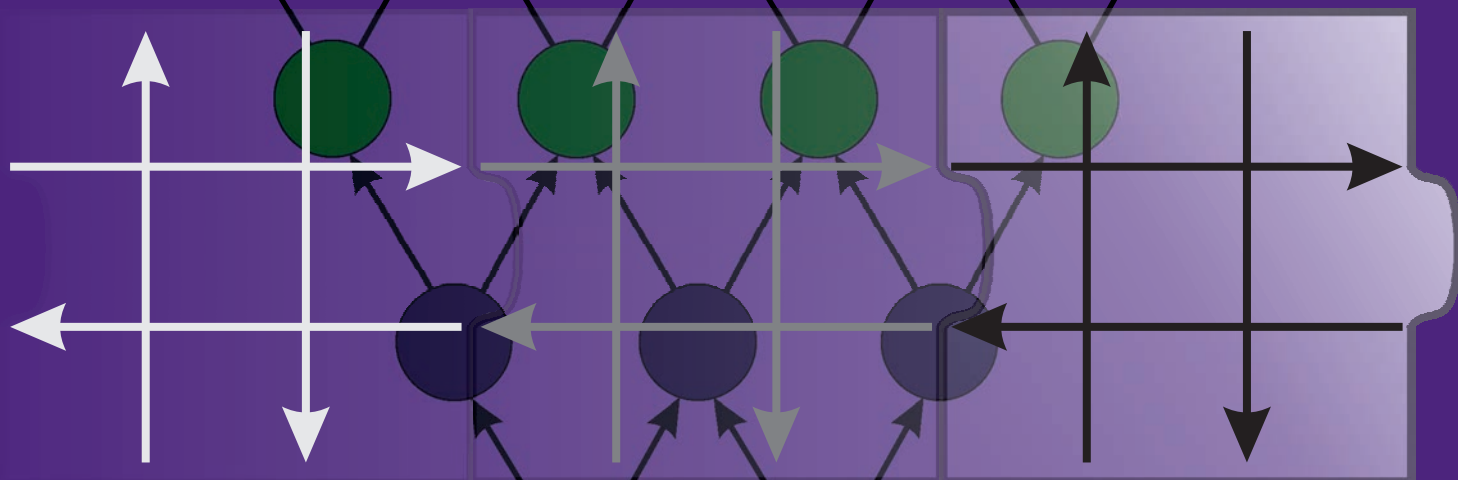


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A study of the connection between lean manufacturing and ergonomics

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Keywords: CERAA, key indicator method, REBA, value stream mapping.

Abstract: If an organization implements lean manufacturing without concurrently considering ergonomic requirements, the anticipated outcome, such as increased production productivity, may not be realized. Several authors have emphasized the significant potential for synergies resulting from the successful integration of lean manufacturing and ergonomics. The objective of this paper is to exemplify the application of lean manufacturing tools in enhancing the productivity of casting aluminium alloys while incorporating ergonomic considerations. The results of the assessment of working positions through the CERAA application before intervention indicate a potential risk of increased physical strain on operator. Utilizing a hybrid research design, we conducted a singular case study that delves into the industrial implementation of a robotic cell in the production line for manufacturing battery covers for electric/hybrid vehicles. The results of the assessment of working positions after the implementation of robotic technology do not indicate a potential risk of increased physical load on the operator. This case study demonstrates the integration of ergonomics and lean manufacturing principles in practice.

1 Introduction

The findings of numerous research studies [1-3] indicate that the implementation of lean manufacturing significantly amplifies the perceived workload among employees. One contributing factor is the elimination of non-value-adding activities in the work process, as part of efforts to reduce waste. This elimination can result in heightened constraints associated with task execution, coupled with a reduction in workload variability. Consequently, the outcome often involves monotonous work characterized by repetitive manual tasks, a prevalence of identical work assignments, or labour at a forced pace with limited breaks and rest opportunities. Such conditions not only adversely impact work performance but also detrimentally affect the health of individuals engaged in the work process.

It becomes evident that implementing lean manufacturing in an organization without simultaneous consideration of ergonomic requirements may thwart the expected outcome of increased production productivity. While lean manufacturing and ergonomics may appear initially to have conflicting objectives, this is not entirely

accurate. Consider the shared goal of eliminating one fundamental type of waste: unnecessary movements. Unnecessary movements contribute to increased employee fatigue, potentially leading to diminished product quality and prolonged production times. Consequently, initiatives that contribute to reducing unnecessary movements can be viewed as mutually beneficial from both lean production and ergonomics perspectives.

2 Literature review

Various authors underscore the substantial potential for synergies resulting from the successful integration of lean manufacturing and ergonomics in this context. Nunes [4] proposed a methodological framework for integrating Lean Six Sigma (LSS) and ergonomics. Alsaffar and Ketan [5] proposed a diagnostic expert system in the form of a software tool that was developed in the Visual Basic 6 environment. The software tool is based on the idea of combining methods aimed at identifying and reducing lost time and ergonomic risks related to the biomechanical and postural requirements of work activities. Brito et al. [6] highlighted the possibility of reducing machine retyping time while improving working conditions from an

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ergonomics perspective. The case study was carried out in a tap manufacturing plant where a high rate of absenteeism and complaints from employees related to excessive strain on the limbs was noted. By applying the SMED (acronym for term Single Minute Exchange of Die) method, the retyping time was reduced by 46 percent and at the same time the risk of damage to the support and locomotion system was reduced to an acceptable level through the REBA (acronym for term Rapid Entire Body Assessment) method. Jarebrant et al. [7] extended the traditional lean manufacturing VSM (acronym for term Value Stream Mapping) tool to include an ergonomic dimension, resulting in the new ErgoVSM tool. The ErgoVSM tool is based on visualization and dialogue to support the process from mapping the current state to the creation of a future state value stream, including a list of actions needed to achieve it. The ergonomic assessment considers the following areas: working postures, muscle strength, variability of physical load and resting ability. Arce et al. [8] further extended the ErgoVSM method to assess mental workload. The assessment of mental workload is carried out through the subjective response of the employee using the NASA TLX method. Botti et al. [1] developed a linear mathematical model that can be used to determine the optimal placement of manual and automated jobs in a hybrid assembly line. The optimization criteria are based on the reduction of work-in-process quantity and total cost, taking into account at the same time, in the case of manual jobs, the risk of health damage due to high-frequency repetitive activities in manual handling through the OCRA (acronym for term Occupational Repetitive Actions) evaluation method. Oliveira et al. [9] demonstrated the synergistic effect of lean manufacturing and ergonomics through the example of material flow optimization in order to increase labour productivity and improve working conditions. By modifying the original logistics processes, they were able to reduce by 94 percent the walking distance that operators have to cover in order to secure the necessary material between the warehouse and the workplace. Yusuff and Abdullah [10] conducted an ergonomic analysis based on observation and evaluation of non-value adding work movements. They used movement time studies, a standardized Nordic questionnaire, and the RULA method (an acronym for term Rapid Upper Limb Assessment) in their evaluation. Based on the results of the analysis, ergonomic interventions were designed to eliminate or reduce unnecessary movements as much as possible. The results of the study confirmed that an inappropriate combination of work positions and work movements not only increases the risk of cumulative trauma disorder, but also decreases the productivity and efficiency of the employee. Colim et al. [11] analyzed the synergism of integrating lean manufacturing principles and ergonomics through the implementation of a collaborative robotic assembly workstation. The evaluation of the workplace before and after the implementation of the robotic technology was carried out by determining various key

performance indicators using a time study and direct observation. The subjects of the ergonomic analysis were 40 work positions during assembly operations. Three methods were used to evaluate the workstations: the RULA, the RSI (acronym for term Revised Strain Index) and the KIM (acronym for term Key Indicator Method). In addition, operators' attitudes towards the introduction of the robot in the assembly workplace were investigated by means of questionnaires. The aforementioned multi-method approach demonstrated that the implementation of a collaborative robotic assembly workstation achieved: a reduction in production times, an improvement in working conditions and an increase in personal well-being at work from the operators' point of view. Pekarcikova et al. [12] and Spirkova et al. [13] focused on the application of simulation tools in creation of the casting process model and simulation of technological operations on the workplace of casting processing. They optimized the workplace layout in terms of ergonomics by using the virtual reality system or Tecnomatix Jack software module and Microsoft Kinect.

Aim of the paper is to demonstrate the use of lean manufacturing tools in increasing the productivity of casting aluminum alloys while taking into account ergonomic requirements.

3 Methods of ergonomic assessment

Similarly, as Colim et al. [11] we adopted a hybrid research design and conducted a single case study. This case study explores an industrial implementation of a robotic cell in production line for the production of battery covers for electric/hybrid vehicles, integrating ergonomics and lean manufacturing principles. We assessed the workplace before and after the implementation of robotic technology and measured different indicators through a time study and direct observation. Originally, the operator manually transferred the castings from the transport basket to the storage basket for heat treatment (Figure 1). Subsequently, after heat treatment and cooling of the castings, operator again manually handled them from the storage basket to the transport basket. After intervention, operator just lifts the castings from the transport basket to the conveyor and the robot arm then places the castings in the storage basket.

Value stream mapping method was used to identify non-value tasks. Basket load/unload task was considered as non-value adding task but necessary so this task cannot be eliminated, just reduced as much as possible.

Ergonomic assessment was performed using following methods:

- CERAA (acronym for Ceit Ergonomic Analysis Application) module Evaluation of working postures and dimensional requirements and module Assessment of manual handling,

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• Key Indicator Method for assessing physical workloads with respect to manual lifting, holding and carrying of loads (KIM-LHC),

• Rapid Entire Body Assessment (REBA).

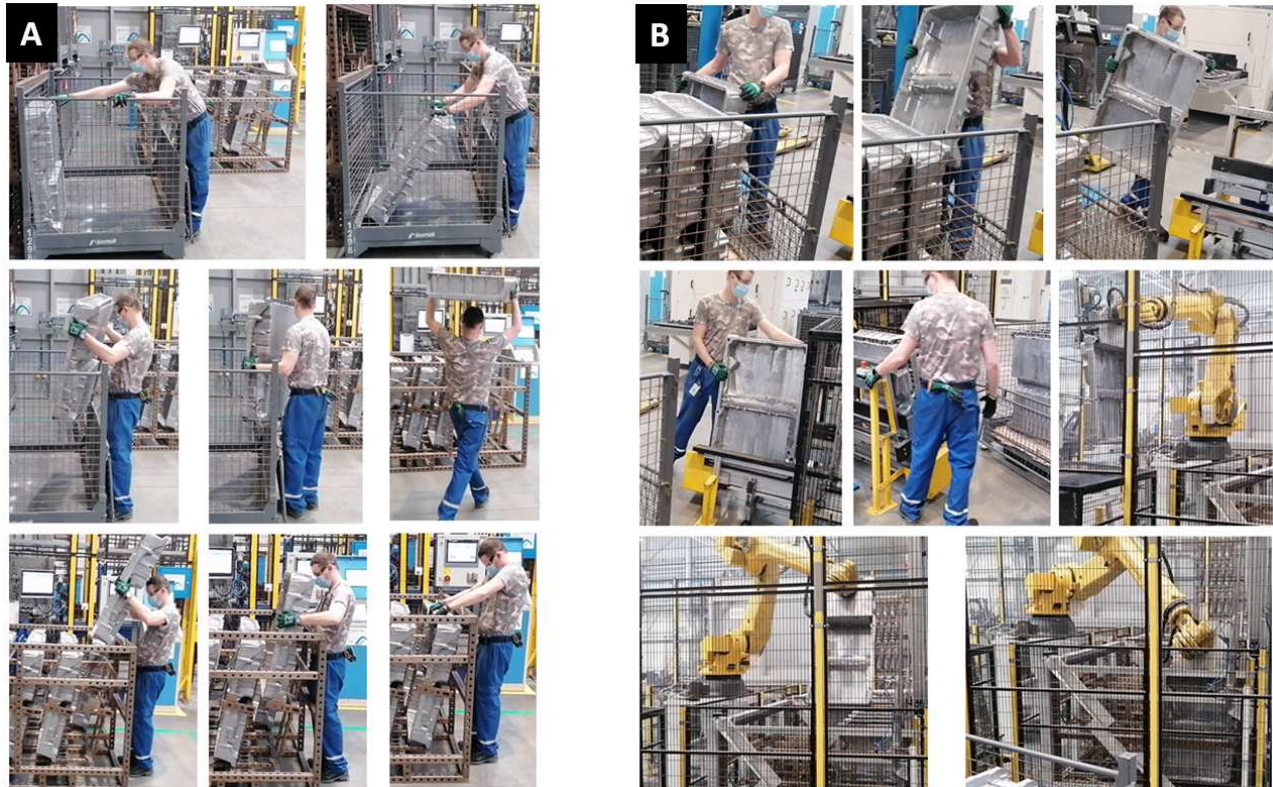


Figure 1 Manual handling of castings: A – before intervention, B – after intervention [14]

4 Results and discussion

Comparison of the workplace before and after the implementation of robotic technology is presented in Table 1.

Table 1 Comparison of the workplace before and after the implementation of robotic technology

Indicator	Before intervention	After intervention
Production lead time	3618 seconds	3587 seconds
Number of operators	2	1
KIM-LHC score Physical loads	101.5 points High intensity of load	49 points Intensity of load is slightly increased
REBA score Task – casting carrying	8 points High risk	4 points Medium risk
Task – placing the cast in the basket	8 points High risk	- -
CERAA Working postures Maximal full shift weight of the load	Limit exceeded Limit exceeded	Limit not exceeded Limit not exceeded

The results of the assessment of working positions through the CERAA application before intervention indicate a potential risk of increased physical strain on operator (Figure 2). During the evaluation of the trunk

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forward bend, it was found that the cumulative duration of the unacceptable working position (trunk forward bend $> 60^\circ$) for the entire shift is 11.44 minutes.



Figure 2 Working postures evaluation in CERA before intervention [14]

During the head tilt assessment, it was found that the cumulative duration of the unacceptable working position (head tilt $> 40^\circ$) for the entire shift is 29.33 minutes. During the evaluation of upper limb flexion, it was found that the cumulative duration of an unacceptable working position (limb flexion $> 60^\circ$) for the entire shift is 24.5 minutes. The total working time in the work shift in individual unacceptable work positions thus exceeds the permitted 30 minutes. When evaluating the maximum full shift weight of the load, it was found that the indicative weight value is

observed only in the case of operators in the age category of 18 to 29 years. In the remaining age categories, the maximum full shift weight is exceeded by 8.4% (30-39 years), by 30% (40-49 years), and by 56% (50-60 years).

The results of the assessment of working positions after the implementation of robotic technology do not indicate a potential risk of increased physical load on the operator. During the evaluation of the trunk forward bend, it was found that the cumulative duration of the unacceptable working position (trunk forward bend $> 60^\circ$) for the entire

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shift is 2.86 minutes. When evaluating head rotation, it was found that the cumulative duration of an unacceptable working position (head tilt $> 15^\circ$) for the entire shift is 18.33 minutes. During the assessment of upper limb flexion, it was found that the cumulative duration of an unacceptable working position (upper limb flexion $> 60^\circ$) for the entire shift is 7.33 minutes. Thus, the total time of work in a work shift in individual unacceptable work positions does not exceed the permitted 30 minutes. During the evaluation of the trunk forward bend, it was found that the cumulative duration of the conditionally acceptable working position (trunk forward bend: 40° - 60°) for the entire shift is 2.2 minutes. When evaluating head tilt, it was found that the cumulative duration of a conditionally acceptable working position (head tilt: 25° - 40°) for the entire shift is 11 minutes. During the assessment of upper limb flexion, it was found that the cumulative duration of a conditionally acceptable working position (upper limb flexion: 40° - 60°) for the entire shift is 14.67 minutes. The total working time in a work shift in individual conditionally acceptable work positions does not exceed the permitted 160 minutes.

5 Conclusions

The findings of this study clearly demonstrate that integrating robotic technology into production processes can significantly reduce the physical workload and ergonomic risks for workers while simultaneously enhancing productivity and operational efficiency. Specifically, the implementation of a robotic cell for handling castings led to a marked reduction in the time workers spent in ergonomically risky positions, as evidenced by improved scores in assessments like KIM-LHC (from 101,5 to 49 points) and REBA (from 8 to 4 points) [15-20]. Following the intervention, the intensity of physical load was reduced, and work postures that previously exceeded recommended limits were brought into acceptable ranges. Thus, the total time of work in a work shift in individual unacceptable work positions does not exceed the permitted 30 minutes and the total working time in a work shift in individual conditionally acceptable work positions does not exceed the permitted 160 minutes. The reduction in time spent handling castings manually and the minimization of monotonous manual tasks not only improved working conditions but also boosted overall productivity.

An important aspect of this study is the confirmation of the synergistic effect of integrating lean manufacturing and ergonomics. Lean manufacturing, which emphasizes eliminating unnecessary movements and waste, need not conflict with ergonomic principles; rather, it can complement them effectively. By removing non-value-adding tasks and optimizing working conditions, both worker well-being and production quality can be improved, with shorter production times as a result.

This study highlights that incorporating ergonomic requirements when implementing lean manufacturing is essential for achieving comprehensive improvements in both performance and employee satisfaction. By doing so, companies can avoid unintended negative impacts on workers' health while supporting long-term sustainability and competitiveness in production processes.

The integration of robotic technologies with an emphasis on ergonomics presents a crucial approach to modernizing production lines, particularly in the context of increasing productivity and improving working conditions. This approach is essential not only for improving operational efficiency but also for safeguarding the health and well-being of employees.

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References

- [1] BOTTI, L., MORA, C., REGATTIERI, A.: Integrating ergonomics and lean manufacturing principles in a hybrid assembly line, *Computers & Industrial Engineering*, Vol. 111, pp. 481-491, 2017. <https://doi.org/10.1016/j.cie.2017.05.011>
- [2] AREZES, P.M., DINIS-CARVALHO, J., ALVES, A.C.: Workplace Ergonomics in Lean Environments: A literature review, *Work*, Vol. 52, pp. 57-70, 2015. <https://doi.org/10.3233/wor-141941>
- [3] SAURIN, T.A., FERREIRA, C.F.: The Impacts of Lean Production on Working Conditions: A Case Study of a Harvester Assembly Line in Brazil, *International Journal of Industrial Ergonomics*, Vol. 39, No. 2, pp. 403-412, 2009. <https://doi.org/10.1016/j.ergon.2008.08.003>
- [4] NUNES, I.L.: Integration of Ergonomics and Lean Six Sigma: A model proposal, *Procedia Manufacturing*, Vol. 3, pp. 890-897, 2015. <https://doi.org/10.1016/j.promfg.2015.07.124>
- [5] ALSAFFAR, I., KETAN, H.: *Integration of Lean Six Sigma and Ergonomics: A Proposed Model Combining Mura Waste and RULA Tool to Examine Assembly Workstations*, In: IOP Conference Series: Materials

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- Science and Engineering, 2nd International Conference on Engineering Sciences 26-27 March 2018, Kerbala, Iraq, Vol. 433, pp. 1-13, 2018.
<https://doi.org/10.1088/1757-899X/433/1/012061>
- [6] BRITO, M., RAMOS, A.L., CARNEIRO, P., GONCALVES, M.A.: Combined SMED methodology and ergonomics for reduction of setup in turning production area, *Procedia Manufacturing*, Vol. 13, pp. 1112-1119, 2017.
<https://doi.org/10.1016/j.promfg.2017.09.172>
- [7] JAREBRANT, C., WINKEL, J., HANSE, J.J., MATHIASSEN, S.E., ÖJMERTZ, B.: ErgoVSM: A Tool for Integrating Value Stream Mapping and Ergonomics in Manufacturing, *Human Factors and Ergonomics in Manufacturing & Service Industries*, Vol. 26, No. 2, pp. 191-204, 2016.
<https://doi.org/10.1002/hfm.20622>
- [8] ARCE, A., ROMERO-DESSENS, L.F., LEON-DUARTE, J.A.: *Ergonomic Value Stream Mapping: A novel Approach to Reduce Subjective Mental Workload*, In: Goossens, R. (eds) *Advances in Social & Occupational Ergonomics*, AHFE 2017, *Advances in Intelligent Systems and Computing*, Vol. 605, Springer, Cham., pp. 307-317, 2018.
https://doi.org/10.1007/978-3-319-60828-0_31
- [9] OLIVEIRA, B., ALVES, A.C., CARNEIRO, P., FERREIRA, A.C.M.: Lean Production and Ergonomics: a synergy to improve productivity and working conditions, *International Journal of Occupational and Environmental Safety*, Vol. 2, No. 2, pp. 1-11, 2018.
https://doi.org/10.24840/2184-0954_002.002_0001
- [10] YUSUFF, R.M., ABDULLAH, N.S.: *Ergonomics as Lean Manufacturing Tool for Improvements in a Manufacturing Company*, In: *Proceedings of the International Conference on Industrial Engineering and Operations Management 2016*, pp. 581-588, 2016.
- [11] COLIM, A., MORGADO, R., CARNEIRO, P., COSTA, N., FARIA, C., SOUSA, N. ROCHA, L.A., AREZES, P.: Lean Manufacturing and Ergonomics Integration: Defining Productivity and Wellbeing Indicators in a Human-Robot Workstation, *Sustainability*, Vol. 13, 1931, pp. 1-21, 2021.
<https://doi.org/10.3390/su13041931>
- [12] PEKARCIKOVA, M., TREBUNA, P., KLIMENT, M.: *Application of simulation tools in the process of casting and processing of aluminium castings*, In: *Proceedings from 28th International Conference on Metallurgy and Materials, METAL 2019*, Ostrava: Tanger Ltd, pp. 1974-1982, 2019.
<https://doi.org/10.37904/metal.2019.995>
- [13] SPIRKOVA, S., STRAKA, M., SANIUK, A.: VR Simulation and Implementation of Robotics: A Tool for Streamlining and Optimization, *Applied Sciences*, Vol. 14, No. 11, 4434, pp. 1-21, 2024.
<https://doi.org/10.3390/app14114434>
- [14] SUSTER, M.: *Application of lean manufacturing tools in increasing the productivity of aluminium alloy casting*, Diploma thesis, Technical University in Zvolen, Zvolen, 2021.
- [15] GRZNAR, P., GREGOR, M., KRAJCOVIC, M., MOZOL, S., SCHICKERLE, M., VAVRIK, V., DURICA, L., MARSCHALL, M., BIELIK, T.: Modeling and Simulation of Processes in a Factory of the Future, *Applied Sciences*, Vol. 10, No. 13, 4503, pp. 1-24, 2020. <https://doi.org/10.3390/app10134503>
- [16] STRAKA, M., HRICKO, M.: Software system design for solution of effective material layout for the needs of production and logistics, *Wireless Networks*, Vol. 28, No. 2, pp. 873-882, 2022.
<https://doi.org/10.1007/s11276-020-02267-6>
- [17] SPIRKOVA, S.: Modelling as a tool of making the company's logistics more efficient, *Acta logistica*, Vol. 9, No. 4, pp. 433-440, 2022.
<http://doi.org/10.22306/al.v9i4.341>
- [18] VILAMOVI, S., BESTA, P., KOZEL, R., JANOVSKA, K., PIECHA, M., LEVIT, A., STRAKA, M., SANDA, M.: Quality quantification model of basic raw materials, *Metallurgija*, Vol. 55, No. 3, pp. 375-378, 2016.
- [19] SIVASANKARAN, P.: Review on PCB assembly line balancing – glance, *Acta Technologia*, Vol. 9, No. 2, pp. 59-71, 2023.
<http://doi.org/10.22306/atec.v9i2.171>
- [20] GUBÁN, M., KOVÁCS, G., KOT, S.: Simulation of complex logistical service processes, *Management and Production Engineering Review*, Vol. 8, No. 2, pp. 19-29, 2017.
<https://doi.org/10.1515/mper-2017-001>

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Optimization of the current logistics network with a focus on a specific company in the state of Nuevo Leon, Mexico

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Keywords: logistics network, consolidation, warehouse location problem (WLP), optimization, forecast.

