F1 1	0.040	0.03	0.194	0.164
F1 2	0.050	0.104	0.138	0.068
F1 3	0.004	0.01	0.341	0.219
F1 4	0.024	0.134	0.221	0.062

Table 17 The AHP-TOPSIS results of first group of factors

Si+	Si-	Pi	Rank
0.192	0.119	0.382	3
0.258	0.094	0.267	4
0.124	0.261	0.678	1
0.199	0.151	0.432	2

The findings show that, even in the absence of information technology, the work system technique may be used as a framework for evaluating and enhancing organizational processes. Contentious because it suggests that profitable businesses must adhere to the same rules. The work system process includes a static and dynamic representation of how a system evolves over time as a result of both deliberate and inadvertent changes. Any analysis or comprehension of a work system must start with the "work system framework," which is the foundation of the static perspective. The first group's results show that the most important ability is conflict management. This is explained by the element's significance to the operation of building projects and consulting organizations.

Group 2:

In order to fulfill the requirements of the customer and achieve the project's objectives from start to finish, the project firm assigns a group of project consultants who are subject to contractual obligations. Even if it means lowering their own company's financial returns, they have to maximize the project's profitability in order to satisfy the needs of the client organization and the project's overall management expectations. Thus, a number of elements may have an impact on the project consultants' team's effectiveness in Iraqi building efforts.

Table 18 The questionnaire results of second group of factors

	Project cost criterion	Project implementation quality criterion	Project completion time criterion	Project profit return criterion	sum
F2 1	2	25	18	28	73
F2 2	16	5	37	15	73
F2 3	18	6	39	10	73
F2 4	27	4	23	19	73

Table 19 The matrix results of second group of factors

	Project cost criterion	Project implementation quality criterion	Project completion time criterion	Project profit return criterion
F2 1	0.0046	0.099	0.076	0.403
F2 2	0.0369	0.02	0.157	0.216
F2 3	0.0415	0.024	0.166	0.144
F2 4	0.0623	0.016	0.098	0.273

Table 20 The AHP-TOPSIS results of second group of factors

Si+	Si-	Pi	Rank
0.089	0.278	0.757	1
0.206	0.111	0.351	3
0.272	0.092	0.253	4
0.178	0.131	0.425	2

An essential step in the project development process, material evaluation and issue resolution are indicated by the AHP-TOPSIS findings. Making decisions and addressing problems are critical skills in this process. In the process of developing consulting office projects, this capability is essential. A maximum level of continuous production may be achieved with the help of an ideal workplace and excellent management. Rework, supplies, tools, heavy machinery, crew interference, quality control inspections, management interventions, and inspections are some of the factors.

Group 3:

Respondents to the survey were open about the advantages of using project consultants in building projects, which clarified the need for these experts in Iraq's construction sector. The factors that made hiring project consultants attractive for the construction company are outlined in the following tables. As per the responses provided, project consultants can aid in accomplishing the goals of construction projects by taking on relevant responsibilities in the field.

Table 21 The questionnaire results of third group of factors

	Project cost criterion	Project implementation quality criterion	Project completion time criterion	Project profit return criterion	sum
F3 1	29	19	9	16	73
F3 2	25	19	21	8	73
F3 3	11	12	40	10	73
F3 4	21	21	17	14	73

Table 22 The matrix results of third group of factors

	Project cost criterion	Project implementation quality criterion	Project completion time criterion	Project profit return criterion
F3 1	0.054	0.056	0.053	0.335
F3 2	0.047	0.056	0.124	0.168
F3 3	0.021	0.035	0.236	0.21
F3 4	0.039	0.061	0.1	0.293

Table 23 The AHP-TOPSIS results of third group of factors

Si+	Si-	Pi	Rank
0.186	0.169	0.476	3
0.203	0.074	0.267	4
0.129	0.19	0.597	1
0.143	0.138	0.49	2

Project overtime costs suggest that the work system method is a set of ideas that can be used to any company's systems for analysis and improvement. Contentious because it suggests that profitable businesses must adhere to the same rules. The work system process includes both static and dynamic depictions of how a system develops over time as a result of both deliberate and inadvertent modifications. Any analysis or comprehension of a work system must start with the "work system framework," which is the foundation of the static perspective. In the process of developing consulting office projects, this capability is essential. A maximum level of continuous production may be achieved with the help of an ideal workplace and excellent management. Rework, supplies, tools, heavy machinery, crew interference, quality control inspections, management interventions, and inspections are some of the factors.

Group 4:

"Variation Costs" refers to the direct expenses and revenue losses that are justifiably incurred as a result of or associated with a variation. These costs may include extra expenses related to design, construction, manufacturing, commissioning, decommissioning, Through Life Support, or financing. "Cost variance" describes the difference between project expenses that were actually incurred and those that were anticipated. If the variance is positive, it means the project stays inside the allocated budget; if it is negative, it means the opposite.

Table 24 The questionnaire results of forth group of factors

	Project cost criterion	Project implementation quality criterion	Project completion time criterion	Project profit return criterion	sum
F4 1	31	31	9	2	73
F4 2	11	34	21	7	73
F4 3	23	5	21	24	73
F4 4	33	20	16	4	73

Table 25 The matrix results of forth group of factors

	Project cost criterion	Project implementation quality criterion	Project completion time criterion	Project profit return criterion
F4 1	0.044	0.06	0.095	0.036
F4 2	0.016	0.065	0.221	0.127
F4 3	0.033	0.01	0.221	0.436
F4 4	0.047	0.038	0.169	0.073

Table 26 The AHP-TOPSIS results of forth group of factors

Si+	Si-	Pi	Rank
0.42	0.05	0.106	4
0.309	0.168	0.353	2
0.058	0.419	0.878	1
0.369	0.087	0.191	3

"Cost variance" refers to the difference between actual project spending and the pre-project budget. For this calculation, the difference between the planned cost of work done (BCWP) and the actual cost of work finished (ACWP) is used. The study determined that the owner's financial difficulties, the difficulty of establishing a consistent design across different districts, design errors and omissions, the contractor's pursuit of profitability, and the lack of an appropriate site prior to the design phase of the construction project were the main causes of variation orders. The creation of standard designs for different districts and the owner's financial restrictions are the most common owner-related grounds for change orders; inadequate staff expertise and difficult access to the project site are the least common. The most common reasons for variation orders are conflicts in contract agreements and inadequate coordination between contract parties, whereas consultant-related concerns include time constraints during the design process and design flaws and omissions. The two most typical variation orders pertaining to contractors are those pertaining to intended profitability and substantial changes to the bill of quantities; the less frequent ones, on the other hand, have to do with the contractor withdrawing from design and, if relevant, asking to be compensated for low price.

Group 5:

In this group**,** cash flow is the entrance and outflow of money related to a construction project over a given time period. When running a construction company or project, it is essential. The careful management of a construction project's financial resources is essential to its sustainability and profitability. The movement of money into or out of a business is referred to as cash flow. When a project brings in money, its cash flow is positive. Exiting the project with funds results in negative cash flow. Adding the time element yields the flow velocity. Cash flows are used by project and business managers to track income and expenses. Project cash flow may be seen as the owner's payment plan for the project's completion over a certain amount of time. It is a part of the long-term financial strategy of an organization or enterprise. When assessing a project's appropriateness, organizations often use the term "relevant cash flow" to indicate the financial evaluation of the endeavor.

Before moving further, the top management of the organization must assess the project's benefits and cash flow and provide their approval. An examination of the project's cash flow may not be as important when collaborating with outside suppliers or providers. If there were no agreements with other parties, there would be no need to spend any money. An examination of project cash flow is useful for allocating project resources, particularly when contractors are not present.

Table 27 The questionnaire results of fifth group of factors

	Project cost criterion	Project implementation quality criterion	Project completion time criterion	Project profit return criterion	sum
F5 1	4	32	33	4	73
F5 2	29	21	20	3	73
F5 3	7	32	31	3	73
F5 4	5	35	31	2	73

Table 28 The numerical matrix of fifth group of factors

	Project cost criterion	Project implementation quality criterion	Project completion time criterion	Project profit return criterion
F5 1	0.008	0.076	0.225	0.2585
F5 2	0.056	0.05	0.136	0.1939
F5 3	0.014	0.076	0.211	0.1939
F5 4	0.010	0.083	0.211	0.1293

Table 29 The AHP-TOPSIS results of fifth group of factors

Si+	Si-	Pi	Rank
0.007	0.166	0.959	**1**
0.124	0.065	0.342	**4**
0.067	0.111	0.624	**2**
0.13	0.094	0.42	**3**

The goal of the inquiry was to clarify the role that project consultants play in the cash flow construction sector. Based on participants' assessments of the advantages of employing project consultants, we were able to collect precise data. An estimate of cash flow can be used to assess the operational and financial stability of a project. These estimates assist the availability of enough money and the early detection of potential financial dangers, providing as a strategic foundation for financial decision-making. These reports help with effective cash flow management, which is necessary to avoid underfunding or improper resource allocation throughout development.

4.3 Overall ranking factors

Analyzing the whole AHP-TOPSIS data for each responder element allowed us to analyze the consultant's effect on the success of the project. You can see all the results of the AHP-TOPSIS investigation in the figure (Figure 6). According to these rankings, the five criteria were considered very important in light of the project's potential impact.

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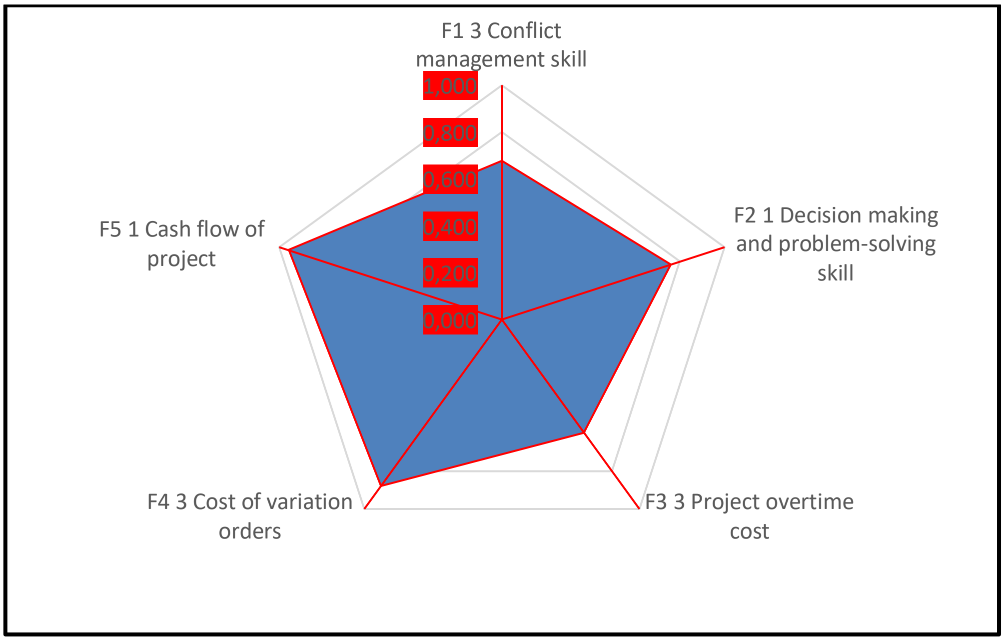

Figure 6 The overall effect of the main factors

In the building sector, the services provided by project consultants are crucial. From the very beginning of a project all the way to its conclusion, consultants offer their specialized knowledge. The use of project consultants greatly enhances the efficiency and effectiveness of construction projects. Project consultants' efficacy and efficiency in connection to the final product quality in Iraqi construction projects is the primary focus of this research. This research made use of a dataset that was compiled from a variety of primary and secondary sources. Secondary data was gathered by conducting a thorough literature review of relevant books, journals, and articles in order to outline and clarify the primary ideas of this study.