Abstract: One of the key strategic decisions to make as an enterprise is the optimization of the current logistics network. The main parameters to be considered are the location and amount of storage facilities, as well as cost, the availability and proper function of existing infrastructure and targeted market expansion milestones. The scope of this paper deals with a construction Company in the state of Nuevo León, Mexico. Nearshoring has been one of the main driving factors of increased population growth in the region. Urban expansion is becoming increasingly complex and decentralized, complicating the flow of materials in material distribution networks. Each allotment is presently developed with a warehouse, which in turn requires an investment in infrastructure, overhead, security and management. This paper aims to establish an optimized supply network through consolidated storage facilities without compromising the reliability of the existing routes. The chosen modelling method is optimization through mixed-integer programming. The main object of study in this paper is the comparison between the existing cost structure and the projected costs that would result from consolidating storage facilities and transportation. The results of the analysis are presented, having executed a successful application of the model, and display a 20.9% decrease in cost associated to operating the logistics in a ten-year forecast for a construction Company.

1 Introduction

Enterprises today have multiple challenges to overcome in the field of logistics. Many aspects of this problem have been successfully understood; transportation, flow materials, inventory and warehouse analysis, through the implementation of digital techniques for collecting and interpreting data that streamline the decision-making process. Logistics poses an interesting challenge in the field of construction, with specific issues that must be resolved. Housing development is a steady state process with increasing complexity and a decentralized nature, which is one of the reasons why consolidating warehouse locations and means of transportation is not usually considered. Having a warehouse that's dedicated to each individual work site allows for the timely delivery of construction materials.

Positioning is important for enterprises in Nuevo León as it perceives approximately 72% of the nearshoring that occurs in Mexico. The automotive and electronics industries concentrate 43% of their presence in Northeastern Mexico. These conditions will create an

increasing need for housing in strategic zones, intensifying the rate of urban development in the area.

Recent events like the COVID-19 Pandemic and the onset of Nearshoring have triggered a series of strategic logistic countermeasures in Nuevo León. This paper aims to ascertain the viability of a consolidation scheme for warehouse locations through a new design of the existing distributions network in such a way that costs, reliance on inventory and warehouse locations is reduces and operating flexibility is increased.

Picking a location and storage capacity for a warehouse is an exercise that requires looking at many different factors, location, average traffic/transit times, shipping loads, availability of transportation and overhead are good examples. A poor choice in warehouse location and/or capacity can very well be the cause for additional expenses and delays in the operating schedule.

The problem at hand deals with choosing a correct logistic structure that allows for an uninterrupted transition in the operating schedule while reducing storage overhead. This process is navigated through the use of cutting-edge techniques that aim to create insight for decision makers in the effort of continued expansion. Some of the key aspects

of this analysis involve forecasting capacities that aim to determine the optimum location for development, with additional analysis dedicated towards acquisition processes.

The desire for a predictive model with increased accuracy is natural and to be expected. Making correct forecasts regarding promising locations and increasing logistic viability are at the forefront of the main objectives in this endeavour. Consolidation of the existing warehouse structure should agree with an overall reduction in operating expenses, increased security measures and custom-made protocols for prefabricated materials. These considerations have an important consequence in storage facility design; warehouse performance must be increased through a streamlined floor plan that allows for on-schedule operation and correct planning for inventory capacity, personnel and delivery vehicles.

This paper reviews a real-world case for the WLP (Warehouse Location Problem). The Optimization model is based on Khairuddin's 2017 paper and showcases a construction Company primarily occupied with residential development in the metropolitan area of Nuevo León, Mexico. The work that follows is structured as indicated; A literature review of the sources cited is conducted, the optimization model is explained in detail, a solution and the subsequent analysis is presented before coming to some general concluding remarks.

2 Literature review

The problem of finding the correct storage capacity and location for warehouses so that costs are optimized without compromising service-rates and fulfilment of orders headed towards different destinations plays a crucial role in determining the profitability of a logistics system. (Weber, 1909) Alfred Weber pioneered the solution to the WLP through a model that allows the user to locate a point in a two-dimensional coordinate system that minimizes the sum of costs towards delivery destinations [1].

Aided by Weber's contributions, Hakimi (1960) formulated extensions of the simpler problems and developed the p-median algorithm, allowing a user to locate the ideal location for a warehouse as a function of distinct delivery points, usually cities or customers, through an objective function that minimizes commute times, distances and cost of transportation [2].

The Simple Plant Location Problem was defined in tasks, Straka (2019), Galli and Letchford (2021) and is based on a system that takes customer location, provider location and miscellaneous points of interest as inputs. The model aims to minimize the transportation costs between nodes along the logistics network, as well as the cost related to construction. Another feature in the model is that it allows for the opening of an additional location, in the event that such a solution achieves a minimization of the parameters described earlier in this paragraph. This model is based on linear programming and has benchmarked

progress in many models that are currently in use today [3,4].

The Capacitated Warehouse Location Problem (UWLP) was developed by Khumawala in 1972 and uses combinatorial algorithms, which makes it a robust tool in the WLP and also popular in unrelated fields such as genetic algorithms [5].

Wang (2013) proposed the Two Stage Capacitated Warehouse Location Problem, which further classifies storage facilities as either primary or secondary. Like other methods here described, its primary task is that of minimizing distribution and delivery costs [6].

Hansen (1994) builds on the work of Perl and Daskin (1985) and introduces the restrictions of variable and fixed costs, as well as transportation cost, in the optimization algorithm [7].

Hidaka and Okano (1997) solved the UWLP for cases where the model is allowed to exhibit divergent behaviour in a specific parameter (storage capacity in this particular case) [8].

In 2001, Kratika proposed a solution to the SPLP through the methodology of genetic algorithms. His model allows the user to solve for systems where up to 1000 customer locations/delivery points are used. By 2004 (Laurent Michel) had developed a solution to the UWLP that incorporated a tabu-search algorithm in the optimization protocol. Efforts to increase the solving capacity of these methods continued with Bhatti (2007) and others, with an implementation of the method that allows for decision makers to input large numbers as parameters through integer-binary programming and a heuristic algorithm [9-12].

El Karim (2020) developed methods for incorporating GIS' (Geographical Information Systems) into the data collection capacities of the algorithm. They further increased the accuracy with which decision-makers can obtain insights into logistics and operation and represented increased progress in the objective of optimizing operating and distribution costs [13].

Given the complex, multi-faceted nature of the quantitative and qualitative analysis of warehouse location, Choquet's Integral has been chosen as a mathematical tool fit for the task of an accurate model that incorporates uncertainty and error. Demirel (2010) uses this method and determines that the main criteria are costs, characteristics of the workforce, infrastructure and the state of the market. Some secondary criteria also mentioned are fiscal incentives, tax structures, access to workforce personnel and the quality and availability of transport [14].

Khairuddin (2017) proposed a simulated annealing process that solves the WLP through a mixed-integer programming solution. The main contribution of this analysis is introducing a restriction that accurately models storage capacity for each warehouse [15].

Adasme (2018) further classified the existence of restrictions to the problem based on topological figures such as the ring, tree and star. Novel methods in mixed-

integer programming and the P-Median problem are also discussed [16].

A comparative method that uses K-Median algorithms and mixed-integer linear programming optimization was published by Meng You (2019) further advancing the capacity of WLP models to incorporate large datasets as inputs. MILP was shown to be more accurate than K-Median based algorithms through a series of partial dynamic optimizations [17].

Doungpan (2020) used the MILP approach to shed light on the Location Setcovering Problem (LSCP), providing solutions that detail storage facility arrays as a function of growing demand in a complex environment [18].

Yachba, Belayachi and Bouamrane (2022) uses an artificial bee hive (ABC) method to optimize the locations for distribution centres that supply customers with a given product. The method is named after observed behaviour of bees as a communal structure [19].

Haoxiang, Yangcheng and Zhenyi (2024) proposed a linear programming model based on the simulated annealing algorithm to address cargo volume allocation following the closure of logistics sites. Additionally, a logistics network optimization model was developed using the particle swarm optimization algorithm to dynamically adjust the structure of the logistics network [20].

Rahman et al. (2025) employed a hybrid approach to optimize the location of logistics centres, sequentially applying different techniques. The process began with a

clustering method using K-Means based on spatial locations, followed by the application of the P-Median method to determine the final placement of the centres of interest. This latter method also incorporates factors such as the number of deliveries and population density as weighting criteria [21].

3 Methodology

This analysis is broken up into three phases: Acquiring and processing raw datasets detailing the recent trends in urban development and population growth from INEGI, so that a forecast can be made as to which areas can show the most promise for future development. Secondly, the processed data is used to conduct a MILP analysis and determine locations and capacities for storage facilities. Lastly our solution and proposed logistics network is compared to the existing network, with commentary and general conclusions.

3.1 Forecast method

Estimating a rate for the expansion of housing can be obtained through the analysis of multiple factors that are readily available from INEGI datasets. Information related to industrial development and population per locality is procured and a forecast is then obtained through regression models, which can then be compared to historical datasets to check for accuracy.

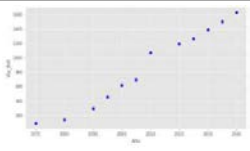
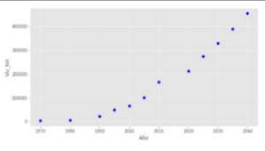
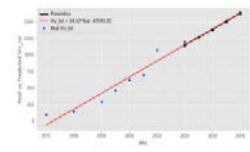
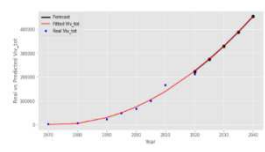
Locality	Linear Regression	Polynomial Regression
	Abasolo	Apodaca
Scatter Plot		
Forecast for number of housing units every five years		
Model Accuracy	$R^2 = 0.9739829908390727$ $MAPE = 24.50100234190121$ $RMSE = 84.1743496863782$	$R^2 = 0.9962462795737199$ $MAPE = 14.11309226558786$ $RMSE = 9246.449698696257$

Figure 1 Forecast for increasing trend in housing for the localities of Abasolo and Apodaca through linear and polynomial regression, years 2020, 2025, 2030, 2035 and 2040

Figure 1 displays results for the forecasting method. The accuracy for the regression model is also displayed for two localities, allowing for a rigorous treatment of data.

The model allows decision makers to understand how the rate of increase for housing units has behaved for

different localities according to its main driving factors like Nearshoring. Figure 2 displays scatter plots for the increment in housing units in the last 50 years for each locality.

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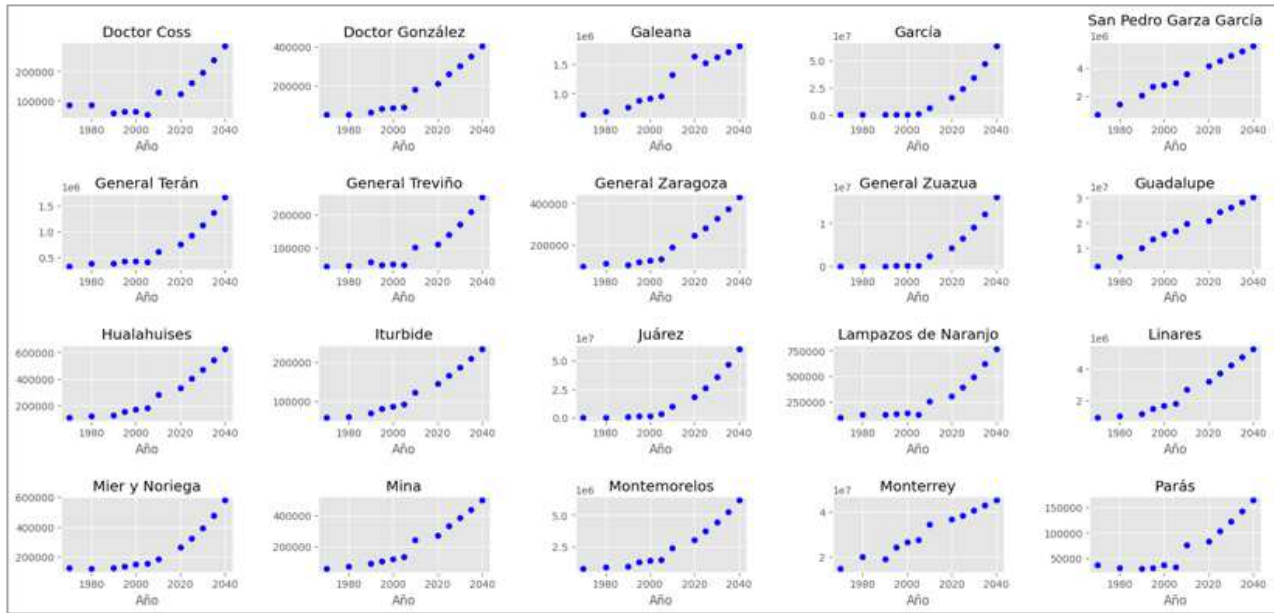


Figure 2 Scatter plots for growth in housing units per locality in the State of Nuevo Leon, 1970-2040

3.2 Location model

Once the viability of future locations is ascertained, raw data can be input into a model to display how the logistic structure in the distributions network will be affected by parameters such as geographical location, amount of housing units, the typology and models for each project.

Glossary and notation:

k : denotes the k th customer; $k = \{1, 2, 3, \dots, K\}$

i : denotes the i th warehouse and/or potential location for a warehouse; $i \in A$

$A = E \cup N$; $(j, i) \in (E \times A)$ where:

- E = set of existing warehouses in each locality
- N = set of locations for future developments under the consolidation scheme

Model Parameters:

$$Z_{ji} = \begin{cases} 1, & \text{If the } j\text{th storage capacity } (j \in E) \text{ is relocated to the } i\text{th site } (i \in A, i \neq j), \text{ or if the } j\text{th existing warehouse } (i \in E, i = j) \text{ remains operational} \\ 0, & \text{Otherwise} \end{cases}$$

Target Function:

$$\begin{aligned} \text{Min } & \sum_{i \in A} \sum_{k \in C(i)} S_{ik} X_{ik} + \sum_{i \in A} r_{ji} Z_{ji} + \sum_{i \in A} f_i^c + \sum_{j \in A} c_j Z_{ji} + \sum_{i \in E} f_i^m Z_{ii} \\ & + \sum_{i \in N} f_i^m W_i - \sum_{j \in E} \left[f_j^s \left(1 - \sum_{i \in A} Z_{jk} \right) + f_i^m \sum_{\{i \in E, i \neq j\}} Z_{ji} \right] \end{aligned} \quad (1)$$

Constraints:

$$\sum_{k \in C(i)} X_{ik} \leq \sum_{j \in E} c_j X_{ji} \quad \forall i \in A \quad (2)$$

S_{ik} : Unitary cost for storage in the i th warehouse and transportation between the i th warehouse and the k th client

r_{ji} : Cost of relocating unitary storage capacity j to consolidated storage facility i ($j \neq i$)

c_j : Storage capacity of j th existing warehouse

d_k : Demand associated to k th customer

f_i^c : Cost per storage capacity unit of the i th warehouse

f_i^m : Fixed overhead cost related to the i th warehouse, excludes costs related to storage capacity

f_i^s : Cost reduction associated to the shutdown of the i th warehouse

Main Variables (Decision Variables):

X_{ik} : Volume of shipped materiel from the i th warehouse to the k th customer

$$\sum_{i \in D(k)} X_{ik} = d_k \quad \forall k \in K \quad (3)$$

$$\sum_{j \in E} Z_{ji} \leq |E| Z_{ii} \quad \forall i \in E \quad (4)$$

$$\sum_{j \in E} Z_{ji} \leq |E| W_i \quad \forall i \in N \quad (5)$$

$$\sum_{i \in A} Z_{ji} \leq 1 \quad \forall j \in E \quad (6)$$

$$X_{ik} \geq 0 \quad \forall i \in A, k \in K \quad (7)$$

$$Z_{ji}, W_i \in \{0,1\} \quad \forall j \in E, i \in A \quad (8)$$

The target function (1) minimizes the combined costs of transportation, relocation and storage, maximizing the amount of savings associated to the closing or consolidation of existing warehouses. Restriction (2) ensures that shipping capacity won't exceed the maximum storage capacity of the warehouse or consolidated storage location servicing a particular order. Restriction (3) satisfies demand according to progress at specific job sites. Restriction (4) states that upon the consolidation of two or more warehouses, at least one must remain operational so that the combined storage capacity can be considered. Restriction (5) states that the current storage capacity of a particular location can't be transported elsewhere without the prior construction of a new warehouse. Restriction (6) considers several scenarios for an existing warehouse j , these include: warehouse j remains open, warehouse j will be consolidated into another existing warehouse, warehouse j 's storage capacity will be relocated to a new site or warehouse j is closed. Restriction (7) is a condition of non-negativity for the variables of interest and Restriction (8) forces them to take values of 1's and 0's.

4 Scope of analysis

The scope of this paper focuses on the improvement of the existing structure for a logistics network belonging to an Enterprise in the residential construction business through the implementation of consolidated storage facilities that can service materiel according to progress and availability of a predetermined expansion scheme. This particular case study happens in the metropolitan area of Monterrey, located in the state of Nuevo Leon, Mexico (Figure 3).

The state is made up of 51 localities and covers a superficial area of 64,156.2 square kilometres (about 3.3% of the surface area for Mexico). Population density is 90.2 inhabitants per square kilometre, there are 1,655,256 inhabited dwelling units (4.7% of the gross national total). Each dwelling unit has an average occupation of 3.5

occupants and 99% of them are equipped with basic sanitation facilities and access to power (INEGI, 2020).

According to INEGI datasets, as of 2020, Nuevo Leon is ranked 7th in a national consensus of gross population. From 2000 to 2020, population has increased by 50.8% with a 13.1% rate between 2015 and 2020. Nuevo Leon's current population is 5,784,442, with an annual growth of 133,000 inhabitants expected. Considering these circumstances, the growth can be identified as exponential and it's subsequent impact has been a driving factor for increasing demand for residential housing units, public services, roadways and transportation (INEGI, 2020).

4.1 Data acquisition

4.1.1 Identifying territories

The forecast model allows decision makers to identify and make predictions in regard to the urban blot in the state of Nuevo Leon. It's important to note that between 85.5 and 86.2% of the increase in housing units for the state will occur within Monterrey and the greater Metropolitan Area over the course of the next twenty years. Localities like Garcia and Juárez, however, will host a considerable majority of the newly developed housing units, outmatching other localities like Monterrey, Apodaca, Guadalupe and Escobedo. Figure 4 displays the forecast for the number of housing units in the localities of Monterrey's Metropolitan Area.

The accuracy in the results offered by this forecasting model is acceptable. The model can only take inputs produced from the INEGI datasets, which have been further shown to contribute to the trending growth in housing in the state. Additional factors, such as commercial infrastructure, healthcare services, transportation, education, recreation and general zoning restrictions could have an impact on the growth rate related to urban development but are not included in the forecasting model due to a lack of available datasets.