5 Conclusion

Delays in building projects and consulting office operations provide substantial obstacles, necessitating a thorough investigation of the underlying causes. This study used the AHP-TOPSIS approach to systematically detect, rank, and mitigate these delays, providing a formal framework for decision-making in project management. The integration of this approach allows for a systematic investigation of disparities, prioritizing numeric risks while resolving qualitative concerns using the Ishikawa diagram.

The study identified 20 significant risk factors influencing the efficiency of consulting firms and building projects using surveys, expert interviews, and exploratory research. These components were evaluated for influence using the AHP-TOPSIS factor ranking system and Microsoft Excel, yielding important insights into critical areas such as conflict resolution, problem-solving capacities, additional project expenses, cost fluctuations, and financial flow management. The methodology was evaluated in an Iraqi consulting firm to ensure its applicability in real-world scenarios by categorizing risks based on environmental factors. The findings revealed that a systematic review procedure considerably enhances project operations while reducing inefficiencies.

To reduce project failures and operational setbacks, it is critical to address common difficulties such as ineffective supervision, insufficient documentation, a lack of motivation, and confusing instructions. Continuous monitoring of construction processes, combined with structured training and professional development programs for supervisors, particularly foremen, is critical to increasing staff productivity. By employing these tactics, consulting firms and construction companies can improve their operations, reduce delays, and achieve long-term success in an increasingly complicated sector.

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Managing supply chains amidst geopolitical instability

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Keywords: global supply chains, supply chain management, uncertainty, risks, supply chain optimisation.
Abstract: The stable functioning of global logistics supply chains is a necessary condition for meeting consumer needs, developing production and growing the economy as a whole around the world. The current situation with global economic uncertainty is seriously testing the sustainability of international supply chains, revealing their vulnerabilities and the need for diversification. The study aims to analyse the transformation of global supply chains in the context of geopolitical changes to substantiate adequate directions and tools for managing and optimising logistics processes to achieve a competitive advantage in a dynamic business environment caused by geopolitical uncertainty using modern supply chain management platforms. The study is based on theoretical and statistical data and comparative analysis to identify the impact of global geopolitical changes on supply chain management. The publication explores the world economy's challenges due to changes in global trade relations caused by factors, including the pandemic and military conflicts. It is proved that the dynamics of international associations and the growth of protectionist policies are the driving forces that lead to the destabilisation of global supply chains and the intensification of trade contradictions. The study identifies ways to optimise global supply chains, considering integrating digital technology tools into supply chains, which can provide more accurate tracking of goods, increase transparency of operations and reduce the risks of counterfeiting and fraud.

1 Introduction

Global geopolitical processes, such as trade wars, climate change and pandemics, are radically restructuring the world economy. Global supply chains are undergoing significant changes due to geopolitical disruptions, economic instability, technological advances and cultural transformations — their complex network is becoming even more uncertain due to the constant changes in international trade. To effectively manage these chains, it is necessary to clearly understand these changes and the impact of these processes on global supply chains to reduce logistics risks and optimise them [1]. Given the current global challenges and transformations, the relevance of studying the impact of these changes on global supply chains is obvious.

High competition in the global market dictates new rules of the game. To meet the growing demands of customers, companies are forced to constantly improve their logistics processes, providing the highest level of service and ensuring impeccable quality, where the speed and quality of logistics processes are critical factors in the competitiveness of companies in a globalised world. Failure to anticipate and mitigate risks can lead to significant disruptions in supply chain operations. Inadequate analysis of potential threats can trigger unforeseen problems that negatively affect all stages of the production cycle and the ability to compete in the market. This limits opportunities for improving global supply chain management [2].

Managing global supply chains in a dynamic environment has become impossible without digital solutions. These solutions provide complete control over the supply chain, real-time tracking of goods and rapid response to market changes. Digital tools provide complete openness and transparency of business processes and control over all stages of the supply chain, enabling them to accurately track the movement of goods, control stock levels in warehouses, identify potential bottlenecks promptly and optimise logistics processes, which helps to increase business efficiency, reduce costs and improve customer service.

That is why, in today's geopolitically uncertain world, supply chain management is the art of coordinated work of all links, from producer to consumer, to deliver the right product to the right place at the right time. Solving the challenges of managing global supply chains in today's business environment requires an integrated approach considering various supply chain optimisation factors, including supply chain performance and optimisation criteria.

2 Literature review

Academic debates and practical experience over the years have shaped the current understanding of foreign trade and geopolitics in the scientific works of many scholars. Based on the results of their study, Góes and Bekkers [3] argue that geopolitical conflicts can significantly harm the global economy; in particular, they can lead to a decrease in international trade, slower economic growth, and slower innovation processes. Rodrik [4] investigated the interaction of globalisation processes and political changes and their consequences for foreign economic relations. The researcher notes that the neoliberal model of globalisation, which preached unimpeded trade and minimal government intervention in the economy, did not always lead to the expected positive results. He argues that this model has often led to increased inequality, job losses in developed countries, and undermined social harmony. Chunikhina et al. [1] studied international trade in the context of global transformations, reviewing key trends and strategic decisions that can be used to develop effective trade policy in the context of globalisation. They argued that a systematic analysis of changes in world trade allows for more accurate forecasts and business adaptation to new conditions.

The transformation of global supply chains, especially in the wake of COVID-19, has intensified academic debate in this area. Researchers such as Sandul [5], Tereshchenko and Yevtushenko [2], Song et al. [6], Tullio [7] find that protectionism, mainly through non-tariff barriers, affects how fast global trade grows compared to the growth of the world economy. Khorana et al. [8] analysed how global supply chains respond to sharp supply and demand changes in the face of increased protectionism, including the benefits and risks this brings to companies affected by the COVID-19 pandemic. Protectionist measures, such as duties and quotas, can protect new or weak sectors of the national economy from foreign competition, giving them time to develop; import restrictions can help preserve jobs and reduce dependence on imports of strategically important goods. However, in their opinion, protectionism can slow down economic growth in the long run as it limits access to cheaper and more efficient resources and technologies.

Analysing the experience of the international business community in overcoming crises, Buckley [9] notes that the disruption of global trade networks requires them to rethink strategies and seek new opportunities. According to the researcher, modern corporate strategies should be more comprehensive and consider social and political contexts, especially in rising nationalist sentiment. Non-market factors, such as geopolitical tensions, are forcing multinationals to focus on increasing their flexibility, expanding their network of partnerships, and adapting business models to changing conditions in global markets. Manag Rev [10] and Mishra et al. [11] emphasise the importance of proactive planning, collaboration, and adaptability of chosen paths in uncertain and complex environments to mitigate the adverse effects of disruptions and ensure the continuity of global supply chains. According to Noble [12], combining lean and agile will increase customer satisfaction and competitiveness and reduce costs, creating a more sustainable and efficient supply chain.

The issue of supply chain optimisation in times of crisis is discussed in detail in Kryveshchenko et al. [13], Zavadska et al. [14], Mittal [15]. Nandy and Md. Mamun Habib [16] emphasise the need for proactive management and rapid response to change. Researchers are deepening their understanding of logistics decision-making processes, particularly regarding uncertainty and risks accompanying global supply chains. The challenge of effective supply chain management in times of crisis is discussed in detail by Remzina [17], who emphasises that success depends on the ability to adapt quickly to change. Bradley and Alderman [18] note that in difficult situations, ready-made solutions are needed that can be used to quickly adapt to changes, as well as to implement innovative solutions to optimise management processes.

The international company McKinsey and Company has conducted several studies in the field of logistics: Alicke and Strigel [19] substantiated the issues of risk management in logistics supply chains; Bartman et al. [20] substantiated the current changes and global challenges in the logistics sector; and Dautner [21] optimised global logistics supply chains. The researchers describe the new types of risks that have emerged in global supply chains in recent years, such as cyber threats, climate change, and pandemics, and offer various strategies and tools for managing them in supply chains. Diversifying suppliers, building inventories, and using innovative technologies to track risks allow us to respond to existing problems, anticipate potential threats and develop measures to prevent them.

In the context of the development of Industry 4.0, researchers led by García-Reyes [22] identify how to modernise supply chains. They propose areas that allow for the gradual integration of new technologies while increasing the flexibility, resilience, and reliability of logistics processes [23], such as increasing efficiency, saving money, and improving customer satisfaction, redesigning supply chain processes to take advantage of digital opportunities, creating reliable processes for collecting, storing, and analysing data. Hassani et al. [24] emphasise that seemingly contrasting models (Lean emphasises efficiency, Agile emphasises flexibility) can be combined to manage a global supply chain effectively. However, only if the need for efficiency is balanced with the need for flexibility. For example, a company can use Lean principles to reduce waste in production while using agile methods to respond quickly to changes in customer demand.

The maturity of supply chain management in terms of sustainability is relevant today in the context of following sustainable development, as noted by Reefke and Sundaram [25], Hong et al. [26]. Digital solutions such as process automation, accurate accounting, warehousing optimisation, and data analytics give companies complete control over their inventory and shipments and identify potential problems at an early stage, as highlighted by Shpak et al. [27]. Although big data technologies are still in their infancy, they are already playing an essential role in transforming various industries, including by facilitating the development of new services, increasing the competitiveness of companies, and developing innovative logistics solutions [28]. As Colback [29] notes, the introduction of digital solutions such as warehouse management systems (WMS), enterprise resource planning (ERP) and transportation management systems (TMS), and the use of blockchain technology to securely and transparently track goods throughout the supply chain, improve agility and response to force majeure disruptions, and reduce costs and waste in the supply chain.

The existence of a significant scientific body of work does not alleviate the urgency of the issue, as the scale of global geopolitical uncertainty in global supply chains requires new solutions that can only be found through further research. The changing global context requires updated management approaches in global supply chains.