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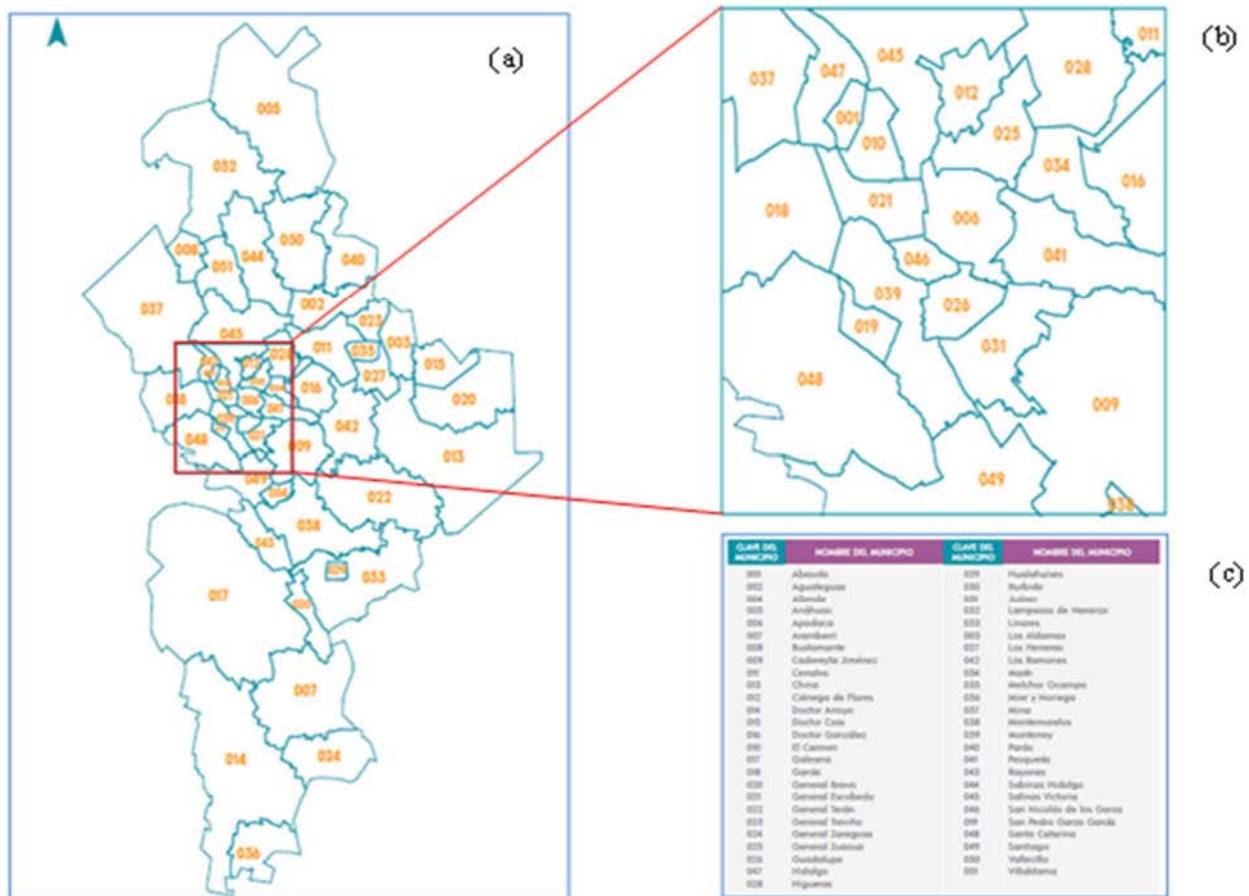


Figure 3 Area of interest: a) Map of Nuevo Leon localities by administrative jurisdictions, b) Monterrey and greater Metropolitan Area, c) key and nomenclature for all 51 localities

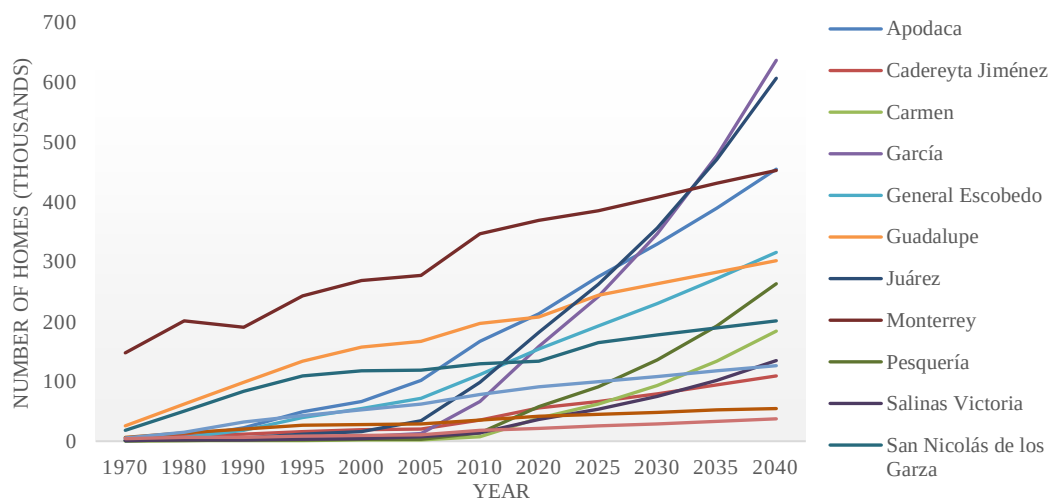


Figure 4 Scatterplot forecast of the increase in housing units in Monterrey's Metropolitan Area

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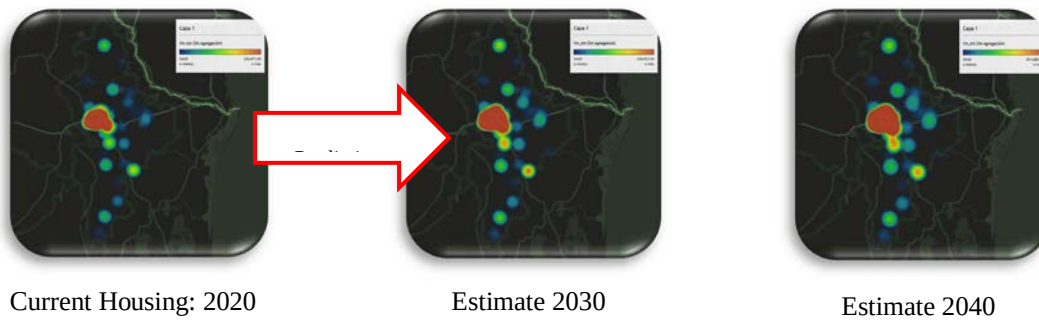


Figure 5 Forecast of the increase in housing developments through linear and polynomial regression, years 2030, 2040, State of Nuevo Leon, Mexico

Using the previously discussed findings and considering our variables of interest/parameters, a complete forecast for the years 2025, 2030, 2035 and 2040 was produced. Figure 5 displays the expansion and increasing demand for land reserves.

4.1.2 Construction masterplan

Forecasting and territorial acquisition immediately has a scaling effect on the master development plan. To begin, a housing unit typology is chosen for construction in each area of interest. Two main types of housing units are considered in this study, low and medium interest housing units. Unrelated to interest rates associated to mortgage loans or other financial instruments, Low and medium interest housing units are associated to housing that's made available for sections of the population with low and

medium income, respectively. An average low interest housing unit spans between 42 to 76 square meters in floor area, while a medium interest housing unit is usually 150 to 220 square meters.

There are over 80 different architectural design models in the Company archives. Each locality is equipped with approximately six different designs in the construction masterplan. A materiel inventory and construction scheduled is procured for each different design. Each of the available designs requires at least 260 unique inventory pieces during the construction process. Construction times are variable and depend on lot size, chosen model and typology. Low interest housing units take between 54 and 72 days to build with medium interest rate housing units taking between 120 and 180 days to complete.

Table 1 Planning schedule for construction per locality (2021-2030) for social interest housing units in Monterrey's Metropolitan Area

Municipality	Cluster	Division	Year									
			2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Juárez-Cadereyta	Affordable housing	Palmanova C y D			243	355	372					
Juárez-Cadereyta	Affordable housing	Villa Palmanova (Ochoa)	92	270	78	361	481	686	750	750	750	750
Juárez-Cadereyta	Affordable housing	Villa Palmanova I3			114	79						
Juárez-Cadereyta	Affordable housing	Porto Alegre Norte			241	299						
Juárez-Cadereyta	Affordable housing	Porto Alegre Sur				79	599					
Juárez-Cadereyta	Affordable housing	Valle de Oporto 2 Sector					120	160				
Juárez-Cadereyta	Affordable housing	Cydsa					300	600	650	650	700	750
García	Affordable housing	Portales de Lincoln Sur	485	558	546	162						
García	Affordable housing	Portales de Lincoln Norte				478	689	700	800	690		
Apodaca	Affordable housing	Rincon de las Fuentes			259	314	318	131				
Pesquería	Affordable housing	Haciendas Sector Frances	274	613	655	649	262					
Pesquería	Affordable housing	Las Haciendas 2					299	700	300			
Zona norte	Affordable housing	Pilares Sector Aurora		56	924	296	400					
Zona norte	Affordable housing	Pilares Sector Aurora 2				402	465	661				
Escobedo	Affordable housing	SMP Solana		444			490	528				
Escobedo	Affordable housing	SMP San Manuel 3					222	250				
Escobedo	Affordable housing	Ladera de San Gabriel						200	300	450	500	454
Escobedo	Affordable housing	San Emilio					342	400	500	600	700	
Juárez-Cadereyta	Affordable housing	Valle Real 2						200	300			

Tables 1 and 2 display the estimated planning as far as 2030. As time passes, new localities are considered and incorporated into the forecast depending on the sales

performance of each available lot. The plan is iterated in tri-annual periods and is modified according to each cycle's performance.

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Table 2 Planning schedule for construction per locality (2021-2030) for medium interest housing units in Monterrey's Metropolitan Area

Municipality	Cluster	Division	Year									
			2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Guadalupe	Mid-range housing	Fontana	77	105	140	151						
Apodaca	Mid-range housing	Puerta jardin		54	134	85	169	300	300	300	300	350
Apodaca	Mid-range housing	Arbado marquesa				80	80					
Apodaca	Mid-range housing	Arbados vi					60	120	140	100		
Apodaca	Mid-range housing	Albero (romero)				80	80	120				
Monterrey	Mid-range housing	PH Linces 2	46	86	89	18						
Monterrey	Mid-range housing	PH Linces 3				70						
García	Mid-range housing	Alcazar				75	75	60	70	70	80	
García	Mid-range housing	Alcazar 2					75	100	100	110	82	
García	Mid-range housing	Arborea (Montenova 2)		155	155	39						
García	Mid-range housing	Altrysa 2			78	154	170	17				
García	Mid-range housing	Azara				94						
García	Mid-range housing	Adara		117	40	161	117	170				
García	Mid-range housing	Parque Zafiro		100	196	47						
García	Mid-range housing	Padre Mier					38	38	38	38		
Santiago	Mid-range housing	Santiago (Linos)		43	44	58	79	70	62			

This study considers a construction plan that spans the years 2023-2030. Forecasted demand is considered from 2024 onward. Opening times were calculated for new job sites and the corresponding servicing needs in the materiel

stage from a consolidated storage facility. Existing job sites or job sites that are currently equipped with storage facilities are considered for selection in servicing multiple job sites across the network in future operation.

Table 3 Amount of forecasted social interest housing units per locality, active job sites or planning phase/concluding phase for site completion

Municipality	Cluster	Division	Active work or planned	Demand 2024-2030	Time remaining until closure (years)
Juárez-Cadereyta	Affordable housing	Palmanova C y D	Active	727	2
Juárez-Cadereyta	Affordable housing	Villa Palmanova (Ochoa)	Active	4528	7
Juárez-Cadereyta	Affordable housing	Villa Palmanova l3	Active	79	1
Juárez-Cadereyta	Affordable housing	Porto Alegre Norte	Active	299	1
Juárez-Cadereyta	Affordable housing	Porto Alegre Sur	Active	678	2
Juárez-Cadereyta	Affordable housing	Valle de Oporto 2 Sector	Planned	280	2
Juárez-Cadereyta	Affordable housing	Cydsa	Planned	3650	6
García	Affordable housing	Portales de Lincoln Sur	Active	162	1
García	Affordable housing	Portales de Lincoln Norte	Active	3357	5
Apodaca	Affordable housing	Rincon de las Fuentes	Active	763	3
Pesquería	Affordable housing	Haciendas Sector Frances	Active	911	2
Pesquería	Affordable housing	Las Haciendas 2	Planned	1299	3
Zona norte	Affordable housing	Pilares Sector Aurora	Active	696	2
Zona norte	Affordable housing	Pilares Sector Aurora 2	Active	1528	3
Escobedo	Affordable housing	SMP Solana	Planned	1018	2
Escobedo	Affordable housing	SMP San Manuel 3	Planned	472	2
Escobedo	Affordable housing	Ladera de San Gabriel	Planned	1904	5
Escobedo	Affordable housing	San Emilio	Planned	2542	5
Juárez-Cadereyta	Affordable housing	Valle Real 2	Planned	500	2

Tables 3 and 4 display locality, housing unit model/typology, residential development nomenclature,

job site status, amount of lots to be developed and time remaining for job completion.

Table 4 Amount of forecasted medium interest housing units per locality, active job sites or planning phase/concluding phase for site completion

Municipality	Cluster	Division	Active work or planned	Demand 2024-2030	Time remaining until closure (years)
Guadalupe	Mid-range housing	Fontana	Active	151	1
Apodaca	Mid-range housing	Puerta jardin	Active	1804	6
Apodaca	Mid-range housing	Arbado marquesa	Active	160	2
Apodaca	Mid-range housing	Arbados vi	Planned	420	4
Apodaca	Mid-range housing	Albero (romero)	Active	280	3
Monterrey	Mid-range housing	PH Linces 2	Active	18	1
Monterrey	Mid-range housing	PH Linces 3	Active	70	1
García	Mid-range housing	Alcazar	Active	430	6
García	Mid-range housing	Alcazar 2	Planned	467	5
García	Mid-range housing	Arborea (Montenova 2)	Active	39	1
García	Mid-range housing	Altrysa 2	Active	341	3
García	Mid-range housing	Azara	Active	94	1
García	Mid-range housing	Adara	Active	448	3
García	Mid-range housing	Parque Zafiro	Active	47	1
García	Mid-range housing	Padre Mier	Planned	152	4
Santiago	Mid-range housing	Santiago (Linos)	Active	269	4

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4.1.3 Material demand

Materiel quantities per day and week, displayed in Figure 6, are calculated for each locality using the construction masterplan and the job site staging classification.

Performance associated to the distribution networks is essential for adherence to operating schedules and resource exploitation. This paper partly intends to demonstrate that decentralizing storage facilities from the Metropolitan

Area and the main construction hubs in Nuevo Leon would not compromise service rates and performance of the distribution networks. No transportation logistics are included in this study beyond a general recommendation in equipment and routing for materiel delivery. The model provides basic information through the parametrization of factors that provide insight into delivery times and transportation costs.

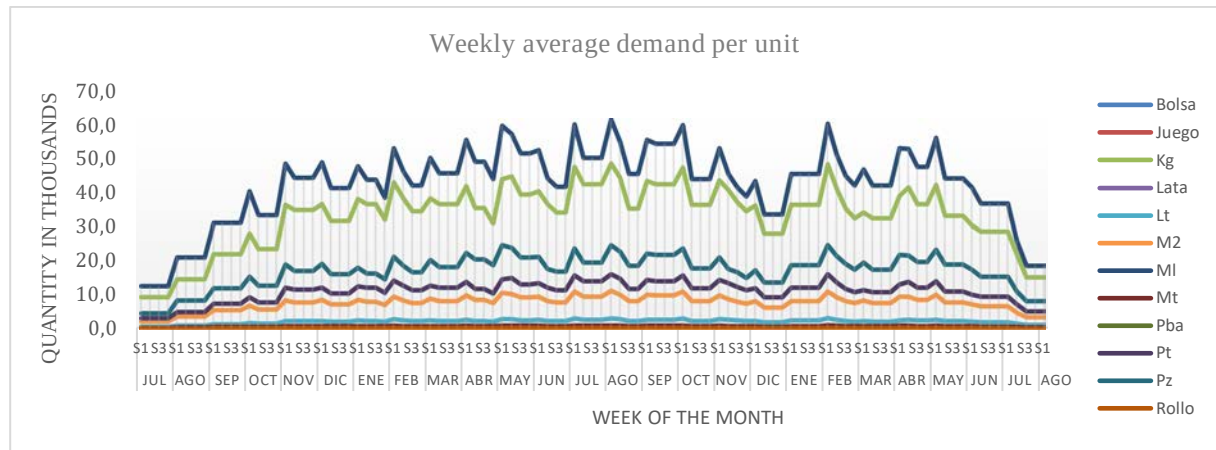


Figure 6 Average demand analysis for a period of two years

4.1.4 Distribution network data

Costs related to infrastructural development were procured from recent and historical datasets, management, security, utilities, inventory, losses and transportation costs were also obtained. Using the construction masterplan and

assuming that new storage facilities are continually implemented and maintained for each locality, the cost analysis forecast calculates \$146,575,03MXN as gross operating overhead. A breakdown of this figure is provided in Table 5.

Table 5 Opening and maintenance costs for warehouses in the construction masterplan (2030)

Concepts	Year								
	2022	2023	2024	2025	2026	2027	2028	2029	2030
Warehouses	12	16	24	24	21	13	10	7	4
Infrastructure	\$969,618	\$820,050	\$844,350	\$854,541	\$875,651	\$982,046	\$931,606	\$813,578	\$901,815
Wages	\$5,114,571	\$6,819,429	\$10,229,143	\$10,229,143	\$8,950,500	\$5,540,786	\$4,262,143	\$2,983,500	\$1,704,857
Security	\$6,387,660	\$8,516,880	\$12,775,320	\$12,775,320	\$11,178,405	\$6,919,965	\$5,323,050	\$3,726,135	\$2,129,220
Uniforms	\$182,081	\$242,775	\$364,162	\$364,162	\$318,642	\$197,254	\$151,734	\$106,214	\$60,694
Services	\$846,092	\$1,128,123	\$1,692,184	\$1,692,184	\$1,480,661	\$916,600	\$705,077	\$493,554	\$282,031
Material loss	\$461,700	\$1,044,600	\$285,800						
Transportation	\$390,960	\$521,280	\$781,920	\$781,920	\$684,180	\$423,540	\$325,800	\$228,060	\$130,320
Total	\$13,961,722	\$18,571,856	\$26,190,959	\$25,915,350	\$22,803,859	\$14,556,651	\$11,373,610	\$8,122,981	\$5,078,616

4.1.5 Costs

Distances between existing and planned points of interest was calculated so as to be fed into our optimization model.

Table 6 Distance measured in kilometres between points of interest in the 30-year forecast

Division	Code	Frente_1	Frente_2	Frente_3	Frente_4	Frente_5	Frente_6	Frente_7	Frente_8	Frente_9	Frente_10	...
Fontana	Frente_1	0.00	14.32	11.25	11.16	11.64	25.00	25.07	29.57	31.60	27.55	...
Puerta Jardin	Frente_2	14.32	0.00	9.97	10.55	10.13	30.43	30.52	34.21	36.31	31.60	...
Arbado Marquesa	Frente_3	11.25	9.97	0.00	0.60	0.41	20.48	20.57	24.37	26.48	21.81	...
Arbados VI	Frente_4	11.16	10.55	0.60	0.00	0.68	19.92	20.01	23.84	25.95	21.29	...
Albero (Romero)	Frente_5	11.64	10.13	0.41	0.68	0.00	20.30	20.39	24.15	26.26	21.58	...
PH Linces 2	Frente_6	25.00	30.43	20.48	19.92	20.30	0.00	0.09	4.63	6.61	3.50	...
Ph Linces 3	Frente_7	25.07	30.52	20.57	20.01	20.39	0.09	0.00	4.56	6.53	3.48	...
Alcazar	Frente_8	29.57	34.21	24.37	23.84	24.15	4.63	4.56	0.00	2.12	2.73	...
Alcazar 2	Frente_9	31.60	36.31	26.48	25.95	26.26	6.61	6.53	2.12	0.00	4.74	...
Arborea (2)	Frente_10	27.55	31.60	21.81	21.29	21.58	3.50	3.48	2.73	4.74	0.00	...
...	...	...	...	...	...	...	...	...	...	...	...	0.00

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Delivery times were estimated for different times of the day in order to determine average commute times. Using this method, delivery schedules can be organized with delivery times between origin and destination nodes calculated also.

Delivery times for suppliers are included in the model absent calculation. A supposition that 100% of providers will complete their schedules deliveries is made and confirmed to agree with the circumstances of this particular case. Through the consolidation scheme, and with fewer storage facilities, providers can count on maintaining the shipping volume required by the company while reducing the overall amount of transportation requirements associated to the operation.

5 Results and discussion

Table 7 displays the aggregate results obtained when implementing the proposed model to the problem of redesigning a logistics network using the construction

masterplan as a main reference. Each scenario allows the user to determine warehouse location and the corresponding serviced localities. The model was developed using the LINGO software (version 20.0.23). Run-time for each iteration of the solution averaged 48 seconds and utilized 366Kb in the memory disk.

If the trend of equipping each locality with an individual storage facility continues up to 2030, the company would have to undergo \$146,575,603MXN in costs. The most cost-effective scenario produced by the model involves keeping 4 storage facilities active until 2030, with the following distributions: Puerta Jardín 17%, Villa Palmanova 36%, Portales Lincoln Norte 21% and Ladera San Gabriel 26%.

Equilibrium solutions are achieved through the minimization of costs related to infrastructure, security, personnel and utilities. Improvements in inventory control have resulted in the reduction of lost and wasted materiel. Costs such as the acquisition of load bearing vehicles are also intended for optimization within this framework.

Table 7 Model output comparing overall costs for each scenario

Scenario	Number of Warehouses	Locality	Assigned Sectors	Total Cost
1	35	Warehouse by project	1	\$146,575,603
2	2	CYDSA y San Manuel3	16 y 19	\$128,472,274
3	3	Albero, Villa Palmanova y Laderas San Gabriel	12, 9 y 14	\$119,058,469
4	4	Puerta Jardín, Villa Palmanova, Portales Lincoln Norte Y Ladera San Gabriel	6, 9, 6 y 14	\$115,808,734
5	5	Puerta Jardín, Villa Palmanova, Portales Lincoln Norte, Pilaes Sector Aurora2 y Ladera San Gabriel	5, 7, 5, 4 y 14	\$126,312,893

Figure 7 displays the different modelled scenarios and their respective total cost. The most cost-effective scenario involves continuing operations for only 4 storage facilities; Puerta Jardín, Villa Palmanova, Portales Lincoln Norte are

existing facilities and Ladera de San Gabriel will be developed ahead of the construction schedule allotted for the modelled period.

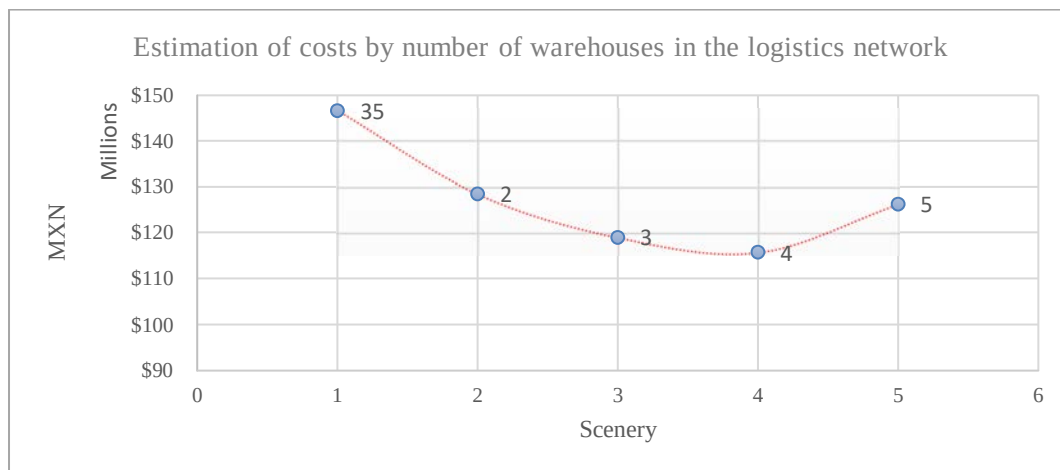


Figure 7 Forecast for overall cost structure of different scenarios depending on amount of storage facilities available for materiel delivery

Figure 8 displays a proposed solution based on the consolidation scheme detailed in this paper. The model

reported a 20.9% increase in savings in the optimized scenario.