The research aims to analyse the transformation of global supply chains in the context of geopolitical changes to substantiate adequate directions and tools for managing and optimising logistics processes to achieve a competitive advantage in a dynamic business environment caused by geopolitical uncertainty using modern supply chain management platforms. Considering the global digitalisation trend, the study aims to identify bottlenecks in the existing global supply chain management system and develop measures to address them in unstable global trade.

3 Methodology

The research methodology involved the collection of theoretical and statistical data, their comprehensive analysis and comparative evaluation in order to identify patterns and trends in the impact of global geopolitical changes on international associations and trade policy in order to increase the sustainability of global supply chains and the volume of investment in the technological development of logistics at the global level. The observation method allowed us to identify long-term trends and patterns necessary for understanding the processes in the geopolitical environment, which primarily affects global supply chains. The abstraction method was used to identify general patterns characteristic of the transformation of global supply chains in times of geopolitical uncertainty and to draw conclusions that can be used to predict this area's future development.

The study of the transformation of global supply chains was based on the application of such a method as analytical diagnostics, which allowed us to identify the main trends of global changes in the geopolitical environment, the dynamics of changes in the international trade community and the problems associated with this sweet economic and political phenomenon. The statistical analysis of the total value of logistics operations by target regions provided a multifaceted picture of how global political changes affect global supply chains and international trade volumes. It is worth noting that there is a significant gap in the development of decision-making methodologies in global supply chain management, especially in the face of uncertainty and multiple criteria.

4 Results and discussion

The global economy is going through a period of turbulence associated with increased protectionism and trade barriers, which is provoked by the growth of nationalist sentiment. The rapid development of technology, especially in transport and communications, has become a powerful catalyst for global economic integration. The transition to Industry 4.0 requires companies to rethink their approaches to supply chain management, considering the growing interdependence of economies and the rapid development of technology. Companies have been actively expanding their supply chains beyond national borders for cost savings. Economic motives drove this process, although it was accompanied by disregarding certain risks associated with globalisation [5].

After a tumultuous period of pandemic and subsequent stagnation, logistics is transforming profoundly through a wave of mergers and acquisitions. These processes are not only changing the landscape of the industry but also shaping new areas for investment and development. Increased geopolitical instability and stronger protectionist policies during this period significantly impacted the decline in international trade. Figure 1 shows that, after the accelerated development caused by the pandemic, global supply chains went into slow motion in 2023, but analysts predict a new round of activity in 2024 [20].

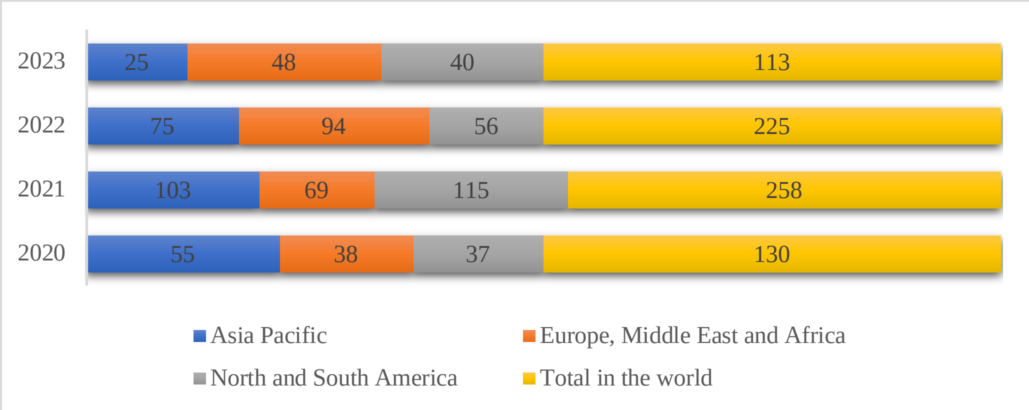

Figure 1 Total Value of Logistics Operations by Target Region, billion USD
Source: compiled by the author based on data from [20]

Growing geopolitical tensions are leading to the fragmentation of global supply chains and their increased dependence on non-market factors. Changes in trade policy are a direct stimulus for the growth or decline in trade volumes. Protectionist policies, which impose trade barriers such as duties and quotas, hurt international trade volumes. In contrast, free trade agreements, which eliminate tariff and non-tariff restrictions, stimulate trade growth between countries, and the formation of international trade associations support the resilience of global supply chains (Figure 2).

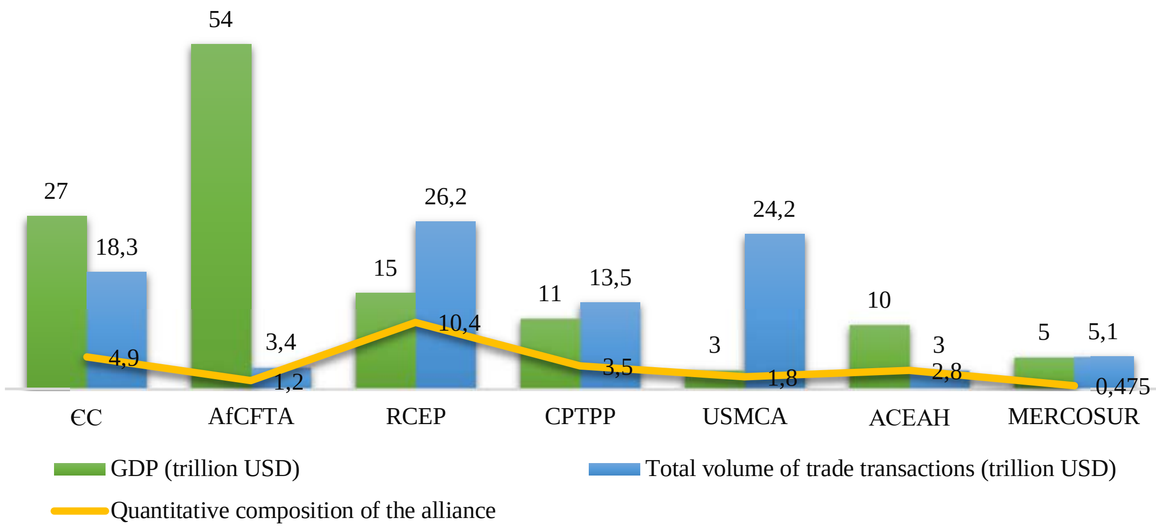

Figure 2 Major International Trade Associations for 2022–2023
Source: built by the author based on [30]

This trend is driven by the fact that international unions and associations do not stand still but actively respond to changes in the global economy. In 2022–2023. The EU focused on the digital transformation of the Single Market and enhancing economic resilience. The African Continental Free Trade Area is actively developing and focusing on digitalisation. The RCEP has become a powerful engine of economic growth in the Asia-Pacific region. providing favourable conditions for trade and investment. The Trans-Pacific Partnership Agreement has successfully continued to realise its trade liberalisation and regulatory harmonisation goals. The USMCA contributes to improving trade security in North America. ASEAN continues to work actively to strengthen economic ties between the region's countries. contributing to their joint development. The South American trade bloc was established to liberalise trade and factors of production between the region's countries and strengthen economic integration. Despite this. The bloc's foreign trade relations remain heterogeneous. as evidenced. in particular. by the complex process of negotiating an agreement with the European Union [1].

Geopolitical conflicts and new international trade rules have become the main drivers of changes in world trade.

which have been initiated by broader global political processes. as noted by Góes and Bekkers [3]:

- The expansion of military blocs such as NATO creates a paradox: on the one hand. it increases security and promotes economic growth. but on the other hand. it can provoke conflicts and limit trade relations;
- Due to the rivalry between China and the United States and difficulties in NATO. countries are reviewing their trade relations and trying not to depend on one country or region;
- In the context of rising international tensions. economic sanctions are becoming an instrument of geopolitical pressure that can lead to trade wars and redistribution of global economic resources;
- Changes in international security and political alliances are forcing companies to rethink their supply chain management strategies. as the regional integration that results from these changes creates both new risks and opportunities for businesses;
- The armed conflict in Ukraine hurts the volume and structure of international trade. mainly through rising prices.

The reorganisation of trade and economic associations and the adaptation of trade strategies open up new opportunities for the development of international trade. but they also carry certain risks. Given this. it is crucial to highlight the main ones associated with changes in geopolitical alliances and trade policy that could disrupt the smooth operation of global logistics networks (Figure 3).

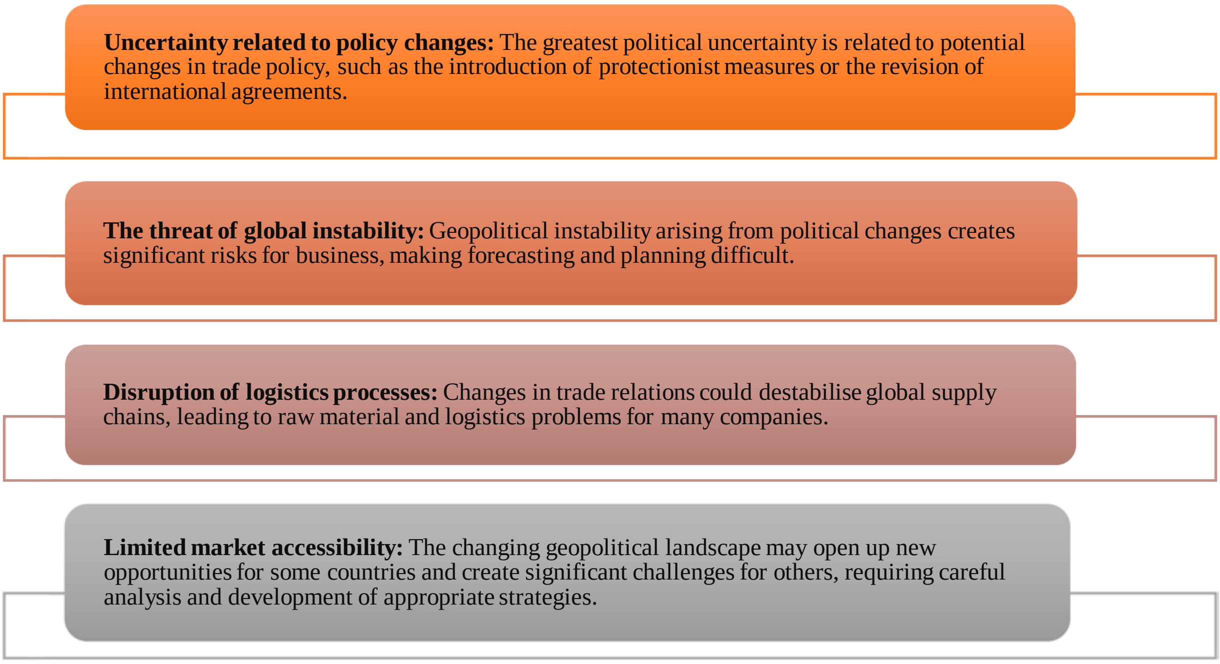

Figure 3 Risks of Global Supply Chain Destabilisation as a Result of Geopolitical Challenges
Source: compiled by the author according to [1]

The rapid pace of globalisation and technological development is forcing businesses to make new choices. requiring them to constantly adapt to changing conditions and build resilient supply chains that can withstand any threat. Based on the pandemic's experience. governments and businesses are developing new models of global supply chains that will be more flexible and adaptive to unforeseen events. Increasing the resilience of supply chains remains a critical task even for the world's largest companies. This process encompasses various activities. from analysing potential threats to using modern technologies and collaborating with partners to create reliable supply chains [19].

As noted by McKinsey and Company (Figure 4). The trend towards investing in technology to reduce costs and increase productivity is becoming increasingly noticeable.

With supply chain finance. exporters and importers can flexibly adjust payment terms. maintain liquidity and ensure the smooth flow of goods and funds between countries. Sustainable finance combines social responsibility with economic benefit. meeting customers' needs and seeking sustainable development. Sustainable finance is expected to be a crucial factor in building sustainable supply chains. and supply chain sustainability will become a new criterion for investment decisions [16].

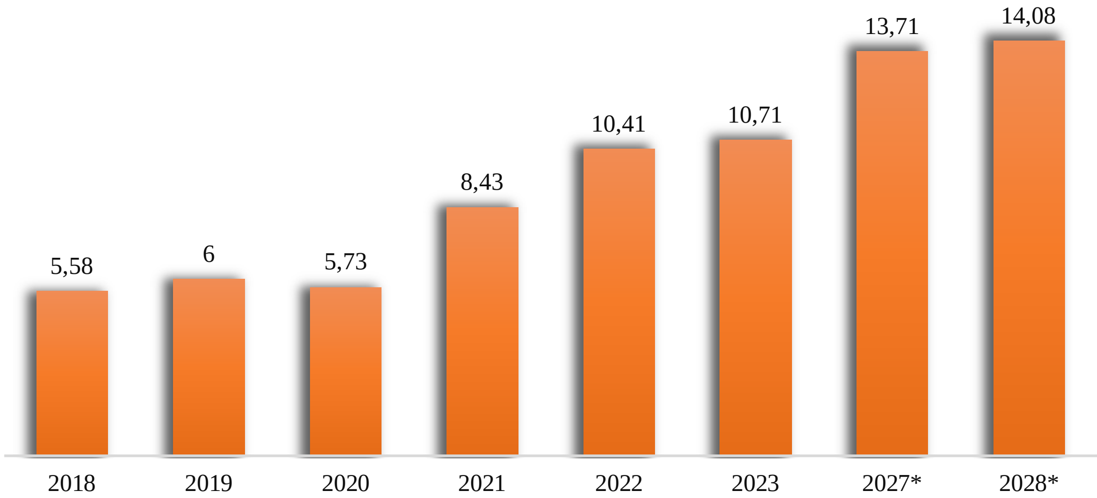

Figure 4 Investments in Logistics Technology Development at the Global Level. trillion USD
Source: [31]

Logistics is a critical factor in ensuring the continuity of business processes in the face of uncertainty. It is essential to clearly understand what criteria determine the efficiency and sustainability of logistics processes. The critical point of optimisation is to establish the optimal criteria for assessing the effectiveness of the supply chain management strategy under conditions of uncertainty. The main criteria are the system's ability to self-adjust. flexibility in responding to changes. resource efficiency. and resilience to external threats [15]. A key element of successful supply chain optimisation is implementing a system of key performance indicators (KPIs) that accurately assesses how effectively the chosen strategy is being implemented. High efficiency is achieved by improving production efficiency by increasing throughput. eliminating bottlenecks and shortening the production cycle. increasing labour productivity. optimising logistics processes and accelerating the turnover of material resources. To minimise the risks associated with uncertainty. strategies to increase the resilience of global supply chains should be applied. as shown in Table 1.

Table 1 Strategies for Optimising Global Supply Chains

Strategy	The essence of the strategy	Areas of application	Advantages of use
Multisourcing	Create backup supply channels	Distributing risks among several sources to minimise the impact of crises	Ensures high security of supply. competitive prices. continuous improvement of product quality and access to the latest technological developments
Niaschoring	Bringing production closer to the consumer	Complete control over all stages of the supply	Speeds up order fulfilment and reduces transport costs
Decentralisation of production	Territorial distribution of production	Reduce logistics costs and increase delivery speed	Reduces the risk of supply chain disruption
Interoperability	Implementation of a single quality standard	Systematisation of actions at all levels of the supply chain	Increases the productivity and efficiency of all business processes
Maintaining surplus production assets	Creating stock or production capacity reserves	Increase in inventory or production capacity	Insure against possible supply disruptions and increase the resilience of supply chains
Building strategic alliances	Creating mutually beneficial partnerships	Entering the shared logistics ecosystem	Encouraging joint efforts. market interaction and exchange of experience.
Flexibility of supply	Creating adaptive logistics networks	Investing in dynamic logistics systems	Ensures prompt adaptation to changing market conditions
Digital modernisation	Introduction of digital tools	Blockchain. AI and cloud computing in supply chain management	Enables supply chain transparency. intelligence and scalability

Source: added by the author based on [13]

Significant fuel price increases. labour shortages and the destruction of transport infrastructures have created a critical situation that requires a radical restructuring of logistics processes using the most advanced technologies.

Digital transformation has become a necessity for global supply chains. which are facing unprecedented challenges. Thanks to IT tools. the supply chain's transparency. efficiency. and responsiveness are reaching a new level. Digital solutions enable tracking every stage of the goods' movement from producer to consumer. monitoring stock levels in warehouses. and detecting possible delays or problems in time [18]. A wide range of software solutions help increase the productivity of the entire supply chain (Figure 5).

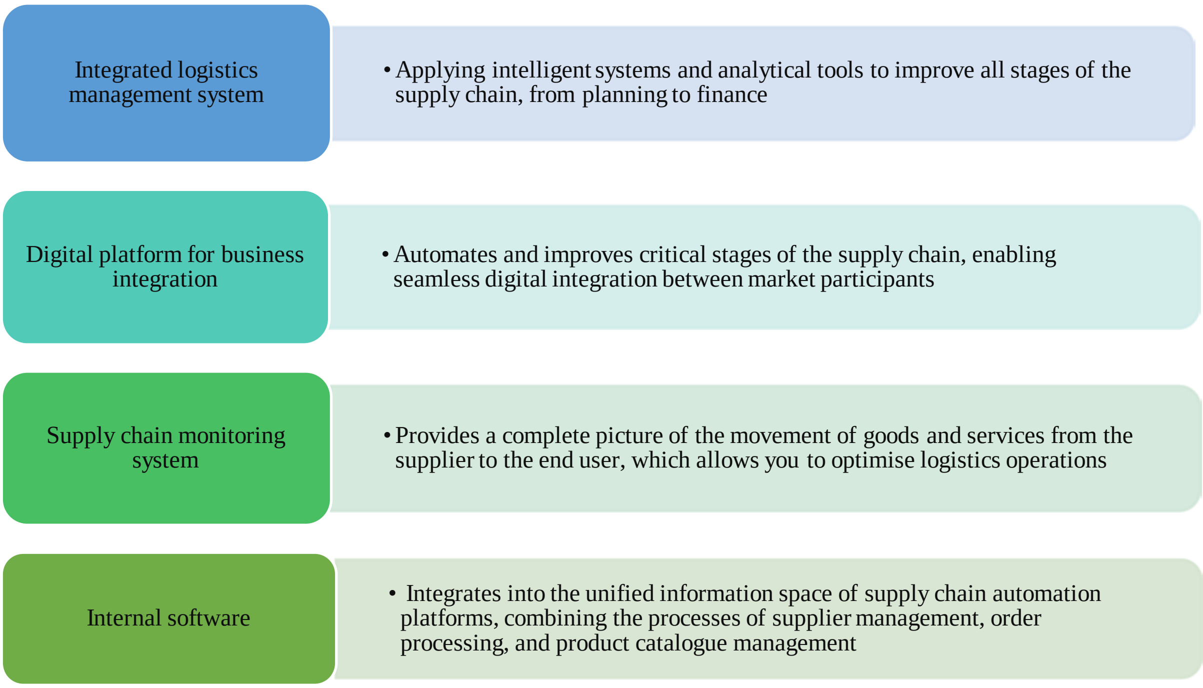

Figure 5 Supply Chain Management Platforms
Source: based on [14]

To achieve maximum transparency and control over task execution. systems that store reliable and undistorted data must be developed. Blockchain technology. for example. guarantees the highest level of data security. making it impossible to tamper with or access unauthorised data. IoT sensors have transformed supply chains into interactive systems where each product has its digital passport containing detailed information about transportation conditions. allowing companies to ensure product quality and meet customer requirements [24].

Digital platforms improve communication and facilitate financial transactions between supply chain partners. ensuring transparency and efficiency of payments [29]. Digitalisation transforms static supply chains into dynamic networks that provide greater transparency. efficiency and adaptability. Integrating heterogeneous big data provides a comprehensive supply chain analysis. enabling quick and informed decisions to be made in a dynamically changing environment [28].

The active formation of global supply chains. driven by globalisation. has been significantly hampered in the 21st century by the growing number of global crises. The COVID-19 pandemic has become a vivid example of such events. which have led to an unprecedented slowdown or even halt in production processes in various industries. thereby negatively affecting the structure and models of supply chains [6]. In addition. optimising global supply chains in times of crisis is a complex process that requires an integrated approach. It is necessary to introduce modern technologies. diversify suppliers. optimise inventory and inventory management. ensure transparency and traceability. invest in own logistics. improve cooperation between chain participants. and adapt quickly to changes.

The global processes of recent years have triggered large-scale changes in international trade. creating new opportunities and challenges for businesses and economies worldwide. It is necessary to critically analyse the transformational processes in global trade to understand their impact on the development of global supply chains. Analysing global supply chains as an integral part of economic ecosystems allows us to understand their impact on economic growth and social development. Analysing the critical factors shaping modern supply chains will allow companies to develop effective strategies for optimising global supply chains to adapt to new market conditions and create a future-oriented business [5].

Geopolitical conflicts. including trade wars between major economies. have exposed deep divergences in the perception of democratic and liberal values between Eastern partners and the Global West. leading to increased instability in global supply chains. Globalisation opens up new horizons for market expansion and cost optimisation in supply chains. but companies must also consider the risks associated with growing de-globalisation trends. Successful global operations management requires constant balancing between changing geopolitical conditions. complex regulatory requirements. volatile trade relations and adapting quickly to changes. Geopolitical risks have pushed companies to rethink their globalisation strategies and look for more local and regional solutions [29].