Optimization of the current logistics network with a focus on a specific company in the state of Nuevo Leon, Mexico

Refugio Chavez Hernandez, Jose Luis Martinez Flores, Claudia Malcon Cervera, Patricia Cano Olivros

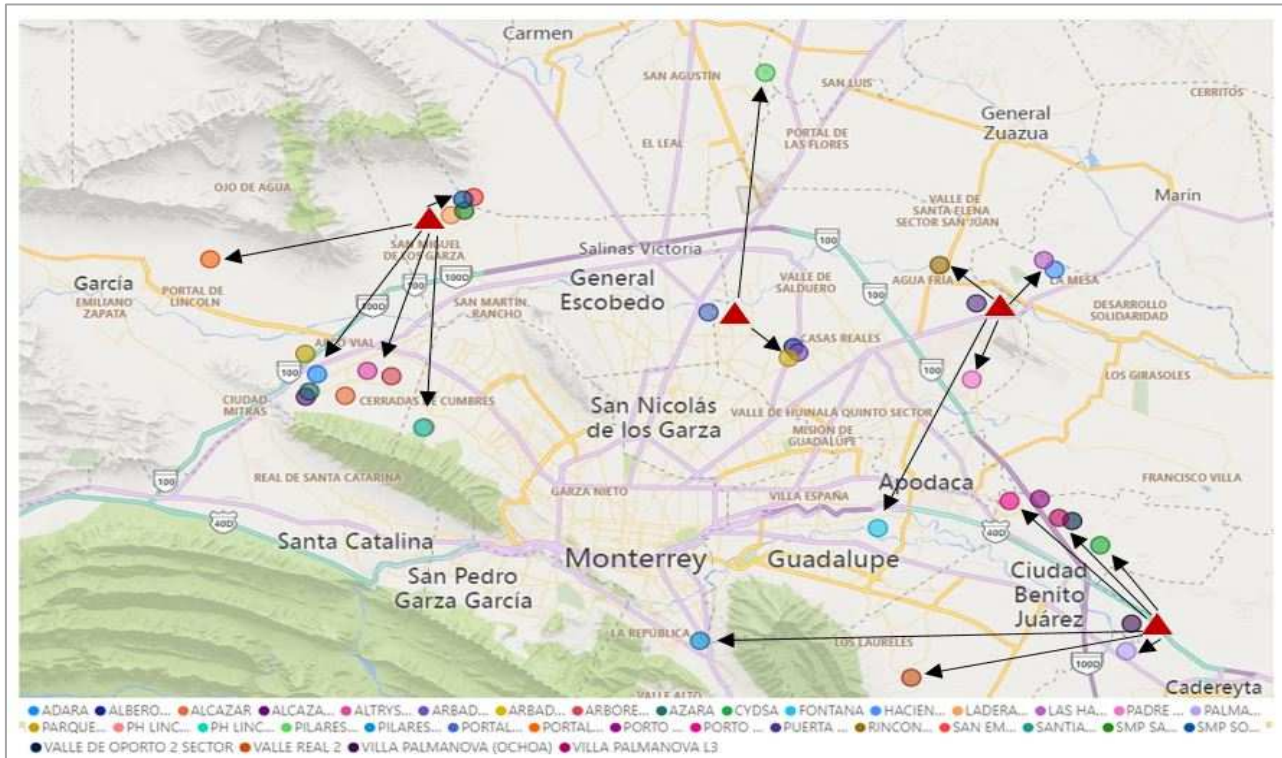


Figure 8 Locations for storage facilities as selected for opening and sourcing for work-site materiel requirements

The results display an interesting bias towards creating assignments that are locality-specific, with an interesting advantage in exploiting the proximity of certain sectors and the corresponding load consolidation/reduced transportation cost without compromising delivery times.

6 Conclusions

One of the primary challenges the company is currently facing is the high operational costs associated with maintaining its existing storage facility structure across different localities. While these costs are considerable, the efficiency of servicing and delivery times remains a critical factor that cannot be compromised. This study has demonstrated that urban development in the state of Nuevo Leon is increasingly decentralized and complex. Using both linear and polynomial regression models, supported by datasets obtained from INEGI, the company has been able to gain valuable insights into real estate acquisition strategies, particularly identifying locations with strong development potential.

A key finding of this research is that many of the most promising developments tend to be clustered in specific areas. This clustering presents an opportunity for optimizing the company's logistics network, specifically regarding the distribution of construction materials and personnel to various job sites. Recognizing this, the proposed master plan incorporates a revamped logistics network, which has been developed using a Mixed-Integer Linear Programming (MILP) algorithm. The primary advantage of this optimized network is its ability to

significantly reduce overall gross operating costs while maintaining if not improving servicing and delivery times.

This paper presents an application of two location models aimed at addressing the facility location and opening problem within the context of a construction industry company. The proposed methodology is designed to streamline the decision-making process by minimizing costs while ensuring that the necessary number of destination nodes continues to be served effectively. By consolidating storage facilities, the company can enhance operational efficiency, reduce redundancy, and improve resource allocation.

It is important to note that certain assumptions were made in the development of this study. Specifically, the forecasting related to real estate acquisition was based on available data trends, and some constraints—such as zoning regulations in different localities—were not explicitly considered. Additionally, variations in demand for materials at job sites due to external factors, including weather conditions and scheduling fluctuations, were not incorporated into the model. While these assumptions simplify the analysis, they also highlight areas for future research and refinement to further enhance the robustness and applicability of the proposed approach.

Overall, this study provides a structured framework for companies in the construction sector to make data-driven decisions regarding storage facility locations. By leveraging predictive modelling and optimization techniques, firms can achieve greater cost efficiency while ensuring seamless logistics operations that support ongoing and future development projects.

References

- [1] WEBER, A.: *Theory of the Location of Industries*, The University of Chicago Press, 1909.
- [2] HAKIMI, S.L.: Optimum Locations of Switching Centers and the Absolute Centers and Medians of a Graph, *Operations Research*, Vol. 12, No. 3, pp. 379-517, 1964. <https://doi.org/10.1287/opre.12.3.450>
- [3] STRAKA, M.: *Distribution and Supply Logistics*, Cambridge Scholars Publishing, New Castle upon Tyne, United Kingdom, 2019.
- [4] GALLI, L., LETCHFORD, A.N.: A separation algorithm for the simple plant location problem, *Operations Research Letters*, Vol. 49, No. 4, pp. 610-615, 2021. <https://doi.org/10.1016/j.orl.2021.06.011>
- [5] KHUMAWALA, B.M.: An Efficient Branch and Bound Algorithm for the Warehouse Location Problem, *Management Science*, Vol. 18, No. 12, pp. B-635-B-749, 1972. <https://doi.org/10.1287/mnsc.18.12.B718>
- [6] WANG, S., WATADA, J.: Capacitated two-stage facility location problem with fuzzy costs and demands, *International Journal of Machine Learning and Cybernetics*, Vol. 4, pp. 65-74, 2013. <https://doi.org/10.1007/s13042-012-0073-0>
- [7] HANSEN, P.H.: A heuristic solution to the warehouse location-routing problem, *European Journal of Operational Research*, Vol. 76, No. 1, pp. 111-127, 1994. [https://doi.org/10.1016/0377-2217\(94\)90010-8](https://doi.org/10.1016/0377-2217(94)90010-8)
- [8] HIDAKA, K., OKANO, H.: *Practical approach to a facility location problem for large-scale logistics*, In: Leong, H.W., Imai, H., Jain, S. (eds) *Algorithms and Computation*. ISAAC 1997. Lecture Notes in Computer Science, Vol. 1350, Springer, Berlin, Heidelberg, pp. 12-21, 1997. https://doi.org/10.1007/3-540-63890-3_3
- [9] BHATTI, A.G.: Optimal model for warehouse location and retailer allocation, *Applied Stochastic Models in Business and Industry*, Vol. 23, No. 3, pp. 213-221, 2007. <https://doi.org/10.1002/asmb.666>
- [10] KRATICA, J., TOŠIĆ, D., FILIPOVIĆ, V., LJUBIĆ, I.: Solving the Simple Plant Location Problem by Genetic Algorithm, *Operations Research*, Vol. 35, No. 1, pp. 127-142, 2001. <https://doi.org/10.1051/ro:2001107>
- [11] MICHEL, L., VAN HENTENRYCK, P.: A simple tabu search for warehouse location, *European Journal of Operational Research*, Vol. 157, No. 3, pp. 576-591, 2004. [https://doi.org/10.1016/S0377-2217\(03\)00247-9](https://doi.org/10.1016/S0377-2217(03)00247-9)
- [12] BOCZEK, M., HOVANA, A., HUTNÍK, O., KALUSZKA, M.: Hölder-Minkowski type inequality for generalized Sugeno integral, *Fuzzy Sets and Systems*, Vol. 369, pp. 51-71, 2020. <https://doi.org/10.1016/j.fss.2020.01.005>
- [13] EL KARIM, A.A., AWAWDEH, M.M.: Integrating GIS Accessibility and Location-Allocation Models with Multicriteria Decision Analysis for Evaluating Quality of Life in Buraidah City, KSA, *Sustainability* Vol. 12, No. 4, 1412, pp. 1-28, 2020. <https://doi.org/10.3390/su12041412>
- [14] DEMIREL, T.: Multi-criteria warehouse location selection using Choquet integral, *Expert Systems with Applications*, Vol. 37, No. 5, pp. 3943-3952, 2010. <https://doi.org/10.1016/j.eswa.2009.11.022>
- [15] KHAIRUDDIN, R., ZAINUDDIN, Z.M., JIUN, G.J.: A simulated annealing approach for redesigning a warehouse network problem, *Journal of Physics: Conference Series*, Vol. 890, 1st International Conference on Applied & Industrial Mathematics and Statistics 2017 (ICoAIMS 2017) 8–10 August 2017, Kuantan, Pahang, Malaysia, pp. 1-6, 2017. <https://doi.org/10.1088/1742-6596/890/1/012109>
- [16] ADASME, P.: p-Median based formulations with backbone facility locations, *Applied Soft Computing*, Vol. 67, pp. 261-275, 2018. <https://doi.org/10.1016/j.asoc.2018.03.008>
- [17] YOU, M., XIAO, Y., ZHANG, S., YANG, P., ZHOU, S.: Optimal mathematical programming for the warehouse location problem with Euclidean distance linearization, *Computers & Industrial Engineering*, Vol. 136, pp. 70-79, 2019. <https://doi.org/10.1016/j.cie.2019.07.020>
- [18] DOUNGPAN, S.: *Application the Facility Location Model for Setting Ready-Mix Concrete Plant: Case Study at Rayong Province, Thailand*, IEEE 7th International Conference on Industrial Engineering and Applications (ICIEA), pp. 615-619, 2020. <https://doi.org/10.1109/ICIEA49774.2020.9101949>
- [19] YACHBA, K., BELAYACHI, N., BOUAMRANE, K.: Towards a Decision Support System for Optimizing the Location of Warehouses in a Supply Chain by Using the Bee Colony Algorithm, *International Journal of Organizational and Collective Intelligence*, Vol. 12, No. 1, pp. 1-16, 2022. <https://doi.org/10.4018/IJOCI.304882>
- [20] HAOXIANG L., YANGCHENG Y., ZHENYI Z.: Research on Cargo Volume Prediction and Adjustment Strategy of Logistics Network Based on Deep Learning and Optimisation Algorithm, *Procedia Computer Science*, Vol. 243, pp. 532-541, 2024. <https://doi.org/10.1016/j.procs.2024.09.065>
- [21] RAHMAN, M.A., BASHEER, M.A., KHALID, Z., TAHIR, M., UPPAL, M.: Logistics Hub Location Optimization: A K-Means and P-Median Model Hybrid Approach Using Road Network Distances, *Transportation Research Procedia*, Vol. 84, pp. 219-226, 2025. <https://doi.org/10.1016/j.trpro.2025.03.066>

Review process

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Comprehensive risk management in agricultural supply chains: strategies and approaches - case of Persian lime in Veracruz

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Keywords: Persian lime, supply chain, risks, failure mode and effects analysis, Decision-Making Trial and Evaluation Laboratory.

Abstract: The Agri-Food Supply Chain (AFSC) is essential for global food supply, economic development, and employment. However, it faces significant risks that undermine its efficiency, mainly due to the perishability of its products, which complicates risk management. Despite its importance, research on risks in this sector, especially for specific agricultural products, remains limited. This study addresses this gap by identifying, evaluating, and prioritizing risks in the first link of the Persian Lime (*Citrus latifolia* Tanaka) AFSC in the Citrus District of Martínez de la Torre, Veracruz, Mexico. Using semi-structured interviews with eleven experts in integrated crop management, 53 risks were identified and categorized into natural, pest, disease, supply, and operational risks. The Decision-Making Trial and Evaluation Laboratory (DEMATEL) technique was applied to analyze cause-effect interactions. At the same time, Failure Mode and Effects Analysis (FMEA) was used to prioritize these risks. The results indicate that pesticide scarcity is the most influential causal risk, while an incidence exceeding 5% of trees affected by gummosis (*Phytophthora* spp.) has the most excellentmost significant impact. Additionally, high staff turnover was identified as the most critical risk. These findings give decision-makers a robust foundation to develop risk management plans that enhance the AFSC's resilience. Such measures will help ensure a continuous food supply and enable processing and packing companies in the subsequent links to meet demand, thus improving the stability and sustainability of the agri-food system amid long-term disruptions.

1 Introduction

The Agri-Food Supply Chain (AFSC) is a cornerstone of food security, economic development, and employment on a global scale. However, the perishability of its products, combined with production variability caused by climatic conditions and biological processes, makes risk management a complex challenge [1]. Identifying, evaluating, and prioritizing risks is essential for developing effective mitigation and control strategies.

Globally, stakeholders in each link of the supply chain work proactively to manage these risks, ensuring operational continuity and food security. Agri-food exports play a critical role in the economy. For instance, in May 2023, Mexico generated USD 2.13 billion in agricultural and fishing exports, ranking as the world's 11th-largest food producer, 7th-largest agri-food exporter, and the second-largest lime producer [2]. The Persian Lime AFSC, which primarily targets export markets, is particularly significant. The United States receives most of Mexico's production, followed by Canada, France, the Netherlands,

Germany, Saudi Arabia, the United Kingdom, Japan, and South Korea. However, in recent years, lime cultivation has faced adverse natural events, including extreme weather conditions, pests, diseases, and viruses, as well as operational and supply challenges. Therefore, identifying and assessing these risks is crucial to anticipate and mitigate their effects.

While risk studies in supply chains are abundant, particularly in the manufacturing sector, research in the agri-food sector remains limited, especially for specific agricultural products. This article addresses this gap by identifying, evaluating, and prioritizing risks in the first link (orchard production) of the Persian Lime AFSC in the Citrus District of Martínez de la Torre, Veracruz, Mexico.

Many risks in this sector are interdependent, which makes hierarchical analysis insufficient. While FMEA is valuable, it does not account for causal relationships between criteria. DEMATEL provides a complementary approach by identifying cause-effect relationships and interdependencies. This study employs both techniques to prioritize risks based on their likelihood of occurrence,

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detection, and impact, supported by insights from eleven experts in Persian Lime integrated crop management.

The results provide a robust foundation for decision-makers to anticipate risks and design mitigation and control plans that strengthen the resilience of the AFSC. These actions will ensure a continuous food supply, meet the demand of processing and packing companies in subsequent links, and enhance the stability and sustainability of the agri-food system amid long-term disruptions.

2 Literature review

2.1 Lime cultivation in Mexico

Mexico's main lime varieties include Mexican lime (*Citrus aurantifolia*), yellow or Italian lime (*Citrus lemon*), and Persian or seedless lime (*Citrus latifolia tanaka*). While Mexican lime is primarily for domestic consumption, Italian and Persian limes are grown for export, with Persian lime dominating in volume and significance. In 2023, Mexico produced 3.2 million tons of lime, with Persian lime accounting for 50.4%. Other producing states contributing to these figures are Jalisco (5.79%), Yucatán (6.58%), and Oaxaca (12.91%).

Veracruz, particularly Martínez de la Torre, contributed 31.89% of the 53.04% of Persian lime produced in the state, making it a key player in the industry [3].

2.2 The Persian lime AFSC

Martínez de la Torre, located in northern Veracruz, Mexico, is bordered by municipalities such as Papantla, Tecolutla, San Rafael, Atzalan, Misantla, Tlapacoyan, and San José Acateno. Its geographical location and soil-climatic conditions make it ideal for Persian lime production, with the fruit meeting the quality standards for export to Europe and Asia. Known as "The World Capital of Persian Lime" the region exports to countries such as the United States, Canada, France, the Netherlands, Germany, Saudi Arabia, the United Kingdom, Japan, and South Korea. The United States is the primary destination for these exports.

The Persian lime AFSC in Martínez de la Torre has three main links as shown in Figure 1. The first involves orchard production (suppliers), the second includes processing and packing facilities, and the third covers commercialization.

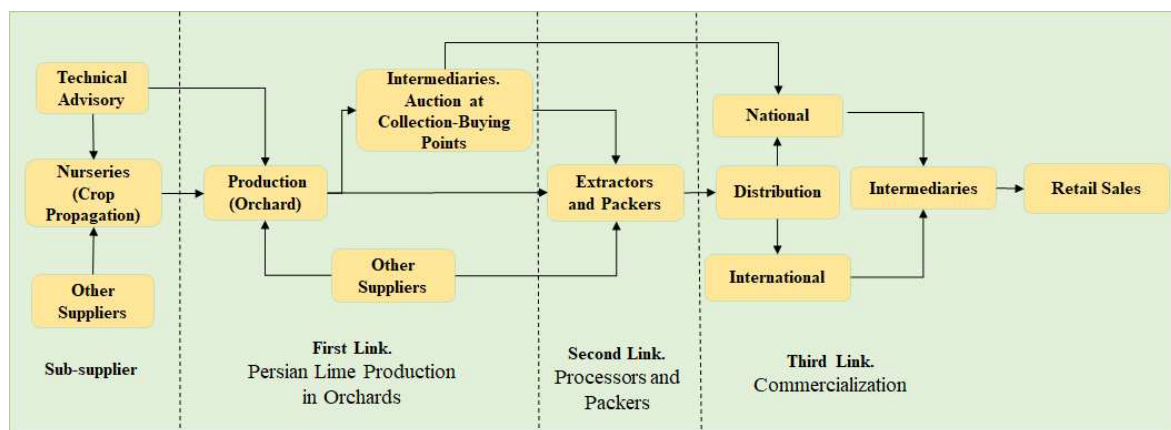


Figure 1 Supply chain of Persian lime

This supply chain represents a significant economic pillar for the district and the country, as it generates numerous direct and indirect jobs across its various stages. However, in recent years, the cultivation of Persian lime has been adversely affected by climatic events that exacerbate other challenges, such as pests, diseases, and viruses, as well as operational issues. These risks must be identified and assessed proactively to anticipate and mitigate their impact.

2.3 Risk management

Risk, in general, refers to the possibility of an undesirable event occurring that has the potential to cause harm. Within the Supply Chain (SC) pertains to uncertain events or conditions that negatively impact the objectives of businesses across its various stages. Risks are categorized as Internal risks, which arise within the

company or SC and include supply, process, demand, logistics, financial, and collaboration risks. External risks stem from outside the SC and encompass natural risks[4]. Identifying and managing risks is crucial to reducing vulnerability and strengthening the SC's resilience [5]. Furthermore, it fosters a risk management culture as a comprehensive business strategy across the entire chain [6].

2.4 Techniques for Risk management

SC risk management is typically divided into four key phases: identification, evaluation, treatment, and monitoring [7,8]. These stages provide a systematic approach to addressing potential threats and ensuring the SC's resilience. The structure of these phases is visually summarized in Figure 2.

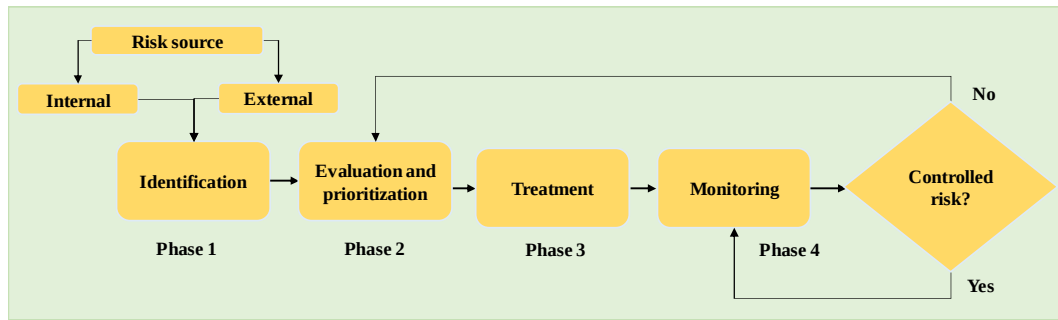


Figure 2 Methodology for risk management (based on [7,8])

2.4.1 Risk identification

The first phase involves pinpointing potential risks that could affect the SC. Techniques such as checklists, event tree analysis, fault tree analysis, Ishikawa cause-and-effect diagrams, and FMEA are commonly employed [8]. Brainstorming sessions and expert interviews are also helpful, though they face the limitation of struggling to anticipate unprecedented events [9].

2.4.2 Risk evaluation

Risk evaluation entails determining probability, severity, and prioritization. Various techniques, including the Delphi Method or expert groups, for estimating probability and severity [8]. Analytical Hierarchy Process (AHP), Data Envelopment Analysis (DEA), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), and FMEA for calculating severity weights and priority indices [10]. For dependent risks, the Analytic Network Process (ANP) and DEMATEL are preferred [11]. Hybrid models, such as FMEA integrated with AHP, have been reported for calculating severity and prioritizing risks [12]. Similarly, FMEA has been combined with ANP and DEMATEL for enhanced risk analysis [13].