The increasing complexity of global supply chains and stricter sustainability requirements force companies to reconsider their management approaches. Particular attention is paid to the responsible selection of partners. minimising the negative impact on the environment and ensuring compliance with ethical standards at all stages of production [10]. The urgency of this transition is related to the need to adequately respond to systemic shortcomings that manifest themselves in the form of negative externalities resulting from a long-term underestimation of the risks associated with market dysfunctions and government regulation [32].

Today. the European Union is a leader in promoting sustainable development. focusing on the financial sector by redirecting investment to environmentally friendly projects and limiting funding for environmentally damaging businesses. The new sustainable finance regulations will make the integration of ESG criteria into supply chains mandatory for all companies. Companies must comprehensively assess their environmental and societal impacts. including greenhouse gas emissions. resource consumption. labour conditions. and supplier performance [33]. Failure to comply with the requirements may restrict suppliers' access to finance and loss of business development prospects. In particular. implementing sustainability standards can devastate the development of countries on the path of modernisation.

As geopolitical competition intensifies and countries seek to protect their markets. large companies must reconsider their business model. They are likely to rely less on global production chains and build more local production facilities to meet the needs of consumers in their regions [14]. This is due to the desire to reduce the risks associated with supply disruptions and increase their resilience to external challenges. However. the decline in globalisation will not necessarily lead to the destruction or radical change of production chains – many companies are beginning to actively work to strengthen their supply chains.

Global supply chains must be flexible and adaptive to survive in a constantly changing environment. The critical characteristic of an adaptive global supply chain strategy is its ability to change quickly in response to unforeseen circumstances. such as market changes or customer needs. Unlike traditional supply chains. agile supply chains are characterised by close collaboration between all participants. rapid data exchange. and innovative technologies. allowing them to respond quickly to market changes [16].

Effective supply chain management in the face of global crises requires not only the use of modern technologies but also a deep understanding of the relationships between all elements of the chain and the ability to quickly adapt to changes in the external environment [34]. The introduction of digital platforms allows for the automation of many processes in the supply chain. reducing the number of manual operations and minimising the risk of errors. The transition from linear to networked supply chains is a key trend in modern logistics. which is enabled by digital technologies.

In a dynamic market environment. where supply chains are constantly subject to change and risk. it is critical to regularly evaluate information on orders. prices. deliveries and other factors affecting logistics operations' efficiency. The key to effective supply chain management in a volatile environment is clearly defining and regularly monitoring key performance indicators that consider all these criteria. In order to adapt to changing conditions and maintain the stability of logistics operations. it is necessary to systematically monitor and analyse key performance indicators that consider these criteria [2].

5 Conclusions

Global instability caused by wars. economic crises. and technological revolutions transforms every aspect of international relations. including global supply chains. Global supply chains play a crucial role in today's world. influencing economies. politics. and people's lives. Understanding their role and the challenges they face is essential for effective decision-making at the national and international levels.

1. The study shows that global change is a powerful driver of transformation in international trade. The emphasis on achieving sustainable development goals in logistics has shifted from declarations to concrete actions. which is especially relevant for global supply chains. where companies must ensure transparency of operations and implement a range of environmental measures.
2. Geopolitical. economic. technological. and cultural factors significantly impact international trade relations and the formation of alliances between states. Exports and imports. trade balance. tariff rates. and global integration indices are key indicators. and analysing the dynamics allows us to assess the impact of these factors on international trade. The growth of globalisation makes it necessary to have an efficient and well-managed supply chain. as it is becoming an essential element for international business.
3. It is determined that managing global supply chains under uncertain conditions involves a detailed study of the company's financial condition. risk assessment.

development of plans to restore solvency. and implementation of measures to stabilise operations. The shaky balance of international alliances and the growth of protectionism have led to high uncertainty in global markets.

4. The introduction of the Internet of Things and artificial intelligence in logistics significantly increases productivity. process efficiency and customer service. In the context of globalisation and a changing market. digital solutions are becoming indispensable for navigating the complexities of global supply chains and maintaining a competitive edge.

The complexity of modern business requires professional management of global logistics supply chains to achieve maximum efficiency. Volatility and uncertainty emphasise the need to focus on adaptability. flexibility and efficiency when optimising logistics management processes. KPIs help identify global supply chain bottlenecks and develop measures to address them. The systematic evaluation of all relevant data is critical to the effective planning and execution of logistics operations in a global environment.

It is worth noting that optimising global supply chains in the face of global crises is not just a sum of individual measures but a set of interrelated actions. Modern technologies. supplier diversification. inventory optimisation. transparency. investment in own infrastructure. cooperation between chain participants. and adaptation to changes are all integral components of successful optimisation. The proposed solutions can contribute to creating new business models in global logistics that will allow for successful operations in a highly competitive and uncertain environment.

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Study on the supply chain for spare parts

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Abstract: The study aims to analyze the reasons for unpunctual service - aspects related to the absence of a spare part during and immediately after the launch of a new product (New Product Interoduction - NPI flag). The data collection for the survey research is based on customer interviews. The customer surveys were conducted with the help of the computer manufacturer of one of the companies that provide after-sales service for computer devices that are not manufactured by the same company and are therefore suitable for the research in order to determine the existing level of after-sales service with spare parts and the possibilities for its improvement. Data collection for the supply chain performance study was conducted from January 1, 2023 to January 1, 2024. The study covered 149,937 processed customer warranty claims from a computer manufacturer and showed the level of customer service over a one-year period. The biggest weaknesses in the supply chain for spare parts that provide after-sales service for new products are the uncertainty of future demand and warranty failures that these products will cause.

1 Introduction

The global interest and scale of distribution of this type of product raises questions about customer service, namely how this technology is maintained once it has been purchased and installed by the end customer. Supply Chain Management (SCM) is responsible for these issues and is constantly challenged by the ever faster development of technologies and their ever increasing distribution. This makes it necessary to explore the possibilities for their improvement in terms of efficiency, speed, cost optimization and offering flexible solutions, as well as working out the weak points of the supply chain through optimization work. Technical service is not only software, but often also hardware - in the form of spare parts. The material flows required for warranty service must be available in warehouses close to the customer and delivered within a short time so that the product can be repaired on time. A delay in delivery or the unavailability of a spare part to repair the device would affect the business of the customers who consume the product and negatively impact the image of the company that manufactures the same product. The introduction of new products in the computer market is a topic of great interest. The introduction of new products in the computer market is a topic of great interest and of great importance for the social, cultural and economic development of society in the context of the dynamism and rapid development of technology and the urgency of artificial intelligence in the personal and professional life of each individual. The sale of this type of product to customers all over the world is associated with the challenge of being technically maintained within the warranty and post-warranty period, not only in terms of software, but also in terms of spare parts, which must be available near the customer and delivered within a short time so that the product can be repaired with minimal loss to the customer's business.

2 Literature review

LeMay et al. [1] collected current definitions of supply chain management into practical and analytical use. Many researchers defined the concept of "supply chain management" (SCM) as an integrated [2,3]. The "supply chain management" (SCM) concept is an integrated management of suppliers and customers. A supply chain is characterized by the network of actors, the relationships between them, and the processes and activities that take place in it. Vodenicharova [4] derives the understanding of SCM from the concept of SCM: "If one adopts the entire concept of supply chain, its participants represent all companies and organizations with which a company interacts directly or indirectly through its suppliers and customers, from the production of raw materials and flow or management of material flow to the time of consumption of the product. A number of researchers are conducting research in logistics [5-9] and supply chain [11,12] in various sectors of the economy, which shows the interest and importance of the topic.

In the derived definitions of the supply chain, there are some unclear elements of logistics that lead to a lack of consistent terminology and clarity about the SC that exists with regard to the production of a final product and the one that exists to ensure after-sales service for the final product. These two chains (forward and backward/production of the end product-customer service) do not always exist at the same time. The finished ICT product is produced and sold for a limited time (usually 2 years, as the technology

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becomes morally obsolete faster and faster), while the after-sales service for the already sold ICT product can last dozens of years after it has already been taken out of production and sale [14]. Effective logistics management supports companies in adapting to changing customer needs and gaining a competitive edge is emphasized by many authors. The article by Christopher and Holweg combines insights of supply chain management with the service to connect fundamental customer requirements [13].

Many researchers [15-17] describe that a well-configured spare parts supply chain (SC) can reduce costs and increase the competitiveness of spare parts retailers. This makes it necessary to consider the after-sales service supply chain as a separate SC, since the challenges it faces after the production of the final product is completed mainly concern the availability and quality of spare parts and all activities in the chain related to the storage and maintenance of obsolete spare parts or their procurement on the gray market. All these activities are part of SCM for spare parts, which deals with the after-sales service of ICT and is not explained in the definitions above. Customer service is extremely important, as is service during the conclusion and execution of the transaction. It creates security for the customer and the conviction that the company understands their needs and offers solutions to their problems. Many companies do not pay attention to the after-sales supply chain as they often suffer from understaffing and underinvestment in this area. However, after-sales services are an important source of revenue for industrial companies. The focus is primarily on the supply chain for manufacturing new products that are sold and have a direct impact on companies' financial performance, so the supply chain required to perform warranty servicing of the same products plays a secondary role in companies' business strategies. Traditional after-sales service and support models are still heavily dependent on human factors, as artificial intelligence is not yet as widespread and the after-sales service supply chain often does not receive enough attention and focus. According to Yao Li et al., companies need to invest heavily in their spare parts supply chain to achieve a high fulfilment rate and reliability [18]. Centralized production is the preferable supply chain configuration in the article Siavash et al. They research provides guidance for the development of additive manufacturing machines and their possible deployment in spare parts supply chains [19].

The importance and role of the supply chain in bringing new products to market should not be overlooked, as this would lead to unsuccessful product positioning combined with high costs, unsatisfied demand, unsatisfactory warranty service and ineffective after-sales service. This in turn would affect the company's competitiveness, regardless of how attractive and innovative the new product is with which it wants to compete in the market. In order to identify the place of the supply chain in the introduction of a new product, the main phases of the introduction of a product in the high technology sector are presented, namely: 1) planning; 2) concept development; 3) system design; 4) detailed design; 5) system testing and improvement; and 6) production. The position of the SC in each of these phases is shown in Figure 1.

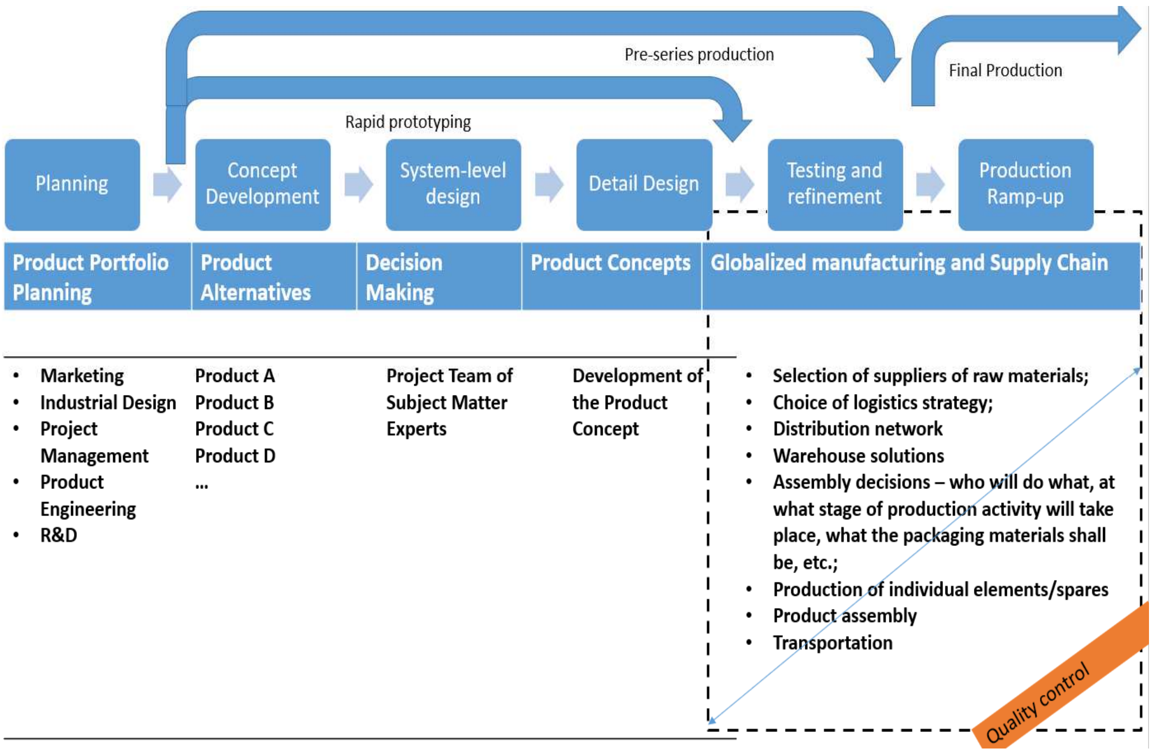

Figure 1 Sequence of activities within a company when introducing a new product to the market
Source: Adapted by [20]

The place of SC, which is visible in all phases of the process, begins in the planning phase, in which the decision is made as to which product the company will put into production. A prototype is then created. In this phase, the production/operations departments are involved and discussions are initiated with the suppliers of the raw materials, components, and services required for production. In the following phases of the process, and especially in the last two, just before the product is launched, decisions are made about outsourcing, the logistics sector and/or production, which is usually carried out in countries with low labor costs. Decisions on where to produce, which logistics strategy to follow, where to assemble and through which distribution channels to distribute finished products and spare parts for maintenance are also made as part of the process of launching a new product. Quality control is carried out at every stage of the logistics cycle and in every functional area: Procurement, Production, and Distribution.

In order to determine the role of the supply chain in the introduction of a new product, it is necessary to look at it from the perspective of its most important functional areas: Procurement, Production and Distribution and to what extent the new product is influenced by the decisions and activities of the SC in each of these areas. One of the main goals and tasks of procurement is to ensure an appropriate quality of material flow management. When introducing a new product and in the decision-making phase of the SC design area required to produce and service the final product, procurement plays a strategic role in the success of the company's new product introduction.

The quality characteristics are defined in the design of the end product or service that the company produces and markets. The design of products and services is carried out by a team of specialists from different areas, including logistics. The tasks and role of procurement experts in this product design process begin with product definition. For this purpose, innovative ideas are collected, some of which originate within the company itself, but some of which are also stimulated by the development of technologies and the needs of the market during product definition. Procurement is involved in providing information on new material and technology developments on the market and, to this end, holds discussions with suppliers, investigates suppliers' design and production capacities through direct visits, attends trade fairs and reviews publications in trade journals. This information can be useful for marketing and design specialists in their search for new product ideas. The ideas received are evaluated in terms of their technological feasibility, market opportunities and financing possibilities. The procurement specialists evaluate the components in terms of their cost-effectiveness, functional properties and market availability. The possibilities of in-house production or purchasing are analyzed for each component. Procurement plays a key role in this process as it provides information on the costs, quality and market availability of material flows and components.

The components and production technology are determined on the basis of the assessments carried out and by other experts. Quality standards in the form of specifications are developed for the most attractive alternatives (taking into account the technical restrictions). They provide the supplier with information about the characteristics of the products to be procured and form the starting point for the search for a suitable supplier and the preparation of delivery orders. In addition, the information contained in them is also necessary for the supplier, who uses it when executing the order in order to meet the customer's requirements. The specifications are used to compare the results of inspections, tests and quality controls of the products. Depending on how the quality characteristics of the materials are described, a distinction is made between two groups of specifications: detailed specifications and regulations/instructions. Detailed specifications can take the form of quality standards designed by the organization - technical drawings and specifications that specify the material and manufacturing method of the product. Instructions provide more general information about the quality characteristics of the product and may take the form of a verbal description of the product function, a brand or trademark, a quality certificate, samples, etc. [21-23].

When determining the quality and technical characteristics of product launches, it is important to consider the original flow of raw materials flow and its suppliers. The flow of materials and services requires strategic decisions such as "buy or make", as far as this is possible in the context of the new product to be developed and brought to market. Deciding who should supply the raw materials depends on factors such as location and delivery times. Quality control is a challenge, and in the event that the product contains unique components with specific technical characteristics that limit the list of possible suppliers, there is the issue of supplier dependency, transportation costs and regulatory requirements for importing the materials in question. At this early stage of launching a new product, it is important to seek the advice of procurement experts in order to make the most profitable decisions for the company.

Manufacturing costs are largely influenced by the complexity of the product to be manufactured and the ability to produce large quantities. The standardization of product components and their unification with the components used in the manufacture of the company's already marketed products reduces the likelihood that production lines will need to be reconfigured to accommodate a different manufacturing process required for the new product. Appropriate product design solutions would use standard manufacturing processes as a basis and shorten or postpone the differentiation and adaptation of production lines only with regard to the new product. The speed of manufacture, avoidance of reconfiguration of production lines, cost and reliance on proven production and control processes would be advantageous and require the opinion of production specialists with regard to the impact on the supply chain and the newly developed product. developed. Product design is an important factor in determining the degree of standardization during the manufacturing process [10]. According to Cantini et al. a structured method for configuring spare parts SCs should be used to determine whether to centralise or decentralise inventory management [15].

Distribution is the final phase of the logistics process. While the first phase is related to the procurement of the necessary material resources (supply) and the second to the control of processes within the company (production), the third phase (distribution) comprises the physical movement of products to the end customer and customer service. How distribution proceeds depends largely on the final outcome of the efforts of many participants in the previous phases of the logistics process. Good results are a prerequisite for increasing market share, achieving higher profits, and thus broader opportunities for product and technology innovation and, of course, for successful market positioning. A rationally organized distribution therefore promotes the partnership between suppliers, manufacturers, dealers, forwarders, and other companies involved in the supply chain and thus becomes a springboard for their success. Conversely, poorly organized distribution demotivates and discredits these companies and worsens their market position. The main objective of distribution is to minimize the cost of storing and delivering products - from manufacture to purchase, while achieving optimal customer service, i.e. delivering products when and where consumers want them, and at the time they would most like to buy them.

The customer's order triggers a series of actions aimed at meeting his requirements in terms of quantity, range, quality, price, delivery time and place of delivery. Distribution therefore begins with the receipt of the order, continues with its processing and compilation and ends with the transportation and delivery of the ordered products to the customer. These are generally the phases that make up the basic sales cycle. Distribution, which is considered the main functional area, consists of various elements, the most important of which are warehousing and transportation. These elements of logistics are considered in the context of making the right decisions for building an SC market when introducing a new product to the market. Most warehouses have standardized shelf sizes and store products on pallets. In the best case scenario, the packaging of the product allows for its optimal placement on a pallet, ensuring safety and stability and optimizing space in the warehouse. Due to their size, some products cannot be stored on a pallet or on pallets already set up in the warehouse, so they have to be stored in separate logistics elements and assembled immediately before delivery. This makes warehouse operations more expensive and leads to additional product handling. Wholesalers and retailers also have a hard time if the product characteristics are not standardized and require special storage and handling methods before the finished product is delivered. The service becomes more expensive, which affects the final price of the product. The dimensions of the product (volume and weight) are the basis for the price of the transportation service, regardless of whether it is rail, air, sea or road transport. Sometimes the products are small in volume but specific in terms of their characteristics. They determine the packaging and the type of transportation, which has a direct impact on transport costs.

3 Methodology

The data collection for the survey research is based on requests to customers who are computer users in one of the three companies examined in the case study. The inquiries to the customers were conducted with the help of the computer manufacturer of one of the companies that provides after-sales service for computer equipment that is not manufactured by the same company and is therefore suitable for the research in order to determine the existing level of after-sales service with spare parts and the ways to improve it. The data was collected through feedback from customers following a warranty failure that required a replacement part to repair the product. The terms and conditions of the after-sales service company's response to the warranty request, as specified in the customer contracts, show how well the company was able to meet the customer's expectations in a timely manner. The respondents are private and corporate customers who use computer equipment (servers) and have active customer service contracts.

The data collection to conduct the after-sales service supply chain performance survey was conducted from January 1, 2023 to January 1, 2024. The study covered 149,937 processed customer warranty claims from a computer manufacturer and showed the level of customer service over a one-year period. The feedback from 1572 respondents (private and corporate customers of the company) was taken into account in the analysis. The respondents are mainly private companies (small and large), schools, hospitals, universities, banks and others that use computer equipment for their business. The data tracks the fulfillment of all registered cases of warranty claims of the company's customers using computer equipment.

Aspects related to the supply chain activities for spare parts immediately after the launch of a new product (up to 6 months) of computer equipment from the point of view of ensuring after-sales service. The data reflect the level of after-sales service provided to 101 customers of new product category (NPI flag) computer equipment who made 1294 requests for warranty services requiring a replacement part. This data is analysed to identify weaknesses in the after-sales service supply chain for replacement parts immediately following the launch of the new product. (The data comes from the survey of 1,572 customers, but has been filtered by the NPI flag, i.e. only the 101 customers who consume products that were launched less than 6 months ago).