2.4.3 Risk treatment

The risk treatment phase involves selecting and implementing strategies to minimize the likelihood of occurrence and mitigate adverse effects, guided by contingency theory. This phase encompasses preparation, response, and recovery. Strategies include maintaining emergency inventory, fostering cooperation between SC members, enhancing flexibility and resilience, and developing agility to anticipate risks [14].

2.4.4 Risk monitoring

Monitoring requires continuous risk-tracking to evaluate control measures and adjust strategies as needed. Emerging technologies such as the Internet of Things (IoT), blockchain, and Artificial Intelligence (AI) enable real-time risk monitoring [10]. Key areas to assess include suppliers, regulations, and political/economic stability indicators. Predictive analytics and AI techniques to anticipate chain production, transportation, and supply chains risks [11].

2.5 FMEA and DEMATEL in risk management

The FMEA is a systematic method for identifying and assessing product, process, or system failures and developing improvement strategies to eliminate or mitigate them. The process involves identifying potential failures or risks, identifying potential failures or risks, and estimating their probability of occurrence (O), detection (D), and severity (S). By multiplying these factors (OxDxS), the Risk Priority Number (RPN) is calculated.

Many decision-making problems cannot be structured hierarchically due to the interaction and dependency between elements at different levels. The ANP addresses such issues and has been applied in areas such as risk evaluation and supplier selection. However, as noted in [12], ANP can become complex and slow when dealing with multiple elements, potentially leading to confusion. As a result, the DEMATEL method is proposed as a more efficient alternative.

The DEMATEL technique is effective for modeling the influence between components and analyzing cause-and-effect relationships within complex systems. Its advantages have garnered significant attention in the past decade, making it a valuable method for solving complex problems and improving decision-making in various settings [13]. Steps for Applying the DEMATEL Technique according to [15]:

1. Constructing the Influence Matrix

For each expert $x^1, x^2, \dots, x^m$, where m is the number of experts, an influence-relation matrix is developed. The weights provided by all experts are averaged using Equation (1). The final matrix X , as shown in Equation (2), represents the average weights of all experts.

$$\bar{x} = \frac{x^1 + x^2 + \dots + x^m}{m} \quad (1)$$

$$X = \begin{bmatrix} \bar{x}_{11} & \dots & \bar{x}_{1j} & \dots & \bar{x}_{1n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \bar{x}_{i1} & \dots & \bar{x}_{ij} & \dots & \bar{x}_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \bar{x}_{n1} & \dots & \bar{x}_{nj} & \dots & \bar{x}_{nm} \end{bmatrix}_{n \times m}, i, j \in \{1, \dots, n\} \quad (2)$$

where, $\bar{x}_{ij}$ represents the influence from the i -th to the j -th attribute. The influence scale consists of five levels: 0 (No

influence), 1 (Low influence), 2 (Medium influence), 3 (High influence), and 4 (Very high influence).

2. Calculating the Normalized Influence Matrix

To determine the value of K , the maximum sum of rows or columns of X is selected, and Equation (3) is applied:

$$K = \max_{i,j} \left\{ \frac{1}{\max_i \sum_{j=1}^n |m_{ij}|}, \frac{1}{\max_j \sum_{i=1}^n |m_{ij}|} \right\} \quad (3)$$

The normalized matrix D is obtained using Equation (4):

$$D = K \times X \quad (4)$$

3. Total Influence Matrix

The total influence matrix T is derived using Equation (5), where I is the identity matrix.

$$T = \lim_{m \rightarrow \infty} (D^1 + D^2 + \dots + D^m) = D(I - D)^{-1} \quad (5)$$

4. Calculating Cause and Effect Values

The r and c values are calculated to represent the sum of the row and column values in T , respectively, as shown in Equations (6) and (7), the r value is considered influence and c dependence:

$$r = [r_i]_{n \times 1} = \left[\sum_{j=1}^n t_{ij} \right]_{n \times 1}; i = 1, \dots, n \quad (6)$$

$$c = [c_j]_{1 \times n} = \left[\sum_{i=1}^n t_{ij} \right]'_{1 \times n}; j = 1, \dots, n \quad (7)$$

5. Threshold Value and Visualization

Where c is the transpose, subsequently, subsequently, the coordinates are calculated using Equations (8) and (9), and the threshold value α is determined using Equation (10). This threshold represents the average of all elements in the matrix T .

The values in cell (i, j) of matrix T that exceed the threshold α indicate that i influences j ; otherwise, no significant influence exists, and these values can be disregarded in the analysis. The interrelation diagram is created by plotting the values of Equation (8) on the x-axis and Equation (9) on the y-axis. This visualization simplifies causal relationships into a valuable structure for decision-making. The final criteria ranking is obtained by sorting the values from Equations (8) and (9). It is recommended that they be arranged in descending order based on Equation (8) to facilitate interpretation.

$$(r_i + c_j) \quad (8)$$

$$(r_i - c_j) \quad (9)$$

$$\alpha = \frac{\sum_{i=1}^n \sum_{j=1}^n t_{ij}}{N} \quad (10)$$

The coordinate from Equation (8) reflects the degree of importance of a criterion within a set, the higher the value, the greater the importance. On the other hand, Equation (10) represents the relationship of a criterion with others and categorizes them into cause-and-effect groups. A positive value indicates that the criterion is a cause, while a negative value signifies that it is an effect. In Figure 3. The Area I includes causal criteria that require immediate action. Areas II and III group irrelevant criteria, which are independent and have limited influence on the system. Area IV contains problematic criteria that need attention, but not directly, as they represent effect-driven elements. As reported in [16], a formula is provided to measure the importance of each criterion. Equation (11) calculates the distances, while Equation (12) normalizes the importance. These calculations determine the final weighting W_i of the criteria for the decision-making process.

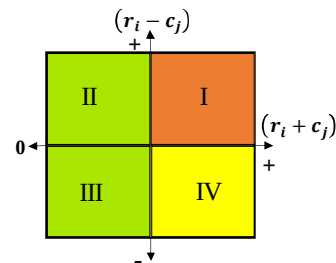


Figure 3 DEMATEL interrelation diagram (based on [17])

$$w_i = \left[(r_i + c_j)^2 + (r_i - c_j)^2 \right]^{\frac{1}{2}} \quad (11)$$

$$W_i = \frac{w_i}{\max(1 \leq i \leq n, w_i)} \quad (12)$$

The literature highlights various applications of FMEA in combination with DEMATEL: [17] integrated both techniques to identify and prioritize the causes of failures in the photovoltaic cell industry in China. [18] employed them to address the root causes of malfunctions in production lines, enabling faster and more effective problem resolution. [19] applied DEMATEL to evaluate the causal relationships among risk dimensions within the Halal supply chain. In addition, [20] utilized FMEA to assess risks in a machining center and applied DEMATEL to analyze the influences and cause-effect relationships among those risks.

3 Methodology

3.1 Description

The proposed methodology consists of two phases: risk identification and risk evaluation. Figure 4 provides a schematic representation of the process to be followed.

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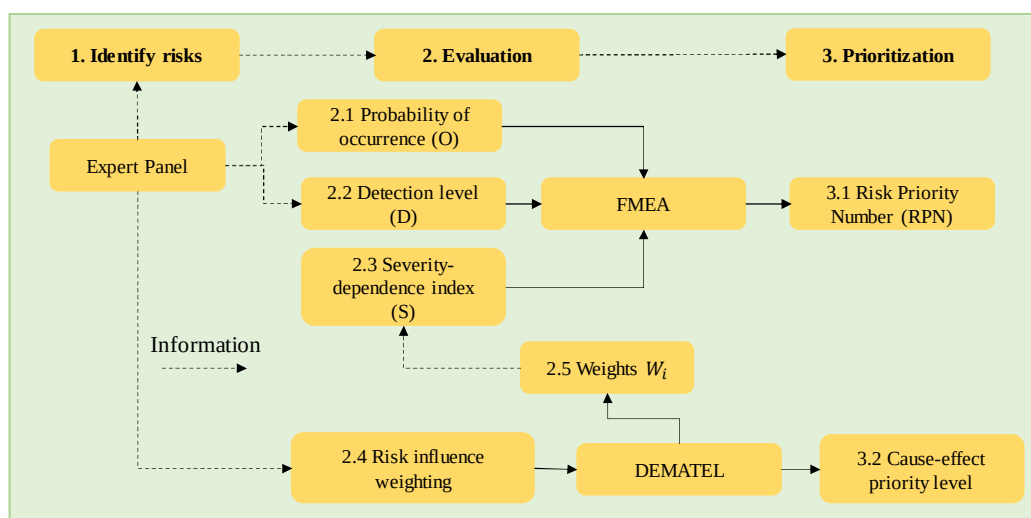


Figure 4 Methodology for the case study

The identification of risks, estimation of the probability of occurrence (O), detection level (D), and weighting of influence are based on the input of eleven experts specializing in the integrated management of Persian lime cultivation. The severity-dependence level (S)-(W_i) is calculated using DEMATEL following Equation (12) referenced in subsection 2.5. Finally, the RPN is determined through FMEA, and the cause-effect relationships among risks are evaluated using DEMATEL.

3.2 Context of the first link in the Persian lime supply chain

The first link in the Agro-Food Supply Chain (AFSC) of Persian lime focuses on its production in orchards,

involving small, medium, and large producers. This link determines fruit the fruit volume and quality and synchronizes its flow with the second link, consisting of processing and packing facilities.

The cultivation includes both perennial and seasonal crops, as well as technologically advanced farms with irrigation systems. Persian lime is notable for its larger size, seedlessness, lower acidity, and high vitamin C content. Figure 5 provides a detailed description of the Persian lime cultivation process.

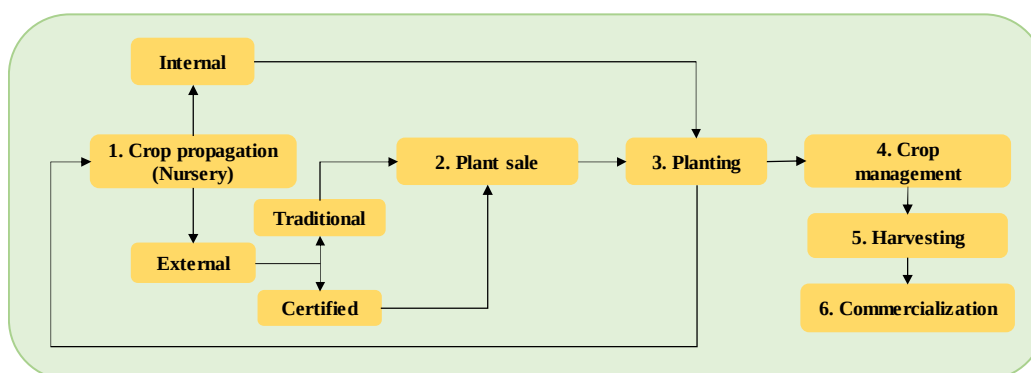


Figure 5 Persian lime cultivation process

The propagation of Persian lime involves activities to reproduce the plant in nurseries. These nurseries can be either internal, owned by producers, or external, focused on production and commercialization. External nurseries can be certified, complying with NOM-079-SAG/FITO-2017, or traditional, which do not follow regulations. Propagation is carried out through grafting onto rootstocks resistant to pests, diseases, and adverse conditions. Once the nursery plant reaches adequate development, it is

transplanted into the orchard. Subsequently, integrated crop management is conducted, including pest control, weed management, nutrition, pruning, and irrigation if the necessary technology is available. Harvesting is performed manually by a team of workers, who select the fruit according to the quality standards required by packing facilities. Harvested limes are placed in 25 kg plastic crates, and after collection, they are transported for commercialization.

3.3 Risk identification

In this initial phase, 11 experts in integrated crop management, identified as E1 through E11, were consulted. According to [21], the recommended number of experts ranges from 7 to 30. A total of 53 potential risks were identified through semi-structured interviews. Due to space constraints, all identified risks are included in Annex 1 at the end of the document. Economic thresholds for citrus pests and diseases were established using the strictest averages provided by the experts, which may differ from the existing literature. This study focuses exclusively on pests and diseases posing significant risks to Persian lime cultivation in the Citrus District of Martínez de la Torre, which notably impact production and quality, potentially causing severe disruptions in the SC.

3.4 Risk evaluation

For this step, measurement scales were defined and adapted from [22]. Risk probability was classified as: very high, high, medium, low, and very low, corresponding to occurrences on a weekly, monthly, quarterly, semi-annual, and annual or longer basis, with weights of 9, 7, 5, 3, and 1, respectively. Detection level was stratified as: impossible, low, moderate, high, and specific, with weights of 9, 7, 5, 3, and 1, respectively. These categories range from undetectable to easily detectable without difficulty. Influence was categorized as none, low, moderate, high, and very high, with weights of 0, 1, 2, 3, and 4.

Each expert assessed the probability of occurrence (O) and the detection level (D) for the FMEA technique. The direct influence matrix X was calculated using Equations (1) and (2), the matrix D using (3) and (4), and the total influence matrix T using (5). Calculations were performed using GNU Octave.

Coordinates were derived using Equations (8) and (9), and the threshold value $\alpha=0.009$ was calculated using Equation (10). All values in matrix T below the threshold were filtered out, resulting in a refined matrix T_2 . The final weights W_i for each criterion, representing the **severity level (S)** for FMEA evaluation, were determined using Equation (12). Complete results from FMEA and DEMATEL are provided in Annex 1.

4 Results and discussion

The results are divided into two sections: The first one shows findings obtained through the DEMATEL technique, while the second focuses on results from the FMEA analysis.

4.1 Results from DEMATEL

The 53 evaluated risks form a complex network, making a tabular analysis challenging. Therefore, the interrelation diagram described in Section 2.5 was employed. Figure 6 presents this diagram, generated using R Software, illustrating the final influence network as shown below.

$$R33 > R1 > R38 > R6 > R10 > R41 > \dots > R4 > R27 > R15 > R26 > R21 > R22$$

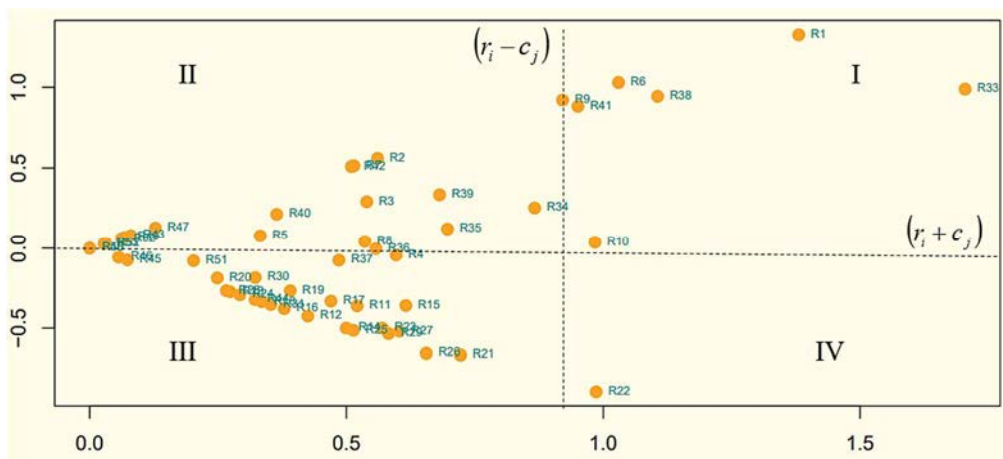


Figure 6 Final cause-and-effect interrelation map

Areas I and II encompass the causal risks that influence others, while Areas III and IV group the effect risks, which are more influenced than they influence.

4.1.1 High-influence causal risks

The most influential causal risks are: $R33 > R1 > R38 > R6 > R10 > R41 > R9 > R34$, most of which are operational in nature. The most significant risk is the "Shortage of pesticides in commercial stores" (R33).

Although its probability is low, the impact on crops would be severe, as pests and diseases cannot be controlled without pesticides. This issue primarily affects small, medium, and micro producers who lack the capital for maintaining safety stock. For large producers, this shortage is more associated with financial policies and planning failures, linked to the risk of "Excessive time for resource authorization for purchasing inputs" (R49). The approval

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process, which may take three to five days, allows pests to proliferate, worsening crop damage.

The second most influential risk is "Hurricane impact" (R1). Hurricanes can cause fruit drop in various growth and flowering stages, uproot trees, damage plants due to wind, and interrupt harvest and commercialization activities. They can also destroy transportation infrastructure and, with heavy rains, increase vulnerability to fungal infections, root rot, and waterlogging damage. The Citric District is highly vulnerable to such events, as seen with hurricanes like Janet (1955), Gilberto (1988), Stan (2005), Karl (2010), and more recently, Grace, which hit near Tecolutla, Veracruz, on August 21, 2021.

Similarly, "High employee turnover" (R38) is related to decreasing workers willing to perform field activities. Low labor supply against high demand drives workers to demand better wages and conditions, leading to short work periods, high turnover, and potential labor disputes. This situation is worsened by absenteeism during local festivals and traditions. Labor is crucial for production, forcing large producers to seek workers from neighboring communities, which raises production costs due to transportation. R38 is linked to other risks such as "Shortage of operational staff" (R34), "Shortage of specialized human resources" (R35), "High labor absenteeism" (R39), and "Operational disruptions due to internal conflicts" (R40).

The warm, humid climate of the Martínez de la Torre Citric District experiences winter temperatures as low as 2°C (December 24, 1989) and spring-summer temperatures reaching up to 43.5°C (April 27, 2011) [23]. This creates risks such as: "High temperatures" (35°C-39°C to >45°C) (R6), "Low temperatures" (<4°C extreme) (R7), "Temperature shifts" (from 22°C-27°C to 28°C-35°C in 1-2 days) (R9), and "Drought (abnormal to extreme)" (R5). Though the region is not officially at risk of extreme drought, [23] reports indicate abnormal to moderate droughts from April to October, occasionally reaching severe to extreme levels. This creates a low likelihood of "Water scarcity or depletion of supply sources" (R8).

The "Impact of a pandemic, epidemic, or seasonal illnesses" (R10) affects the entire supply chain. The COVID-19 health emergency, for instance, negatively impacted the global economy, restricted worker movement, altered demand, and caused production shutdowns. These disruptions in supply chains led to shortages of essential products. It is vital for decision-makers to design contingency plans to increase business resilience, considering other events, such as dengue outbreaks in the warm, humid zone, leading to labor absenteeism. The "Operational disruptions due to external socio-organizational conflicts and/or stakeholders (protests, demonstrations)" (R41) is a low-probability risk, although its frequency is increasing. Protests and road closures due to insecurity and political issues can halt orchard activities for hours or days, delaying scheduled operations.

4.1.2 Low-influence causal risks

Section II of Figure 6 includes low-influence causal risks that affect fewer risks but should still be addressed. These risks are: R35>R39>R2>R3>R8>R7>R42>R40>R5>R47>R43>R49>R32>R52>R53>R48>R50.

Risks like R35, R39, R40, R8, R7 and R5 were previously discussed. The risk of "An earthquake" (R2) has a very low probability, as the region is not in a seismic zone, although seismic waves have been felt. Its including catastrophic effects such as damage to infrastructure and communication routes, injuries, loss of life, operational interruptions, and labor absenteeism.

"Heavy rainfall (>30 mm/h)" (R3) can occur in isolated, atypical events, such as tropical storms, or in severe to extreme conditions, between May and October, particularly from August to October. Intense rains can lead to "Hydrometeorological flooding or hydraulic infrastructure failures" (R4), especially in low areas near rivers or rapid-response streams. The Martínez de la Torre municipality has declared emergency zones on several occasions due to these phenomena. Combined with humidity, these conditions promote the proliferation of pests and diseases in citrus crops.

"Interruption or closure of operations due to non-compliance with regulations" (R42) is a low-probability risk; however, if it occurs, it could severely impact production, resulting in reduced yields and economic losses due to fines. This risk is linked to the lack of permits for operating deep wells and non-compliance with agricultural, labor, and environmental regulations.

"Insufficient processing capacity for integrated pest and disease management" (R47) affects small and medium-sized producers who lack the resources to invest in machinery and tools. This risk is like "Insufficient technological resources for pest and disease monitoring" (R45).

The "Financial impact of crime and insecurity" (R43) manifests as fruit theft and assaults, forcing producers to increase their security expenses. The "Excessive time for financial resource authorization" (R49) mainly affects large producers; bureaucracy can delay the purchase of inputs, exacerbating pest damage. "Acquiring nursery plants carrying diseases" (R32) is a latent risk, especially when buying plants from uncertified nurseries, which can propagate undetectable diseases.

The "Lack of knowledge in integrated crop management" (R53) is common among small producers who rely on inherited practices and lack the resources to hire specialized technicians. This risk relates to "Inadequate nutritional management of the plant" (R52), "Lack of phytosanitary care after pruning" (R48), and "Operational failures in integrated pest management" (R44). The first is critical since a well-nourished plant is more resistant to pests; the second arises from negligence that facilitates the entry of diseases, while the third stems from poor planning and organization.

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Finally, "Pesticide restrictions in the market" (R50) is a low-probability but high-impact risk. Restrictions force the use of more expensive, potentially less effective products, which can reduce yields. Continued use of banned or restricted pesticides risks export bans, product rejections, or fines for pesticide residue detection.

4.1.3 Low-effect risks

The risks classified as low effect are: R46>R45>R51>R20>R28>R13>R24>R44>R30>R18>R31>R16>R19>R12>R17>R37>R14>R25>R11>R36>R23>R29>R4>R27>R15>R26>R21. In Quadrant III of Figure 6, these risks mostly involve citrus pests and diseases, influenced by climatic factors and poor crop management.

The group includes "Failures in agricultural machinery and equipment" (R46), an independent event, similar to "Insufficient technological resources for pest and disease monitoring" (R45). However, both can be influenced by other risks, significantly impacting crops. The same applies to "Accidental orchard fire" (R51) and other dangers like R37, R36, R44, and R4.

The topic of citrus pests and diseases is extensive, but only some are briefly described. Most are influenced by natural risks such as hurricanes (R1), heavy rains (R3), floods (R4), high temperatures (R6), low temperatures (R7), abrupt temperature changes (R9), droughts (R5), and water scarcity (R8). For example, "Sectorial streaking" (R28) is associated with heat stress and water shortages, causing chlorotic spots and potentially tree death, with symptoms like "Huanglongbing (HLB)" (R23), complicating diagnosis. Other risks influenced by climatic factors include Green stink bug (R13), Scab (R24), Thrips (R16), Sooty mold or arador (R12), Red spider mite (R14), Melanosis (R25) and White mite (R11).

Among fungal diseases associated with high humidity are: "Dieback" (R27) which causes annual losses of up to 35% of Persian lime trees, reducing production by 60%

[24]. It leads to shoot necrosis and defoliation, potentially spreading to roots and killing the plant. "Greasy spot" (R26) primarily affects leaves, causing black spots and premature defoliation, reducing fruit yield by 20% to 45% [25]. "Anthracnose" (R21) leads to flower and fruit drop, resulting in significant production losses.

Some pests promote the development of other diseases. For instance, "Sooty mold" (R29) arises from sugary secretions of pests like the Diaphorina citri (R15), Mealybug (R19), Snow scale (R17) and the Blackfly (R20). Diaphorina citri is also the vector for HLB (R23), a devastating citrus disease that decreases yield and kills trees [25]. This destructive invasive species poses a severe threat to the citrus industry. Another economically impactful disease is the "Citrus tristeza virus" (R31), mainly spread by aphids such as the "brown citrus aphid" (R30).

Lastly, reference must be made to area IV in Figure 6, highlighting high-effect risks that require attention but cannot be improved without addressing their causal risks first. This group includes "Incidence above 5% of trees with Gummosis" (R22), a fungal disease responsible for 10% to 30% of citrus crop losses [26].

4.2 Results obtained with FMEA

The Pareto Law was applied to identify the 20% risks responsible for 80% of the consequences. This grouping, illustrated in Figure 7, includes risks R38, R22, R27, ..., R28, and R18. Full FMEA results can be found in Annex 1 at the end of the document. It is important to note that the FMEA evaluates the Probability of Occurrence (O) and the Detection Level (D), which can result in high RPN. However, it is essential to determine whether the risk is causal or an effect. If a risk is an effect, causal risks must be identified and prioritized for mitigation based on their RPN values. Therefore, priority should be given to addressing all causal dangers first.

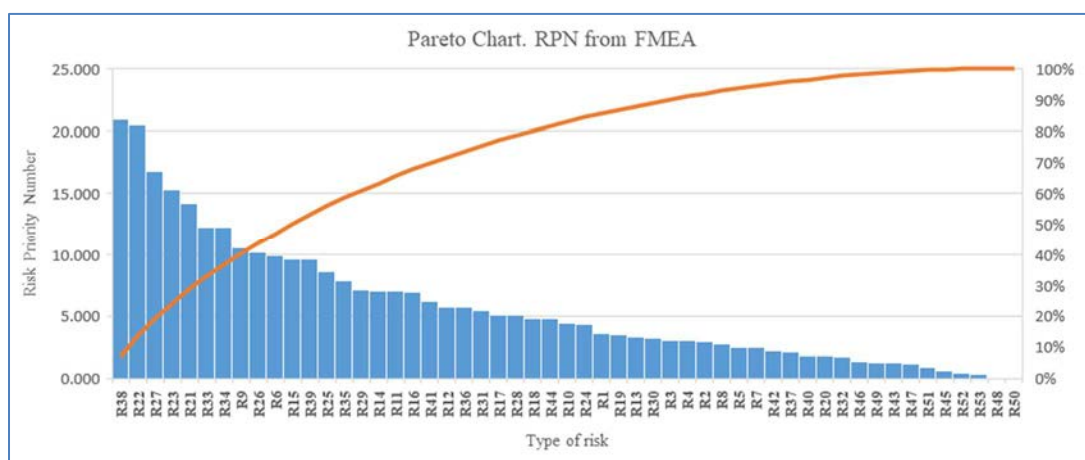


Figure 7 Pareto diagram, results from FMEA

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The highest-priority risk identified is “High employee turnover” (R38), followed by “Incidence of more than 5% of trees with Gomosis” (R22). Gomosis, a high-impact risk identified through DEMATEL analysis, is influenced by causal risks such as R1, R3, R4, R5, R6, R7, R9, R17, and R27, which must be addressed first to manage its effects. The third priority is “Dieback” (R27), an effect-driven risk linked to natural causes. Similarly, HLB (R23) is another effect-based risk that requires controlling its vector, *Diaphorina citri* (R15). “Anthracnose” (R21) is another effect-driven risk caused by natural factors.

Among causal risks within the critical 80%, those requiring priority intervention are: “High employee turnover” (R38), “Scarcity of pesticides in commercial outlets” (R33), “Lack of field workers for diverse tasks” (R34), “Sudden temperature changes” (from 22°C-27°C to 28°C-35°C in 1-2 days) (R9), “High temperatures” (35°C-39°C to >45°C) (R6), “Operational disruptions due to social-organizational conflicts (protests, demonstrations)” (R41). The low-influence causal risks include: “Shortage of specialized human resources” (R35) and the “High absenteeism” (R39), all other risks are effect-based. The least critical risks include R51, R45, R52, R53, R48, and R50.

4.3 Discussion

This study aimed to identify, evaluate, and prioritize risks based on their interdependencies and cause-effect relationships. Data from eleven experts in integrated crop management were processed using DEMATEL for interdependence analysis and FMEA for prioritization. 53 risks were assessed and categorized as natural, pest-related, disease-related, supply-related, and operational risks.

The results were categorized into high- and low-influence causes and low- and high-impact effects. Among the high-influence causes, eight risks were identified, with the scarcity of pesticides in commercial outlets standing out. Although its likelihood of occurrence is low, its realization could significantly impact the crop. Additionally, the effects of hurricanes, high temperatures, and sudden temperature changes directly influence the spread of pests and diseases in citrus crops. Moreover, the pandemic, operational disruptions due to socio-organizational conflicts, workforce shortages, and high employee turnover negatively affect the normal progression of harvest and commercialization activities.

17 risks were classified as low-influence causes, with operational risks predominating, followed by natural-origin risks to a lesser extent. These risks affect a limited number of factors; some are considered independent. Among them are shortages of specialized personnel, high employee absenteeism, and seismic events. Natural risks, such as intense rainfall, water scarcity, and low temperatures, are of particular concern due to their significant impact on the proliferation of pests and diseases.

Effect-group risks are primarily those of natural origin, such as pests and diseases, which are influenced by the causal risks mentioned earlier. A total of 27 low-effect risks were identified, with the most notable being failures in agricultural machinery and equipment, insufficient technological resources, and accidental orchard fires. The remainder pertains to citrus pests and diseases. Notably, only one risk is classified as having high influence: a fungal disease known as Gomosis.

Regarding risk prioritization through FMEA, 25 risks account for 80% of the consequences. Among these, six are considered high-influence causes, and two are low-influence causes. These include a high turnover of operational personnel, shortages of pesticides, shortages of operational personnel, abrupt temperature changes, high temperatures, operational interruptions due to external socio-organizational conflicts, shortages, scarcity of specialized human resources, and high labor absenteeism. The remaining 17 risks are effect-based and depend on addressing the causal risks.

Risks with the lowest RPN include a lack of knowledge about integrated crop management, insufficient phytosanitary care after tree pruning, and restricting or prohibiting certain pesticides in the target market. This study involved input and evaluations from eleven experts who assessed risks based on defined scales. However, potential individual bias influenced by personal experience or perceptions of risks that do not directly affect them could impact the results. Limited openness to dissent also highlights an area for improvement in the qualitative methodology.

The lack of comprehensive literature on risks in the first stage of the Persian lime supply chain complicates comparisons with previous studies. Nevertheless, this work provides essential literature to support decision-makers in designing risk mitigation strategies. Additionally, it serves as an academic reference for validating results and techniques in future studies, offering a clearer perspective for more effective risk management.

4.4 Conclusions

The results obtained are satisfactory. Experts highlighted notable consistency between the causes and effects of the risks and prioritization based on the likelihood of occurrence and the severity of damage, primarily caused by pests and diseases in crops. Currently, the literature on pest and disease control is fragmented, comprising isolated or outdated studies. Therefore, this document should update economic thresholds, present the best treatments and practices, and address the risks associated with the crop.

The Persian lime SC is a crucial economic pillar for the Martínez de la Torre Citrus District, Veracruz, and Mexico. It generates numerous direct and indirect jobs across its links. The production and commercialization of this fruit have significant economic value for producers and intermediaries, with payments made immediately at the

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time of sale at auction. Furthermore, as a perennial crop, Persian lime allows for near-year-round harvests.

To meet international market demands, the number of planted hectares and packing houses in the region increases annually. In 2020, Mexico ranked as the world's second-largest lime producer, with Martínez de la Torre contributing 31.85% of Veracruz's state production. However, in recent years, the crop has faced a series of natural events related to adverse climatic conditions, pests, diseases, and viruses and operational and supply challenges. Consequently, identifying and assessing these risks is essential to anticipate their effects.

Given the significance of the Persian lime SC, identifying, evaluating, and prioritizing risks in the first link (orchard production) of the supply chain in the Martínez de la Torre Citrus District, Veracruz, Mexico, is of particular interest, as this link ensures supply to the second link (processors and packing houses). The strategy for addressing these risks will depend on individual producers and decision-makers. However, the common goal is to mitigate their impact and reduce their likelihood of occurrence.

This study provides decision-makers with a foundation for designing risk management plans that strengthen the supply chain's resilience. These actions will ensure the continuous food supply and enable processing and packing companies in the second link to meet demand, thereby enhancing the stability and sustainability of the agro-food system against long-term disruptions.

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References

- [1] KUNCORO, D., PROFITA, A.: *Integrating supply chain risk management in agriculture: A case study of East Kalimantan granary*, Earth and Environmental Science, IOP Conference Series, Canada, pp. 1-8, 2022. <https://doi.org/10.1088/1755-1315/1063/1/012033>
- [2] Secretariat of Agriculture and Rural Development (SARD), Agricultural and fishing exports grow 4.9% in May, [Online], Available: <http://www.gob.mx/agricultura/prensa/crecen-4-9-exportaciones-agropecuarias-y-pesqueras-en-mayo> [29 Jun 2023], 2023.
- [3] Agricultural and Fisheries Information Service (AFIS), Statistical Yearbook of Agricultural Production, [Online], Available: <https://nube.siap.gob.mx/cierreagropecuaria/> [19 Jun 2024], 2024.
- [4] SHAHBAZ, M., SOHU, S., KHASKHELLY, F., BANO, A., SOOMRO, M.: A Novel Classification of Supply Chain Risks, A Review, *Engineering, Technology & Applied Science Research*, Vol. 9, No. 3, pp. 4301-4305, 2019. <https://doi.org/10.48084/etasr.2781>
- [5] BOGATAJ, D., BOGATAJ, M.: Measuring the supply chain risk and vulnerability in frequency space, *International Journal of Production Economics*, Vol. 108, No. 1-2, pp. 291-301, 2007. <https://doi.org/10.1016/j.ijpe.2006.12.017>
- [6] NEL, J., SIMON, H.: Introducing a process for radical supply chain risk management, *International Journal of Business Performance Management*, Vol. 21, No. 1-2, pp. 149-165, 2020. <https://doi.org/10.1504/IJBPM.2020.106120>
- [7] FAN, Y., STEVENSON, M.: A review of supply chain risk management: definition, theory, and research agenda, *International Journal of Physical Distribution & Logistics Management*, Vol. 48, No. 3, pp. 205-230, 2018. <https://doi.org/10.1108/IJPDLM-01-2017-0043>
- [8] TUMMALA, R., SCHOENHERR, T.: Assessing and managing risks using the Supply Chain Risk Management Process (SCRMP), *Supply Chain Management: An International Journal*, Vol. 16, No. 6, pp. 474-483, 2011. <https://doi.org/10.1108/13598541111171165>
- [9] BRADLEY, J.: An improved method for managing catastrophic supply chain disruptions, *Business Horizons*, Vol. 57, No. 4, pp. 483-495, 2014. <https://doi.org/10.1016/j.bushor.2014.03.003>
- [10] JOHN, B., CHHABDA, P., NIHLANI, A.: Risk Evaluation and Management Involved in Supply Chain Management, *Migration Letters*, Vol. 20, No. S13, pp. 35-44, 2023. <https://doi.org/10.59670/ml.v20iS13.6266>
- [11] SCHROEDER, M., LODEMANN, S.: A Systematic Investigation of the Integration of Machine Learning into Supply Chain Risk Management, *Logistics*, Vol. 5, No. 3, pp. 62-78, 2021. <https://doi.org/10.3390/logistics5030062>
- [12] KADOIĆ, N., DIVJAK, B., BEGIČEVIĆ, N.: Integrating the DEMATEL with the analytic network process for effective decision-making, *Central European Journal of Operations Research*, Vol. 27, No. 3, pp. 653-678, 2019. <https://doi.org/10.1007/s10100-018-0601-4>
- [13] SI, S., YOU, X., LIU, H., ZHANG, P.: DEMATEL Technique: A Systematic Review of the State-of-the-Art Literature on Methodologies and Applications,

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- Mathematical Problems in Engineering*, Vol. 2018, No. 1, pp. 1-33, 2018.
<https://doi.org/10.1155/2018/3696457>
- [14] CHANG, W., ELLINGER, A., BLACKHURST, J.: A contextual approach to supply chain risk mitigation, *The International Journal of Logistics Management*, Vol. 26, No. 3, pp. 642-656, 2015.
<https://doi.org/10.1108/IJLM-02-2014-0026>
- [15] ALINEZHAD, A., KHALILI, J.: *DEMATEL Method*, In: New Methods and Applications in Multiple Attribute Decision Making (MADM), International Series in Operations Research & Management Science, Vol. 277, Springer, Cham., pp. 103-108, 2019. https://doi.org/10.1007/978-3-030-15009-9_15
- [16] DALALAH, D., HAYAJNEH, M., BATIEHA, F.: A fuzzy multi-criteria decision-making model for supplier selection, *Expert Systems with Applications*, Vol. 38, No. 7, pp. 8384-8391, 2011.
<https://doi.org/10.1016/j.eswa.2011.01.031>
- [17] TSAI, S., ZHOU, J., GAO, Y., WANG, J., LI, G., ZHENG, Y., REN, P., XU, W.: Combining FMEA with DEMATEL models to solve production process problems, *PLOS ONE*, Vol. 12, No. 8, pp. 1-15, 2017.
<https://doi.org/10.1371/journal.pone.0183634>
- [18] LEE, Y., CHU, W., CHEN, Q., TSAI, S., WANG, J., DONG, W.: Integrating decision-making trial and evaluation laboratory model and failure mode and effect analysis to determine the priority in solving production problems, *Advances in Mechanical Engineering*, Vol. 8, No. 4, pp. 1-12, 2016.
<https://doi.org/10.1177/1687814016641011>
- [19] KHAN, S., HALEEM, A., KHAN, M.: Risk management in Halal supply chain: an integrated fuzzy Delphi and DEMATEL approach, *Journal of Modelling in Management*, Vol. 16, No. 1, pp. 172-214, 2020.
<https://doi.org/10.1108/JM2-09-2019-0228>
- [20] BUJNA, M., KOTUS, M., MATUŠEKOVÁ, E.: Using the Dematel Model for the FMEA Risk Analysis, *System Safety: Human - Technical Facility - Environment*, Vol. 1, No. 1, pp. 550-557, 2019.
<https://doi.org/10.2478/czoto-2019-0070>
- [21] VARELA, M., DÍAZ, L., GARCÍA, R.: Description and uses of the Delphi method in health research, *Investigación en Educación Médica*, Vol. 1, No. 2, pp. 90-95, 2012.
- [22] CHANG, T., LO, H., CHEN, K., LIOU, J.: A Novel FMEA Model Based on Rough BWM and Rough TOPSIS-AL for Risk Assessment, *Mathematics*, Vol. 7, No. 10, 874, pp. 1-20, 2019.
<https://doi.org/10.3390/math7100874>
- [23] National Water Commission (NWC), Climatological Statistical Information, Climatological database. [Online], Available: <https://smn.conagua.gob.mx/es/climatologia/informacion-climatologica/informacion-estadistica-climatologica> [19 Jul 2023], 2023.
- [24] LEYVA, G., BAUTISTA, M., ALMAGUER, G., COLINAS, M., TOVAR, J., CAMACHO, M.: Effectiveness of fungicides and Trichoderma spp. for the control of Lasiodiplodia spp. in "Persian" lemon orchards in Veracruz, *Revista Mexicana de Ciencias Agrícolas*, Vol. 12, No. 2, pp. 345-353, 2021.
<https://doi.org/10.29312/remexca.v12i2.2551>
- [25] SÁENZ, C., OSORIO, E., ESTRADA, B., POOT, W., DELGADO, R., RODRÍGUEZ, R.: Main citrus diseases, *Revista Mexicana de Ciencias Agrícolas*, Vol. 10, No. 7, pp. 1653-1665, 2019.
<https://doi.org/10.29312/remexca.v10i7.1827>
- [26] VAN, Q., HA, V., VVEDENSKY, V., HAN, V.: Current status and characterization of Phytophthora species associated with gummosis of citrus in Northern Vietnam, *Journal of Phytopathology*, Vol. 171, No. 9, pp. 478-488, 2023.
<https://doi.org/10.1111/jph.13204>

Review process

Single-blind peer review process.

Annexes

Annex 1 DEMATEL and FMEA evaluation results

Legend: "Type" classifies the risk as 1 = internal and 2 = external. C-E refers to cause-effect: CA = Causal with high influence, CB = Causal with low influence, EB = Low effect, EA = High effect.

S	No	Risk	T	FMEA					DEMATEL			
				P	D	S(Wi)	RPN	Rank	ri+ci	ri-ci	Rank	C-E
Natural	R1	Impact of a hurricane.	2	1.000	3.666	0.9711	3.561	29	1.3807	1.3247	2	CA
	R2	Impact of an earthquake.	2	1.000	7.333	0.4023	2.950	35	0.5605	0.5605	11	CB
	R3	Intense rainfall, exceeding 30 mm/h.	2	2.666	3.666	0.3113	3.044	33	0.5396	0.2916	12	CB
	R4	Hydrometeorological flooding or failures in hydraulic infrastructure.	2	2.000	5.000	0.3037	3.037	34	0.5968	-0.0425	48	EB
	R5	Abnormal to extreme drought (lack of rainfall).	2	4.333	3.333	0.1732	2.501	37	0.3320	0.0784	17	CB
	R6	High temperatures, intense heat (35°C-39°C), very high (40°C-44°C) to extreme (45°C or more).	2	4.000	3.333	0.7391	9.854	10	1.0297	1.0297	4	CA
	R7	Low temperatures, moderate (20°C-15°C), strong (14°C-10°C), very strong (9°C-5°C), extreme below to 4°C.	2	2.000	3.333	0.3693	2.462	38	0.5145	0.5145	14	CB
	R8	Water scarcity or depletion of the water supply source	2	3.000	3.333	0.2728	2.728	36	0.5358	0.0423	13	CB

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	R9	Temperature changes in a short period, from cool 22°C-27°C to heat 28°C-35°C or more within 1 to 2 days.	2	5.333	3.000	0.6610	10.576	8	0.9209	0.9209	7	CA
	R10	Impact of a pandemic, epidemic, or seasonal diseases (can impact labor shortages, absenteeism, and mobility restrictions).	2	1.666	5.333	0.4998	4.443	27	0.9840	0.0374	5	CA
Pests	R11	Incidence greater than 2u/cm ² of White mite (<i>Polyphagotarsonemus latus</i>)	2	5.000	4.333	0.3216	6.968	17	0.5209	-0.3608	44	EB
	R12	Incidence greater than 3u/cm ² of Citrus blackfly (<i>Phyllocoptruta oleivora</i>)	2	4.333	4.333	0.3049	5.725	20	0.4248	-0.4248	39	EB
	R13	Presence of Citrus green stink bug (<i>Closterotomus trivialis</i>)	2	3.333	5.000	0.1961	3.268	31	0.2732	-0.2732	31	EB
	R14	Incidence greater than 3u/cm ² of Red spider mite on fruit (<i>Panonychus citri</i>)	2	5.333	3.666	0.3587	7.014	16	0.4997	-0.4997	42	EB
	R15	Presence of Asian citrus psyllid (<i>Diaphorina citri</i> Kuwayama) on new shoots.	2	6.666	4.000	0.3618	9.647	11	0.6157	-0.3591	50	EB
	R16	Incidence greater than 1u/cm ² of Thrips (<i>Pezothrips kellyanus</i>)	2	6.333	4.000	0.2718	6.885	18	0.3787	-0.3787	37	EB
	R17	Presence of Snow scale (<i>Unaspis citri</i>)	2	4.333	4.000	0.2919	5.059	23	0.4699	-0.3315	40	EB
	R18	The presence of leaf miner (<i>Phyllocnistis citrella</i>) in new shoots.	2	5.000	4.000	0.2404	4.809	25	0.3350	-0.3350	35	EB
	R19	Incidence greater than 2 Mealybugs (<i>Planococcus citri</i>) per sampled plant.	2	3.333	4.333	0.2400	3.466	30	0.3905	-0.2665	38	EB
	R20	Presence of Citrus blackfly (<i>Aleurocanthus woglumi</i>) (Proposed by E5; it affected citrus cultivation in the region in 2004).	2	2.666	4.333	0.1577	1.822	42	0.2485	-0.1865	29	EB
Diseases	R21	Incidence greater than 5% of Anthracnose (<i>Colletotrichum gloeosporioides</i>) per sampled tree during flowering.	2	5.666	5.000	0.4986	14.128	5	0.7221	-0.6661	52	EB
	R22	Incidence greater than 5% of trees with Gummosis (<i>Phytophthora spp.</i>).	2	5.666	5.333	0.6755	20.416	2	0.9862	-0.8939	53	EA
	R23	Incidence greater than 3% of trees showing visible signs of damage caused by citrus Greening disease (<i>Huanglongbing, Candidatus liberibacter asiaticus</i>).	2	5.666	7.000	0.3846	15.256	4	0.5698	-0.4996	46	EB
	R24	Incidence greater than 2% of fruits with citrus Scab (<i>Sphaceloma fawcetti</i>).	2	3.666	5.666	0.2099	4.361	28	0.2924	-0.2924	32	EB
	R25	Incidence greater than 3% of trees with melanoma (<i>Diaporthe citri</i>).	2	3.666	6.333	0.3686	8.559	13	0.5135	-0.5135	43	EB
	R26	Incidence greater than 4% of trees with Greasy spots (<i>Mycosphaerella citri</i>).	2	4.333	5.000	0.4704	10.193	9	0.6554	-0.6554	51	EB
	R27	Incidence greater than 2% of the plantation shows visible signs of damage caused by Dieback (<i>Lasiodiplodia theobromae</i> and <i>Fomitopsis meliae</i> , the causative fungi).	2	5.666	7.333	0.4036	16.774	3	0.6029	-0.5187	49	EB
	R28	Incidence greater than 2% of the plantation showing visible signs of damage caused by Sectorial streak (wood pocket).	2	4.666	5.666	0.1911	5.052	24	0.2662	-0.2662	30	EB
	R29	Incidence greater than 3% of fruits per tree with Sooty mold (<i>Capnodium citri</i>).	2	3.333	5.333	0.4009	7.127	15	0.5820	-0.5340	47	EB
	R30	Incidence of 2-3 units/cm ² of the plantation with Brown citrus aphid (<i>Toxoptera citricida</i>).	2	4.200	4.000	0.1885	3.167	32	0.3224	-0.1844	34	EB
	R31	Incidence greater than 2% of the plantation showing visible signs of damage caused by citrus Tristeza virus (<i>Citrus tristeza virus</i> , severe strain).	2	2.666	8.000	0.2532	5.401	22	0.3527	-0.3527	36	EB
Supply	R32	Acquisition of nursery plants carrying undetectable diseases.	1	5.000	7.666	0.0446	1.708	43	0.0621	0.0621	21	CB
	R33	Shortage of pesticides in commercial stores.	2	3.333	3.666	1.0000	12.222	6	1.7046	0.9881	1	CA
	R34	Shortage of operational staff for various field activities.	2	6.666	4.000	0.4581	12.217	7	0.8666	0.2527	8	CA
	R35	Shortage of specialized human resources (technicians, tractor operators, pruners).	2	4.666	4.666	0.3589	7.817	14	0.6967	0.1214	9	CB
	R36	Shortage of special spare parts for machinery or agricultural equipment.	2	4.666	4.333	0.2828	5.719	21	0.5572	-0.0032	45	EB
	R37	Fuel shortages (diesel or gasoline).	2	2.333	3.666	0.2493	2.133	40	0.4853	-0.0751	41	EB
Operations	R38	High turnover of personnel.	1	5.666	5.000	0.7379	20.907	1	1.1059	0.9437	3	CA
	R39	High absenteeism.	1	5.000	5.000	0.3853	9.632	12	0.6814	0.3346	10	CB
	R40	Operational interruptions due to internal conflicts (work stoppages, strikes, protests, sabotage).	2	2.333	3.666	0.2142	1.832	41	0.3642	0.2132	16	CB