Analyze the reasons for unpunctual service during and immediately after the introduction of a new product (data collection through a survey). The following data is collected in order to investigate improvement opportunities in the spare parts supply chain during and immediately after the introduction of a new product and to suggest improvement opportunities that should be implemented in the initial phase of the introduction of a new product: The internal activities of the spare parts supply chain during the introduction of a new product are analyzed from the perspective of ensuring customer service. The data includes: the number of new products introduced in the computer category (116 new products) and the product tree for each product (or the spare parts required for customer service (839 spare parts)). The time periods in which each newly introduced spare part must be available in the computer manufacturers' warehouse network and ready for after-sales service are taken into account. This data is analyzed to identify weaknesses in the spare parts supply chain during the introduction of the new product that are the cause of delays in ensuring the availability of spare parts required for after-sales service in the warehouse network

- Stage 1: Assess the level of timely introduction of spare parts when introducing a new product (using a balanced scorecard);

- Stage 2: Identify the main reasons for the lack of spare parts during and immediately after (6 months) the introduction of a new product using a Pareto analysis and root cause analysis;

- Stage 3: Identify the weak points in the after-sales supply chain during the launch of a new product by identifying the reasons for missed deadlines in the implementation of after-sales service for new products due to the lack of a spare part.

4 Results and discussion

Activities in the spare parts supply chain immediately after (up to 6 months) the introduction of a new computer product from a customer service perspective. Data shows the level of customer service for 101 new product category (NPI flag) computer device customers who submitted 1294 requests for warranty service requiring a replacement part. This data is analyzed to identify weaknesses in the after-sales service supply chain immediately following the launch of the new product. Table 1 shows the number of computer hardware products (116) and the number of spare parts (839) introduced by computer hardware manufacturers during the reporting period. The data is broken down by quarter and includes information on the percentage of cases where a replacement part was made available in time for the new product to be serviced. This is to ensure that a spare part required to service the new product is available in the warehouse network at the time of initial sale. In general, new generations of computer products are sometimes sold to customers years before they are manufactured and launched. The date of expected first service of new products is known to the company 90 days before the product is sold and installed at the customer's site. In the data, this date is referred to by the abbreviation FSD and is the target/date by which the company must ensure the stock of spare parts. Within 90 days prior to the FSD, the supply chain staff must ensure that all spare parts of the product tree of the new product that are expected to be needed for after-sales service are available in the warehouse network.

Table 1 shows that 116 new products were introduced within one year and 839 spare parts were added to the after-sales network to support these products. The performance of the after-sales service supply chain for spare parts is measured at a global level. It is measured and presented by comparing the number of spare parts that are not guaranteed to be available on the FSD date with the total number of spare parts that need to be provided for service support for each of the new products. The data in Table 1 shows that performance was below target in three out of four quarters during this period. Consequently, the Company's target of having spare parts available at FSD was not met. Table 1 contains data on the introduction of new computer hardware products and their spare parts as well as performance metrics for the customer service supply chain, as described in the text.

Table 1 After-sales service supply chain of spare parts regarding the provision of stocks for the first service order

Quarter	Number of New Products Introduced	Number of Spare Parts Introduced	% Spare Parts Available at FSD	Performance vs. Target
Q1	29	205	88%	Below Target
Q2	30	210	91%	Below Target
Q3	28	200	89%	Below Target
Q4	29	224	95%	Met Target

Note: FSD (First Service Date) refers to the target date by which spare parts should be available in the warehouse network

Having established that the performance of the spare parts supply chain in customer service does not achieve its goal of providing a stock of spare parts for the first service order, the reasons for this are examined using a Pareto analysis. Figure 2 shows a Pareto chart of the main reasons why the spare part did not arrive at the IT company's central warehouses in time to secure the first service order. Three main categories of reasons stand out. The main reason, which accounts for 32% of all cases where a spare part did not arrive in time for the first service order, is the MOQ — the minimum order quantity required by the supplier-manufacturer of the spare part from the computer technology manufacturers. The weakness in this case is that when new products are introduced, the company requires minimum quantities (insufficient to meet the spare part manufacturer's MOQ conditions) from the supplier-manufacturer of a spare part to position them in the stock network in case a warranty claim occurs in the first six months after the new product is introduced. These minimum quantities ensure availability in the warehouse network and guarantee that the company has a spare part in the warehouse network in the event of a warranty claim. However, the supplier of this spare part is not always prepared to fulfill the request in the quantities required by the computer companies, as this can disrupt their production plans and processes. Example: computer manufacturers, when launching a new product, only want to have 3 cables (one in each central warehouse/region) in stock in sufficient quantities to ensure warranty failures in the first 6 months after the launch of the new product (as no failures are expected with the new technology), while the cable manufacturer requires a minimum order quantity of MOQ 100 pieces. For certain categories of spare parts, such as cables, it would not be possible to link the after-sales service supply chain order to the order placed by the supply chain for the manufacture of the final product with the same cable manufacturer, as the manufacture of the final product is at "chassis" level - the requirement is for the same manufacturer to pre-assemble the cables in the chassis required to manufacture a final product. However, maintenance is done at the cable level, not at the chassis level, and for this purpose the same component, but at a different level, is ordered separately from the same manufacturer. Negotiations are held between the PC companies and the spare parts manufacturers to reduce the minimum order quantity or to agree that the same component will be purchased by the PC companies within a certain period of time and not only when a new product is launched. These time-consuming negotiations are the main reason for the delay in ensuring the availability of spare parts in the PC manufacturers' warehouse network at the time of the first service order.

In second place is GBU late release (firmware) with 22% of all cases in which a spare part did not arrive in time for the first service order. The reason for this problem lies in the lack of synchronization between the supply chain that deals with the production of an end product and the one that deals with after-sales service. When a final product in the computer category is manufactured, the after-sales service waits to validate all technical aspects related to the correct functioning of the new product and all its components before giving the green light to the service activity. One of these technical checks relates to the system board or motherboard of the new server. Before customer service receives the order to take the system board into stock, production must ensure that it is working properly and that the latest version of the so-called firmware is installed. The production delay on the software side affects the chain and delays the readiness to add the hardware system board to the company's stock network as a spare part. The production delay is not taken into account when updating lead times and end dates for spare part availability. This poses a challenge for the after-sales supply chain, as it is directly dependent on production and its deadlines.

In third place is "delays due to the installation of a new supplier" with 20% of all cases in which a spare part did not arrive in time for the first service order. This cause of delay occurs when the company enters into a new contractual relationship with a supplier with whom it has no previous experience. In the dynamic world of information technology, the emergence of a new supplier and its rapid rise in the market is no longer as rare as it was in the past. Despite the company's desire to consolidate its suppliers and work exclusively with a few key suppliers, it sometimes needs to establish a new relationship with a supplier with whom it has not previously worked in order to bring a new competitive product to market. Establishing a new relationship with a supplier that offers better quality or better pricing terms for spare parts (or both) that the company needs to manufacture a new product is a time-consuming process. Negotiating price contracts, return options for defective parts and repair contracts takes time and causes delays in the introduction and positioning of these parts coming from the new supplier with whom the computer manufacturers are technically building new relationships.

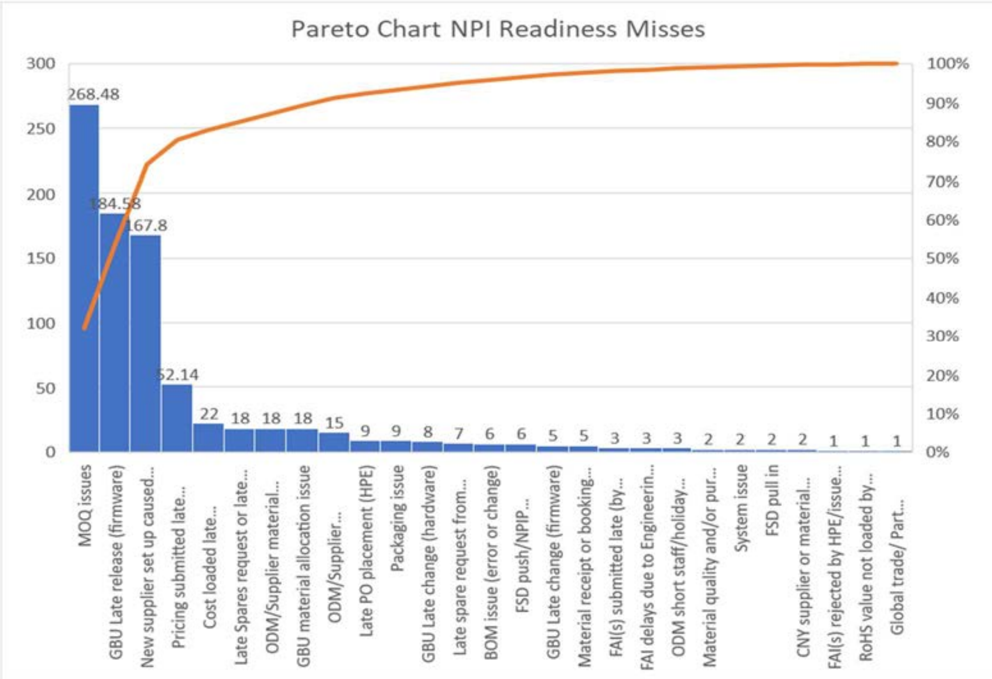

Figure 2 Pareto analysis of the causes of missed deadlines for providing spare parts on time, for servicing new products

In order to identify the main weaknesses of the after-sales service for spare parts when new products are launched, an analysis of the efficiency of the after-sales supply chain for spare parts is carried out immediately after the market launch (6 months) of a new product. The study focuses on the after-sales supply chain immediately after the new product has already been positioned with the customers (the service provided by the after-sales supply chain for spare parts of 101 customers was analysed) and the first (6 months after the product launch) warranty orders with spare parts have taken place (1294 requests). For the year under review (January 2023 to January 2024), Figure 3 shows that of all service orders (149,937), only 0.86% (1,294) concerned products that were placed on the market less than six months ago (NPI labeling).