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R41	Operational interruptions due to external socio-organizational conflicts and/or stakeholder actions (protests, demonstrations).	2	2.333	4.000	0.6582	6.143	19	0.9507	0.8821	6	CA
R42	Operational interruptions or shutdowns due to non-compliance with national and international laws and regulations.	2	2.000	3.000	0.3659	2.195	39	0.5098	0.5098	15	CB
R43	Negative financial impact due to crime and insecurity (theft, kidnapping, additional security costs, etc.).	2	4.333	5.000	0.0574	1.244	46	0.0800	0.0800	19	CB
R44	Operational failures in integrated pest and disease management (poor monitoring, delayed interventions, etc.).	1	3.6667	5.666	0.2312	4.804	26	0.3221	-0.3221	33	EB
R45	Insufficient technological resources are needed to support pest and disease monitoring and prediction, as well as climatic conditions (systems, software, technology).	1	7.000	1.666	0.0527	0.614	49	0.0734	-0.0734	27	EB
R46	Failures in main agricultural machinery and equipment (tractors, implements, pumps, etc.).	1	6.000	5.666	0.0405	1.376	44	0.0564	-0.0564	26	EB
R47	Insufficient capacity for integrated pest and disease management (limited resources, conventional machinery, equipment, and tools).	1	5.333	2.333	0.0919	1.143	47	0.1280	0.1280	18	CB
R48	Lack of phytosanitary attention after tree pruning.	1	5.333	3.333	0.0000	0.000	52	0.0000	0.0000	24	CB
R49	Excessive time is required for financial resource approval to purchase pesticides and fertilizers (bureaucracy, extensive paperwork, or hierarchy).	1	7.000	3.666	0.0495	1.271	45	0.0690	0.0690	20	CB
R50	Restriction or prohibition of pesticide molecules in the destination market.	2	2.000	3.000	0.0000	0.000	53	0.0000	0.0000	25	CB
R51	Accidental orchard fire (due to grassland or sugarcane field burning or drought).	2	1.333	6.000	0.1101	0.881	48	0.2023	-0.0783	28	EB
R52	Improper nutritional management of plants.	1	3.666	5.666	0.0223	0.462	50	0.0310	0.0310	22	CB
R53	Lack of knowledge of integrated crop management (control of pests, diseases, and nutrition).	1	4.000	4.333	0.0201	0.348	51	0.0280	0.0280	23	CB

Improving performance measurement through quality management in logistics 4.0: case of a smart port

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Abstract: This research project focuses on improving logistics performance in the context of Logistics 4.0, by implementing the use of quality management principles. In addition, the study looks at international companies operating in the port of Tangier Med. The objective is to measure the impact of improving overall performance on overall business results, taking into account quality standards, management tools and the effectiveness of decisions made. The research will take a quantitative approach by examining logistics performance improvement variables in a 4.0 context. It focuses on how the integration of quality management methods can influence business performance. This study contributed to the development of scientific research in the field by providing tangible information and quantitative data on the impact of improving logistics performance in an international environment. The results of this research aim to provide innovative solutions for international companies operating in the port of Tangier Med. By combining the concepts of Logistics 4.0 with quality management practices, companies could benefit from a significant improvement in their operational efficiency and overall results. Ultimately, this research project has contributed to the promotion of best practices and the adoption of innovative approaches in the field of Logistics 4.0, thus providing competitive advantages to companies operating in this sector. A quantitative methodology was adopted. Surveys of 300 employees at the port provided quantitative data.

1 Introduction

The advent of Logistics 4.0 has revolutionized the way companies manage their operations, highlighting the integration of technology and automation to optimize workflows and improve efficiency. In this constantly changing environment, the focus on improving performance becomes paramount to maintaining competitiveness on the global stage. It is with this in mind that this research project aims to examine in depth the improvement of performance in the field of logistics 4.0, highlighting the importance of quality management methods. More specifically, this study focuses on a relevant case: that of international companies established in the port of Tangier Med. This port, as a major hub for international trade, provides an ideal setting to explore how quality management principles can be applied to strengthen logistics performance in the era of Logistics 4.0. The methodological approach adopted for this research is based on an in-depth quantitative study. The use of surveys of 300 employees working in the port made it possible to collect rich and varied quantitative data. By measuring the key variables related to improving overall performance, this study aims to assess the impact of quality management methods on the results of companies operating in the port of Tangier Med. By contributing to the development of scientific research, this study aspires to open new perspectives in the field of logistics 4.0. By taking a close look at how global companies can benefit from integrating quality management principles, this research aims to provide innovative solutions to optimize operational

performance and overall results. This study offers an informed vision of the opportunities and challenges in the quest for a more efficient and competitive 4.0 logistics in the dynamic context of the port of Tangier Med.

2 Literature review

Logistics 4.0, as an integral component of the fourth industrial revolution, represents a paradigm shift in global logistics and supply chain management. It integrates emerging technologies such as the Internet of Things (IoT), artificial intelligence (AI), big data analytics, cloud computing, and cyber-physical systems to create intelligent, responsive, and highly interconnected supply chains [2-6]. In the port environment, these technologies enable real-time monitoring and optimization of cargo flows, significantly reducing delays and operational bottlenecks while improving the coordination between multiple stakeholders including shipping lines, terminal operators, customs authorities, and logistics service providers [3-7]. The deployment of smart sensors and automated handling equipment enhances the precision and speed of cargo operations, while AI-driven predictive models facilitate better resource planning and decision-making, particularly in large and complex port infrastructures like Tangier Med [8,9]. Moreover, the integration of blockchain technology within Logistics 4.0 ecosystems ensures greater transparency, traceability, and security of transactions, thus reducing the risks of fraud and administrative errors that often hamper international trade operations [10]. These technological advancements not

only streamline operations but also contribute to the environmental sustainability of ports by optimizing energy consumption and reducing carbon emissions through intelligent route planning and automated systems [11,12]. However, despite these promising opportunities, the adoption of Logistics 4.0 faces several challenges such as resistance to change, a lack of standardized protocols, and the need for upskilling human capital to manage and operate these advanced systems effectively [13,14]. Consequently, ports embracing Logistics 4.0, such as Tangier Med, position themselves as strategic nodes in global supply chains, enhancing their competitiveness and resilience in the face of ever-evolving market demands and technological disruptions [13,15,18].

2.1 Logistics 4.0 and its impact on ports

Logistics 4.0 is based on a complete digitalization of logistics activities, facilitating real-time operations and dynamic decision-making across the entire supply chain. By leveraging advanced technologies such as big data analytics, artificial intelligence (AI), and the Internet of Things (IoT), it promises a significant improvement in port performance in terms of speed, reliability, and traceability [1,2]. In the specific context of ports, the integration of smart IoT sensors enables continuous data collection on cargo status, equipment usage, and environmental conditions, allowing operators to anticipate congestion, optimize resource allocation, and prevent delays. Collaborative digital platforms enhance communication and coordination between shipping companies, terminal operators, and customs services, thereby streamlining administrative procedures and reducing vessel turnaround times [16]. Intelligent management systems further support predictive maintenance, automate container handling operations, and improve inventory management, ensuring better space utilization and reducing human error. These technological advancements collectively contribute to maximizing quay capacity, enhancing operational efficiency, and strengthening the port's competitiveness on an international scale. However, the successful adoption of Logistics 4.0 in ports is not without challenges. Resistance to change often stems from the reluctance of traditional actors to modify established workflows and adopt new digital tools. Moreover, the absence of global standards for data exchange and technology interoperability complicates the seamless integration of these systems. Ports in developing regions, in particular, face additional barriers due to limited technical skills and insufficient investment in infrastructure and training, which hinders the full realization of Logistics 4.0 potential [17-23]. Addressing these challenges is crucial for ports aspiring to become smart, resilient, and competitive hubs in the global logistics network.

2.2 The role of quality management in logistics performance

Quality management (QM) focuses on the implementation of standards, processes, and approaches to continuously improve the performance of organizations [18-24]. In a port environment, QM can enhance the reliability of operations, minimize human and technical errors, and improve customer satisfaction [11-19]. The adoption of international standards such as ISO 9001 in ports helps structure and standardize logistics processes, thereby promoting proactive management and increased responsiveness.

These principles are equally applicable in complex operational settings, such as ports, where the efficiency of logistics and operations significantly impacts the broader supply chain. In a port environment, quality management is crucial for maintaining smooth and efficient operations, which directly influence the reliability of services provided to customers. By focusing on quality, ports can reduce both human and technical errors, which are common sources of delays and inefficiencies. This can range from minimizing mistakes in cargo handling and documentation to ensuring the timely maintenance of machinery and equipment. Through the systematic application of QM principles, ports can significantly enhance operational reliability, reduce operational costs, and improve the safety and security of both workers and cargo. Furthermore, adopting internationally recognized quality standards such as ISO 9001 is an effective way for ports to standardize their processes. ISO 9001, with its rigorous focus on process control, customer satisfaction, and continual improvement, provides a structured framework for ports to assess and optimize their operations. This global standard promotes a consistent approach to managing quality, fostering transparency, accountability, and collaboration between different departments and stakeholders within the port ecosystem. Additionally, it strengthens a port's competitive advantage by ensuring that it meets international expectations, thereby attracting global business partners and customers.

The adoption of ISO 9001 and other quality management practices can also lead to increased responsiveness in port operations. With a structured system in place, ports can more easily adapt to changes in demand, emerging challenges, and unexpected disruptions, such as weather events, labor strikes, or supply chain shifts. This proactive approach ensures that ports remain agile and can quickly implement corrective actions or improvements where necessary. Ultimately, the integration of quality management practices not only elevates the operational standards within ports but also enhances customer satisfaction by ensuring the timely, efficient, and reliable delivery of services.

2.3 Interaction between Logistics 4.0 and quality management

Quality management acts as a key lever to maximize the benefits of Logistics 4.0. Advanced technologies such as AI and data analytics improve quality control systems by enabling early detection of anomalies and process optimization [4-23]. Ports that adopt a strategy combining Logistics 4.0 and QM see improvements in their key performance indicators, including reduced operating costs, increased productivity, and increased stakeholder satisfaction.

Several case studies show how modern ports, such as Rotterdam and Hamburg, have integrated Logistics 4.0 solutions while relying on quality frameworks to optimize their performance. These ports have notably invested in digital platforms to coordinate logistics actors and ensure full traceability of goods [16]. In North Africa, ports such as Tanger Med are also beginning to adopt this combination to position themselves as competitive logistics hubs [18].

3 The specific impact of Logistics 4.0 on global supply chains

The emergence of Logistics 4.0 has profoundly transformed global supply chains by integrating cyber-physical systems, the Internet of Things (IoT), artificial intelligence (AI), big data analytics, and advanced automation [5-21]. These technological advancements are no longer limited to operational support but have become strategic assets that redefine global trade and supply chain management.

One of the most significant impacts of Logistics 4.0 is the enhancement of supply chain visibility. Real-time tracking systems and connected devices enable continuous monitoring of goods flows from production to final destination. This capability improves demand forecasting, supports proactive decision-making, and strengthens the resilience of global supply chains, particularly during disruptions such as port congestion or health crises [21-26].

Furthermore, Logistics 4.0 fosters process optimization and resource efficiency. The use of smart sensors, autonomous vehicles, and predictive maintenance reduces operational costs and downtime while improving asset utilization. This optimization contributes to faster transit times, lower inventory costs, and increased flexibility in supply chain operations [20-25].

Another essential aspect is the integration of blockchain technologies, which enhances transparency and trust among global supply chain stakeholders. Blockchain secures transactions and documentation, reduces fraud risks, and accelerates customs clearance processes — a crucial advantage for large transshipment hubs like the Port of Tanger Med [18-27].

Logistics 4.0 contributes to supply chain sustainability by enabling data-driven environmental optimization. Advanced analytics help reduce fuel consumption and

emissions through route optimization, thus meeting growing environmental and corporate social responsibility demands [28]. However, these benefits come with challenges. Data standardization, interoperability, and digital skills gaps remain major obstacles to the full deployment of Logistics 4.0 within global supply chains [29,30]. Diverse technological capabilities across international actors can hinder seamless integration and limit the expected efficiency gains.

The impact of Logistics 4.0 on global supply chains is transformative. By enhancing visibility, operational efficiency, transparency, and sustainability, while also demanding significant organizational adaptation, Logistics 4.0 provides a competitive edge to major logistics hubs like Tanger Med Port, reinforcing their position as pivotal players in international trade [18].

4 Materials and methods

The literature highlights that major shipping companies operating at the Tanger Med container terminals include Maersk Line, CMA-CGM/Delmas, Hamburg Süd, Hapag Lloyd, ARKAS, and Tanger Alliance [1]. Tanger Med Port has four container terminals with a total capacity of 9 million TEUs, making it the leading container port in Africa and the Mediterranean by volume. In 2022, it handled 7.6 million TEUs, ranking as the fourth most efficient port globally according to the Global Container Port Performance Index (CPPI). The port is connected to 174 ports in 74 countries [18] and serves as a strategic hub for transshipment and trade, particularly for Morocco's import/export activities. Tanger Med I connect the port to inland areas via rail and highways, enhancing its role in the region's logistics network.

Maersk Line, founded in 1928 and headquartered in Copenhagen, Denmark, began operations at Tanger Med in 2005. As the largest container shipping company globally, Maersk operates a fleet of 639 ships and handles approximately 12 million containers annually. In 2016, Maersk reported a net income of \$20.7 billion and invested \$822 million to improve Tanger Med's infrastructure. APM Terminals, also part of the Maersk Group, has operated at Tanger Med since 2005 and handles 43% of transshipments and 48% of container movements at the port.

The CMA-CGM Group, founded in 1978 and based in Marseille, France, started operating at Tanger Med in 2008. With 449 ships and 29,000 employees, the company handles 15.6 million TEUs globally. CMA-CGM/Delmas operates at the second terminal of Tanger Med in partnership with EUROGATE, Contship Italia, and MSC. In 2016, CMA-CGM/Delmas managed 16% of container movements at Tanger Med, a significant increase from 13.4% in 2014.

Hamburg Süd, established in 1871 and headquartered in Hamburg, Germany, has operated at Tanger Med since 2008. With 177 ships and a capacity of 4.3 million TEUs, Hamburg Süd handles around 7% of the port's container

movements. The Maersk Group acquired Hamburg Süd in 2016.

ARKAS, founded in 1996 and based in Istanbul, Turkey, began operating at Tanger Med in 2008. The company's fleet of 39 vessels handles containers from Europe, Africa, the Middle East, and recently South and Central Asia. Arkas contributes 3-4% of container movements at the port.

Hapag-Lloyd, headquartered in Hamburg, Germany, is the fifth-largest container shipping company globally. Operating at Tanger Med since 2006, Hapag-Lloyd contributes 9-10% of the port's container movements and transshipments.

X-Press Feeders, founded in Singapore in 1972, began operating at Tanger Med in 2008. With a fleet of 110 vessels, X-Press Feeders handles about 2% of the port's transshipments and 5% of container movements.

The aim of this study is to explore how quality management can improve logistics performance, particularly for international companies operating at Tanger Med Port. By measuring performance improvements and applying quality management tools, the study will assess the effectiveness of management decisions, contributing to scientific research and the development of innovative solutions for Logistics 4.0.

For data processing, we chose to use SPSS software for this study due to its ease of use and accessibility, although it has some limitations compared to more advanced software. SPSS is known for its user-friendly interface, making it particularly suitable for researchers and practitioners who are not necessarily experts in statistics or programming. This simplicity allowed us to focus more on data analysis without wasting time mastering complex software, which was essential for our study. In addition, SPSS performs well for standard statistical analyses such as correlation tests, regressions, t-tests, and analyses of variance, which were sufficient to meet the needs of our research. The software is also widely validated in academia, making it a reliable choice for basic to intermediate quantitative analyses. However, we are aware that SPSS has limitations compared to software like R or Python, which are better suited for processing large amounts of data or for more advanced statistical analyses, such as machine learning or complex models. In terms of flexibility, SPSS offers fewer possibilities than these other tools, as it is less customizable and less powerful for certain nonparametric analyses or advanced models. In addition, the cost of using SPSS can be a disadvantage, especially in comparison to R or Python, which are free and open source. Nevertheless, due to its effectiveness for simple to moderate analyses, its availability in many academic institutions, and its robustness, SPSS was a pragmatic

choice for our study. For future analyses requiring more sophisticated tools, we may consider using more advanced software like R or Python.

5 Results and discussion

In the software industry, the developers will never state that the product is free of imperfections, dissimilar to other modern item makers generally do. This distinction is because of the accompanying reasons.

5.1 Technical performance and quality management within port terminals

A Pearson correlation is used when it is necessary to find a relationship between two or more variables and check if there is significance ($p\text{-value} < 0.05$). There can be a positive or negative correlation between two or more variables. So, if the value exceeds the significance level of 0.05, a null hypothesis should be accepted, and if the value does not exceed the significance level, the alternative hypothesis can be accepted. To use a Pearson correlation; the variables should be both quantitative and the research hypothesis should be about linear relationships. Thus, for each increase in the independent variable, the dependent variable will also increase. In this part of the chapter, the correlation analysis was assessed between technical, organizational and governance factors (independent variables) and the level of (dependent) significance.

Table 1 shows the correlation coefficient between the technical services provided at the Tanger Med port, the level of services and the challenges that guide port operations. Correlation analysis is basically done to assess the interrelation between two quantitative variables and to analyze the statistical association between them. From the table, it can be assumed that the technical support variables have a high Pearson correlation. However, the $p\text{-values}$ of 'Transport vehicles' (0.040), 'Equipment and facilities are automated' (0.021) and 'Beachside cranes' (0.025) indicate that these variables are significant at the 0.05 level. . Thus, it is shown that these variables have a confidence interval of 95% and that since they do not exceed the level of 0.05, they reject the null hypothesis and are consistent with the alternative theory. In addition, the $p\text{-values}$ of "the water depth of the port" (0.001), "the length of the quay is suitable" (0.000), "the volume of cargo handled by the port" (0.000), "The quality and the quantity of transport and transfer equipment used in the port are sufficient and efficient for good port performance" (0.001), "Port containerization" (0.000) and "stacking equipment" (0.000) indicate that these variables are significant at the 0.01 level. Thus, the variables are consistent with the alternative theory and reject the null hypothesis.

Table 1 Correlation analysis statistics for technical services at Tanger Med Port

		Niveau du service
Terminal water depth	Pearson correlation	0.463**
	sig. (2-tailed)	0.001
	N	50
Mooring length is suitable for vessels of all sizes	Pearson correlation	0.592**
	sig. (2-tailed)	0.000
	N	50
The quality management of the cranes used are optimal for handling incoming containers	Pearson correlation	0.473**
	sig. (2-tailed)	0.001
	N	50
Containerization at the Terminal	Pearson correlation	0.542**
	sig. (2-tailed)	0.000
	N	50
stacking equipment	Pearson correlation	0.514**
	sig. (2-tailed)	0.000
	N	50
Management processes	Pearson correlation	0.291*
	sig. (2-tailed)	0.040
	N	50
Equipment and facilities are automated	Pearson correlation	0.327*
	sig. (2-tailed)	0.021
	N	50
The volume of goods handled by the terminal	Pearson correlation	0.697**
	sig. (2-tailed)	0.000
	N	50
Available seaside cranes are effective	Pearson correlation	0.317*
	sig. (2-tailed)	0.025
	N	50

Regression analysis of post-correlation studies was also conducted to test effective variables that influence overall port operations. With studies of regression models, ANOVA and regression coefficient, was done to predict that the dependent variable, Level of services, influences port operations at Tanger Med port. An analysis of the regression coefficients was performed to check the importance of the predicted variable and how the predicted variable is influenced by the independent variables.