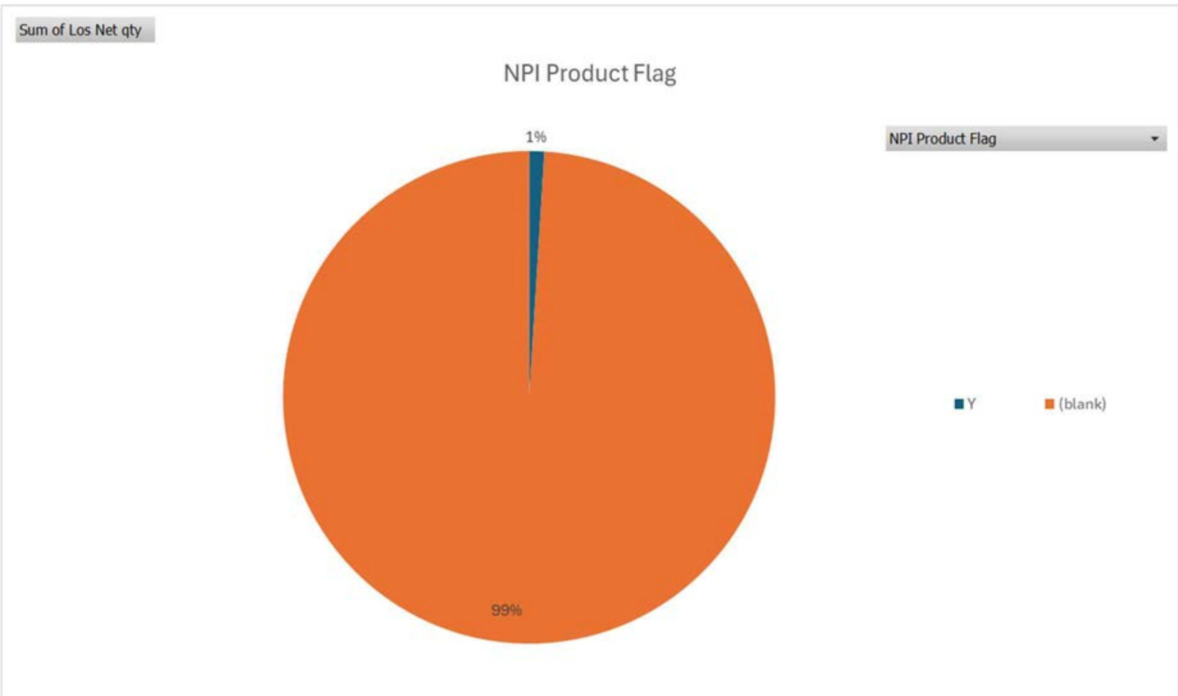

Figure 3 Number of serviced requests for after-sales service of customers who purchased new computing products

This percentage is to be expected as products sold to customers under warranty in the early stages of the life cycle are relatively rarely damaged and warranty claims increase with the degree of moral obsolescence of the equipment and, accordingly, with its operation. It is common practice for computer companies to technically test the performance of a product at the manufacturing facility before the product is installed at the customer's premises. It is expected that all possible tests and replacement of a spare part will have taken place before the product is installed in the customer's data center. It is assumed that no failures that would require the replacement of a spare part are to be expected in the first 6 months after installation.

Figure 4 shows the number of service requests received for new products that were responded to promptly and for which a replacement part was provided to fulfill the warranty. Figure 4 shows that in 94% of cases a replacement part was available and warranty services were provided on time, but in 6% of cases this was not the case. Considering the company's goal to provide a 100% spare parts service for new products, it is necessary to identify the reasons why the requested spare parts were not available at the time of the request.

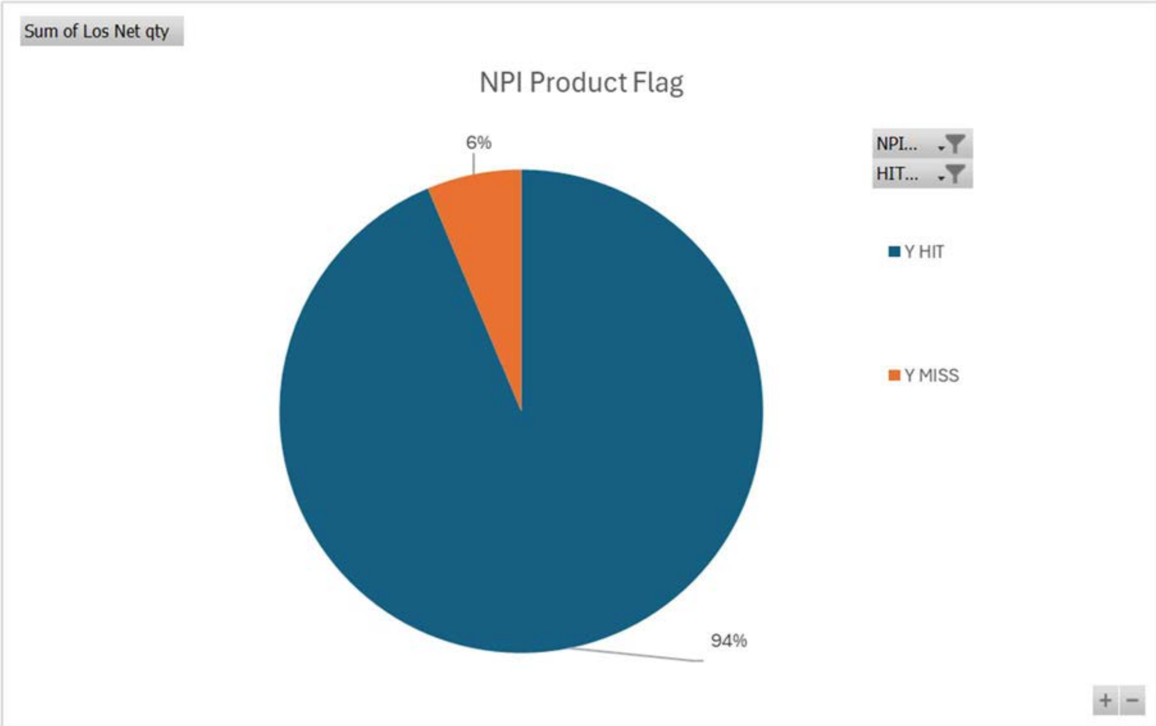

Figure 4 Level of after-sales service achieved with spare parts for new computing products (missed (MISS) / fulfilled on time (HIT) warranty claims)

Figure 5 shows the reasons for missed deadlines for the timely execution of a service order with a spare part for products launched less than 6 months ago. Figure 5. shows that the reason is the same for all requested spare part categories, namely a delivery delay ("Delivered too late"). This means that a spare part was available (usually in a central warehouse) but not close to the customer (it was not available in a regional company warehouse). It is a common practice for computer companies to keep a stock of spare parts needed for after-sales service in central warehouses at the beginning of the product life cycle. This practice serves to optimize inventory levels, optimize costs and later make the right decisions - in which regional warehouses, what types of parts and in what quantities to position them so that customers in the region can be served in a timely manner. Regarding the types of spare parts requested for the maintenance of products launched less than six months ago, Figure 5 shows that it is hard disks in 61% of cases, followed by network spare parts (switches and routers) in 31% of cases and in third place cables, adapters and chargers in 8% of cases.

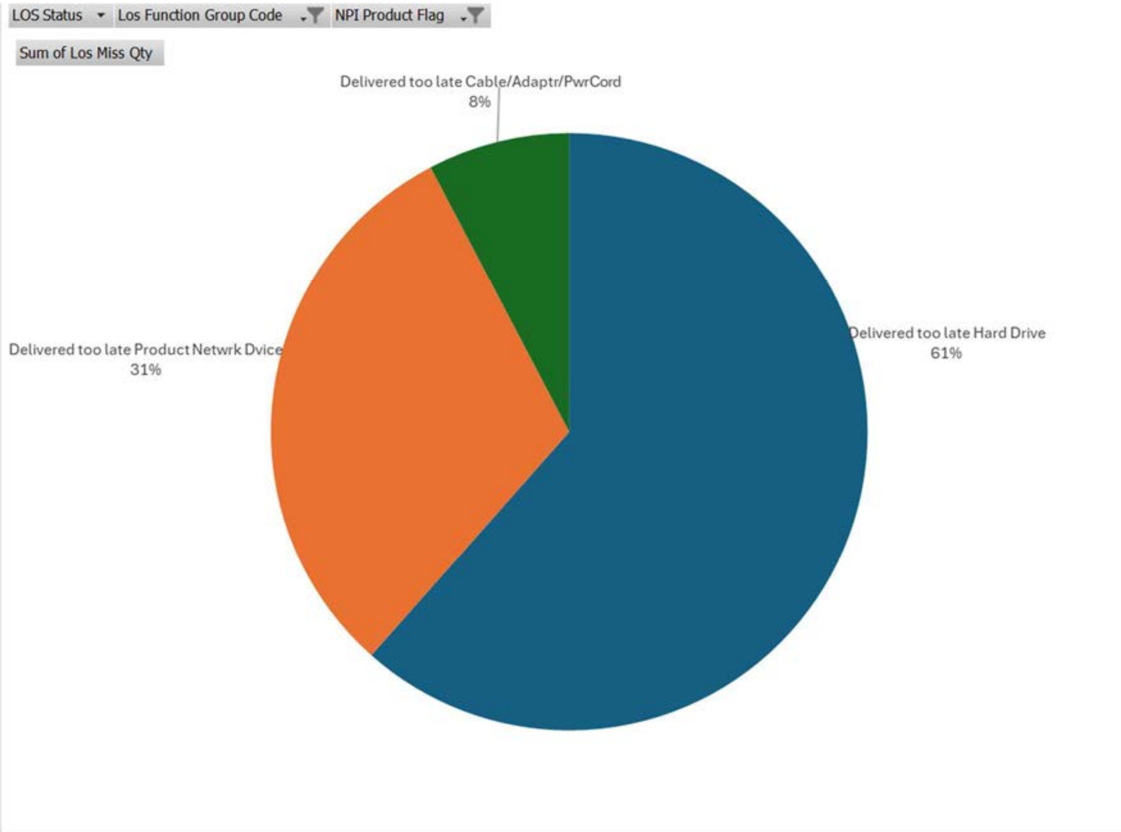

Figure 5 Reasons for missed deadlines for the implementation of after-sales service but new products due to the lack of a spare part

Due to uncertain demand and warranty failures, computer equipment manufacturers often take the risk of not stocking spare parts in regional warehouses for the first six months after product launch. Instead, they wait until demand has stabilized so that they can make better decisions about stocking in regional warehouses.

5 Conclusions

The analysis of the research data shows that computer companies work with several suppliers and manufacturers of spare parts. A large proportion of the spare parts used for the production and after-sales service of finished products are supplied by non-company manufacturers (third-party suppliers such as Intel or AMD (processors), Nvidia (graphics cards), Amphenol (special cables), Samsung, Kioxia, Seagate and others (hard disks), etc.). The problem that arises from this is the large number of suppliers and third-party providers that computer companies work with. This presents a challenge as there are not always uniform/centralized rules for managing relationships with each vendor, but a different approach is required due to the specific agreements with each vendor. This sets the stage for errors due to communication gaps or failure to recognize delivery delays in a timely manner, as well as opportunities for unfulfilled contracts, inaccuracies and difficult traceability and control of relationships with the various suppliers. The lack of centralized operating rules alone can lead to instability in the spare parts supply chain and present management with the challenge of managing all relationships with different suppliers in different ways (depending on the established requirements and the agreements made with each of them).

Some of the spare parts are produced by the computer manufacturer itself - these are spare parts that require special processing of the software part, which is combined with the hardware part to match the finished product (firmware, etc.). The problem that may arise with in-house production of spare parts is the maintenance of equipment and highly qualified personnel (engineers), which means additional costs for the computer company. One of the ways to improve the after-sales service supply chain for spare parts could be sought in cost rationalization in the area of spare parts production.

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