5.2 ANOVA model and statistics between technical services and port operations

Statistical correlation analysis of organizational services provided by Tanger Med port authorities has been shown in Table 4.20. From the statistical analysis, it was found that all the factors have very high Pearson correlation values and variables like; "Online customs service is available" (0.754), "Transactions are available online" (0.749), "The quality and quantity of transport and transfer equipment used in the port are sufficient and efficient for good performance port" (0.723) and "Loss settlement" (0.711) were proven as they were able to achieve the highest Pearson correlation values. Furthermore, the p-values for these variables were also found to be 0.000, which means that the variables are

significant at a level of 0.01 and a confidence level of 99%. Other Pearson low correlation variables such as, "Customs service" (0.581), "Availability of port accessibility information online" (0.543), "Vessel movement can be tracked online" (0.521) and rest of the variables also showed significance at a level of 0.01 and a confidence level of 99%. Thus, one can interpret that, since the variables have p-values less than 0.05 and do not cross the threshold, the variables can accept.

Table 2 shows the regression coefficient evaluated between the factors and the level of services at the Tanger Med port. Thus, from the table, it was found that "Mooring length is suitable" (0.000), "Port containerization" (0.015), "Stack equipment" (0.011) and "Volume of goods handled by the port" (0.001) have a positive and significant value (<0.05), which implies that an increase of one unit would respectively increase the overall operations of the Tanger Med port. Thus, these variables can be considered as the most significant variable of the technical services which influence the whole port operations. Moreover, with a high beta value, "Mooring length is adequate" (0.326), "Containerization at the port" (0.217), "Stack equipment" (0.213) and "Volume of goods handled by the port" (0.343) indicate that the more the effective improvement of these factors will have a positive impact on the whole of the

operations of the port. This is interpreted as with each one standard deviation increase in "mooring length is adequate", "port containerization", "stacking equipment"

and "volume of cargo handled by port", port operations in Tangier Med will also increase.

Table 2 ANOVA model and statistics between technical services and port operations

Factors		Standardized coefficients Beta	T	Sig.
1	(Constant)		-4.079	0.000
	Terminal water depth	0.131	1.661	0.105
	La longueur de l'amarrage convient aux navires de toutes tailles T2	0.326	4.170	0.000
	La quantité et la qualité des grues utilisées sont optimales pour traiter les conteneurs entrants T3	0.047	0.572	0.571
	Mooring length is suitable for vessels of all sizes	0.217	2.542	0.015
	L'équipement d'empilement T5	0.213	2.674	0.011
	Les véhicules de transport T6	0.067	.876	0.386
	The quality management of the cranes used are optimal for handling incoming containers	0.116	1.523	0.136
	The volume of goods handled by the Terminal	0.343	3.579	0.001
	Available seaside cranes are effective	0.031	0.374	0.711

5.3 Quantitative data, normality and reliability test

The methodology employed to conduct and assess the research on port performance indicators and the challenges affecting port operations was outlined. In this section of the study, the results and interpretations of the primary data collected and analyzed are presented. Various intervariable tests, including reliability, correlation, regression, and ANOVA, were performed using primary data gathered from employees of different shipping companies at the Tangier Med port. The findings from the quantitative analysis contributed to addressing the research questions and testing the hypotheses. Reliability tests were conducted to assess the internal consistency between the study variables, while correlation, regression, and ANOVA tests were used to analyze the hypotheses. Descriptive analysis provided insights into the frequency distribution of responses, while inferential analysis demonstrated the relevance of the primary data and helped answer the research questions.

On the other side, we will present the main results and interpretations of the analysis of secondary data collected and processed.

Quantitative data from 100 employees of logistics companies in the Tangier Med Port then analyzed the data using SPSS (v21.0) and Microsoft Excel statistical tools. The "Cronbach's Alpha" reliability test is crucial for assessing the internal consistency between the study variables. It is used to examine the interrelationship and

proximity of the variables to one another. However, a high reliability score does not indicate a unidimensional nature of the variable; it is merely a test to evaluate the stability of a theoretical measure. Additionally, another hypothesis test was conducted to validate the collected data and its expected values. The normality test for the hypothesis was performed to determine if the dataset followed a normal distribution. When conducting this test, it is essential to check whether the variables show a "Shapiro-Wilk (W)" statistic less than "1," which indicates that the observed distribution deviates from a normal distribution. Furthermore, when the "W" value is sufficiently small, the p-value must also be below 0.05 (at the 5% significance level).

Table 3 Shapiro-Wilk normality test for the collected data set

	Shapiro-Wilk		
	Statistics (w)	Ddl	Signification (p)
Overall performance	0.864	50	0.000
Technical	0.941	50	0.015
Organizational	0.924	50	0.003
Quality management	0.922	50	0.003

Table 3 presents the results of the Shapiro-Wilk normality test for the respondents working at the port of Tangier Med. The normality test was conducted on several operational factors affecting port performance, and the

results indicate that the data for most of these factors do not follow a normal distribution. Specifically, the p-values for the variables related to Technique (0.015), Organization (0.003), and State Benefits (0.003) are all below the critical threshold of 0.05. This suggests that the data for these variables significantly deviate from a normal distribution, as the Shapiro-Wilk test indicates non-normality when the p-value is less than 0.05. Therefore, based on the outcomes of the normality test, it can be concluded that the dataset collected from the port of Tangier Med does not exhibit a normal distribution across these key operational factors. This non-normality has implications for the choice of statistical methods to be used in subsequent analysis, as non-parametric tests may be more appropriate for interpreting these results.

Table 4 Co-effectiveness of Cronbach's Alpha reliability

Cronbach reliability test		
Factors	Cronbach's alpha	Number of items
Technical performance	0.887	10
Organizational Performance	0.890	12
Quality management	0.847	5

The reliability test was conducted to assess the stability and consistency among the key factors—Technical, Organizational, and the Benefits granted by the State—that influence port operations. The primary objective of this test was to evaluate the internal consistency of the data collected through the survey, ensuring that the variables measured are reliable and produce stable results. As indicated in Table 4. The Cronbach's alpha coefficients for each factor were found to be well above the commonly accepted threshold of 0.6, with values of 0.887 for Technical, 0.890 for Organizational, and 0.847 for benefits granted by the State. These high Cronbach's alpha values suggest a strong internal consistency between the items within each factor, demonstrating that the data collected is both stable and reliable. This high level of consistency reinforces the validity of the factors in accurately reflecting the operational aspects of port management, and it supports the robustness of the study's findings. Consequently, the results can be interpreted as indicating that the factors under consideration are stable and consistent in their influence on port operations, providing a solid foundation for further analysis.

Table 5 Model of regression analysis between logistics performance and quality management

Model	R	R-R	R- R adjusted
1	0.855	0.923	0.920

Table 4 presents an in-depth regression analysis that explores the links between the different organizational services offered by the companies defined in the port of Tangier Med. The results revealed by this statistical

analysis present significant indicators. Indeed, the coefficient of determination, also called R-squared, displays a value of 0.923, equivalent to 85.5%. Moreover, the adjusted R-squared, which reached 0.920, or 92.0%, highlights the strong correlation between logistics services and overall business operations. In other words, each logistics service plays a crucial role in influencing the overall operations of companies operating from the port of Tangier Med.

A crucial observation follows from these results. Indeed, they show that the rise in organizational performance variables exerts a direct influence on the increase in overall operations within companies in this logistics area. In other words, an improvement in organizational performance factors will inevitably lead to a concomitant increase in operational activities on a global scale thanks to an optimal quality management system. This finding highlights the crucial importance of logistics services in the overall operations of companies, thus conferring an in-depth understanding of the mechanisms underlying the optimization of organizational and operational performance in the specific context of the port of Tangier Med.

5.4 Discussion

Our study centered on enhancing performance within the framework of Logistics 4.0 by utilizing quality management practices, with a particular focus on international companies operating within the port of Tangier Med. This research aimed to explore how the integration of quality management methodologies could contribute to optimizing performance in the evolving landscape of Logistics 4.0, specifically in the context of global players in the port's logistics ecosystem. The objective was to gain a deep understanding of how these practices could be applied to enhance the operational efficiency of companies and improve overall logistics performance. To achieve this, we adopted a comprehensive approach to data collection, drawing from both qualitative and quantitative sources. On one hand, we utilized official Port Authority publications, such as press releases, newsletters, and other resources available through the port's website, to gather secondary data. These sources provided valuable insights into the operations and strategies in place at the port of Tangier Med, particularly in relation to Logistics 4.0 and the practices being implemented by international companies. Additionally, the resources from the Tanger Med Special Agency (TMSA) were integral to our research, offering detailed information about port policies, infrastructural developments, and strategic objectives that align with the broader logistics goals of the region. On the other hand, to complement and deepen our findings, we incorporated a quantitative research approach, engaging port employees through a structured survey. A questionnaire was specifically designed and distributed to gather primary data on their perspectives regarding the impact of quality management

on performance in the context of Logistics 4.0. To ensure the reliability and validity of the collected data, we employed the "SPSS" software for statistical analysis, which allowed us to manage, analyze, and interpret the responses effectively. The core of our methodology involved testing hypotheses related to the influence of quality management practices on performance enhancement within the Logistics 4.0 framework. This rigorous empirical approach enabled us to probe and assess the correlation between quality management strategies and improvements in logistics performance, providing a quantitative dimension to our study and strengthening the credibility of our findings. Through this combined approach, we were able to draw valuable conclusions about the significant role of quality management in driving performance improvement in the dynamic environment of Logistics 4.0, with particular attention to international companies at Tangier Med. The integration of both qualitative and quantitative data not only enriched our understanding of the subject but also contributed to a more comprehensive exploration of the ways in which logistics performance can be optimized in global port environments. This research ultimately provided a robust empirical foundation for understanding and applying the principles of Logistics 4.0 in the context of international ports, offering new insights into the pivotal role of quality management in enhancing performance across complex logistics networks. The combination of diverse data collection techniques and advanced analytical methods has provided substantial value to our results and opened up important perspectives for future research and practical applications within the domain of Logistics 4.0.

6 Conclusion

In conclusion, this research project has shed new light on performance improvement within the dynamic context of Logistics 4.0, based on the integration of quality management practices. Particularly focused on international companies established at the port of Tangier Med, this study has provided significant insights into the optimization of logistics operations in a constantly changing environment. The objective of this research was to quantify the impact of quality management methods on improving the overall performance of companies. Performance improvement variables have been thoroughly analyzed to understand their influence on overall business results. Quality management requirements and tools served as a common thread to guide this exploration, while examining the effectiveness of decisions made in the logistics 4.0 context. The methodology adopted, based on a quantitative approach, made it possible to gather tangible and substantial data. Surveys of 300 port employees provided crucial information to support our analyses. The results highlighted the significant correlation between improved logistics performance and quality management practices in international companies. The importance of this research lies in its contribution to the development of

scientific research in the field of Logistics 4.0. By highlighting the links between quality management practices and performance improvement, this study paves the way for innovative solutions for optimizing logistics operations. The conclusions drawn from this research offer practical and strategic perspectives for companies operating in a constantly changing environment, such as the port of Tangier Med. This research lays the groundwork for a more informed and efficient approach to Logistics 4.0 by highlighting the crucial role of quality management methods. The results obtained offer concrete opportunities to improve business performance, thus propelling operational efficiency and competitiveness on the international scene.

References

- [1] BENABDEJLIL, N., LUNG, Y., PIVETEAU, A.: *L'émergence d'un pôle automobile à Tanger (Maroc)*, Emergence of an automotive cluster in Tangier (Morocco), Groupe de Recherche en Economie Théorique et Appliquée, Université de Bordeaux, France, 2016. (Original in French)
- [2] WINKELHAUS, S., GROSSE, E.H.: Logistics 4.0: a systematic review towards a new logistics system, *International Journal of Production Research*, Vol. 58, Vol. 1, pp. 18-43, 2019.
<https://doi.org/10.1080/00207543.2019.1612964>
- [3] SULTANA, J., TEOH, S.Y., KARANASIOS, S.: The Impact of Blockchain on Supply Chains: A systematic Review, *Australasian Journal of Information Systems*, Vol. 26, pp. 1-38, 2022.
<https://doi.org/10.3127/ajis.v26i0.3755>
- [4] KAMBLE, S.S., GUNASEKARAN, A., GHADGE, A., RAUT, R.: A performance measurement system for industry 4.0 enabled smart manufacturing system in SMMES- A review and empirical investigation, *International Journal of Production Economics*, Vol. 229, No. November, 107853, 2020.
<https://doi.org/10.1016/j.ijpe.2020.107853>
- [5] ROGERSON, M., PARRY, G.C.: Blockchain: case studies in food supply chain visibility, *Supply Chain Management*, Vol. 25, No. 5, pp. 601-614, 2020.
<https://doi.org/10.1108/SCM-08-2019-0300>
- [6] LERMAN, L.V., BENITEZ, G.B., MÜLLER, J.M., DE SOUSA, P.R., FRANK, A.G.: Smart Green Supply Chain Management: A Configurational Approach to Enhance Green Performance through Digital Transformation, *Supply Chain Management*, Vol. 27, No. 7, pp. 147-176, 2022.
<https://doi.org/10.1108/SCM-02-2022-0059>
- [7] GONZÁLEZ-CANCELAS, N., MOLINA SERRANO, B., SOLER-FLORES, F., CAMARERO-ORIVE, A.: Using the SWOT Methodology to Know the Scope of the Digitalization of the Spanish Ports, *Logistics*, Vol. 4, No. 20, pp. 1-20, 2020.
<https://doi.org/10.3390/logistics4030020>

- [8] CHANG, A., EL-RAYES, N., SHI, J.: Blockchain Technology for Supply Chain Management: A Comprehensive Review, *FinTech*, Vol. 1, No. 2, pp. 191-205, 2022. <https://doi.org/10.3390/fintech1020015>
- [9] MRUGALSKA, B., AHMED, J.: Organizational Agility in Industry 4.0: A Systematic Literature Review, *Sustainability*, Vol. 13, No. 15, 8272, pp. 1-23, 2021. <https://doi.org/10.3390/su13158272>
- [10] THOBEN, K.D., WIESNER, S., WUEST, T.: "Industrie 4.0" and smart manufacturing-a review of research issues and application examples, *International Journal of Automation Technology*, Vol. 11, No. 1, pp. 4-16, 2017. <https://doi.org/10.20965/ijat.2017.p0004>
- [11] PACAUX-LEMOINE, M.P., TRENTESAUX, D., REY, G.Z., MILLOT, P.: Designing intelligent manufacturing systems through Human-Machine Cooperation principles: a human-centered approach, *Computers and Industrial Engineering*, Vol. 111, pp. 581-595, 2017. <https://doi.org/10.1016/j.cie.2017.05.014>
- [12] ASIF, N.W., MUHAMMAD, A.K.: The Role of Logistics 4.0 and Industry 4.0 in Promoting Sustainable Operations and Performance, *Jordan Journal of Mechanical and Industrial Engineering*, Vol. 19, No. 1, pp. 105-128, 2025. <https://doi.org/10.59038/jjmie/190108>
- [13] HAI, T., STEPHEN, C., SHU-LING, C.: Quality management for seaports integrated in supply chains, *Journal of Shipping and Transport Logistics*, Vol. 4, No. 4, 2012. <https://doi.org/10.1504/IJSTL.2012.049309>
- [14] HAYDER, A.A., HASSAN, J.M.: Smart ports: towards a high performance, increased productivity, and a better environment, *International Journal of Electrical and Computer Engineering*, Vol. 13, No. 2, pp. 1472-1482, 2023. <http://doi.org/10.11591/ijece.v13i2.pp1472-1482>
- [15] ZAID, A.A., BAIG, J.: *The Impact of Supply Chain Quality Management Practices, Supply Chain Quality Management Capabilities and Knowledge Transfer on Firm Performance: A Proposed Framework*, Proceedings of the 5th NA International Conference on Industrial Engineering and Operations Management Detroit, Michigan, USA, August 10 - 14, pp. 367-374, 2020.
- [16] NGUYEN, H.P., NGUYEN, P.Q.P., NGUYEN, D.K.P., BUI, V.D., NHUYEN, D.T.: Application of IoT Technologies in Seaport Management, *International Journal on Informatics Visualization*, Vol. 7, No. 1, pp. 228-240, 2023. <http://doi.org/10.30630/joiv.7.1.1697>
- [17] MARTIN, J., THOMAS, B.J.: The container terminal community, *Maritime Policy & Management*, Vol. 28, No. 3, pp. 279-292, 2001. <http://doi.org/10.1080/03088830110060831>
- [18] IMRANI, O.E., ASSABANE, I.: Impact of industrial free zones on the business environment of emerging countries, *Acta logistica*, Vol. 10, No. 1, pp. 105-110, 2023. <https://doi.org/10.22306/al.v10i1.361>
- [19] MCAFEE, A., OOMS-WALL, K., AL QASIMI, L.: Dubai ports authority (A), *Harvard Business School*, Vol. 2003, 603061-PDF-ENG, pp. 1-19, 2003. <https://hbsp.harvard.edu/product/603061-PDF-ENG>
- [20] CALDEIRINHA, V.M.R., FELÍCIO, J.A., SALVADOR, A.S., NABAIS, J., PINHO, T.: Sistema comunitário portuário (SCP) e desempenho do porto [Port community systems (PCS) and port performance], Conference: Congresso Internacional de Desempenho Portuário, Santa Catarina – Brasil, 30.11-01.12.2018, pp. 1-28, 2018. (Original in Portuguese) <https://doi.org/10.17648/cidesport-2018-89344>
- [21] MEERSMAN, H., VAN DE VOORDE, E., VANELSLANDER, T.: *Port competition revisited*, University Antwerpen, 2010.
- [22] MOROS-DAZA, A., AMAYA-MIER, R., GARCIA-LLINAS, G., VOß, S.: *Port community system Adoption: Game theoretic framework for an emerging economy case study*, In: Paternina-Arboleda, C., Voß, S. (eds) *Computational Logistics, ICCL 2019, Lecture Notes in Computer Science*, Vol. 11756, Springer, Cham., pp. 136-153, 2019. https://doi.org/10.1007/978-3-030-31140-7_9
- [23] KAMBLE, S.S., GUNASEKARAN, A., SHARMA, R.: Analysis of the driving and dependence power of barriers to adopt Industry 4.0 in Indian manufacturing industry, *Computers in Industry*, Vol. 101, pp. 107-119, 2018. <https://doi.org/10.1016/j.compind.2018.06.004>
- [24] PSARAFTIS, H.N.: Green Maritime Logistics: The Quest for Win-win Solutions, *Transportation Research Procedia*, Vol. 14, pp. 133-142, 2016. <https://doi.org/10.1016/j.trpro.2016.05.049>
- [25] WINKELHAUS, S., GROSSE, E.H.: Logistics 4.0: a systematic review towards a new logistics system, *International Journal of Production Research*, Vol. 58, No. 1, pp. 18-43, 2020. <https://doi.org/10.1080/00207543.2019.1612964>
- [26] RIZWAN, A., KARRAS, D.A., KUMAR, J., SÁNCHEZ-CHERO, M., TABOADA, M.M.M., ALTAMIRANO, G.C.: An Internet of Things (IoT) Based Block Chain Technology to Enhance the Quality of Supply Chain Management (SCM), *Mathematical Problems in Engineering*, Vol. 2022, 9679050, pp. 1-12, 2022. <https://doi.org/10.1155/2022/9679050>
- [27] CHAWLA, R.N., GOYAL, P.: Emerging trends in digital transformation: a bibliometric analysis, *Benchmarking: An International Journal*, Vol. 29, No. 4, pp. 1069-1112, 2022. <https://doi.org/10.1108/BIJ-01-2021-0009>

- [28] CULOT, G., PODRECCA, M., NASSIMBENI, G.: Artificial intelligence in supply chain management: A systematic literature review of empirical studies and research directions, *Computers in Industry*, Vol. 162, 104132, pp. 1-17, 2024. <https://doi.org/10.1016/j.compind.2024.104132>
- [29] MALAGON-SUAREZ, C.P., ORJUELA-CASTRO, J.A.: Challenges and Trends of the logistics 4.0, *Ingeniería*, Vol. 28, No. suppl, e18492, pp. 1-28, 2023. <https://doi.org/10.14483/23448393.18492>
- [30] LEE, S.-Y., TONGZON, J.L., KIM, Y.: Port e-Transformation, customer satisfaction and competitiveness, *Maritime Policy & Management*, Vol. 43, No. 5, pp. 1-14, 2015. <https://doi.org/10.1080/03088839.2015.1105394>

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Supply chain resilience as a mitigating factor for the impact of the Sudan Crisis on the performance of food manufacturing enterprises in Egypt

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Keywords: Sudanese Crisis, Egyptian food industry, supply chain resilience, multigroup analysis, risk mitigation.

Abstract: This research investigates the Sudan Crisis's impact on the performance of food industry enterprises in Egypt. It focuses on the moderating role of supply chain resilience (SCR) capabilities in mitigating these effects and their direct influence on enterprises' performance. Employing the quantitative approach, a questionnaire survey was used to examine the hypotheses and theoretical framework. Data were collected from 365 Egyptian food industry enterprises, and partial least squares structural equation modelling (PLS-SEM) with multigroup analysis (MGA) was used to analyse the data. The results show that the Sudanese Crisis has a negative impact on the performance of enterprises, with a path coefficient (-0.111) for both grouping sectors, indicating that these effects are not statistically significant (p -values > 0.05). Also, the results indicate a significant and positive relationship between supply chain resilience (SCR) capabilities and enterprises' performance across the animal-based industry and 0.616 for the plant-based industry groups of food industries. The path coefficients for the SCR impact on ECP are 0.596 and 0.616 for the two industries, respectively. However, supply chain resilience capabilities demonstrate a significant moderating effect in the plant-based industry, p -value of 0.029, underscoring the importance of resilience measures in mitigating disruptions. The research concludes that fitted resilience strategies are essential for enhancing supply chain adaptability and protecting firm performance, particularly in industries exposed to regional conflicts. Recommendations include investments in diversified supply chains, enhanced logistical strategies, and policy support to strengthen SCR capabilities within the food industry.

1 Introduction

Political, environmental, or economic crises significantly impact supply chains across various industries worldwide, disrupting the continuous flow of goods, raw materials, and information, leading to delays, increased costs, and challenges in meeting consumer demand. For instance, political armed conflicts can result in the closure of trade routes, border restrictions, and increased uncertainty, which affects industries dependent on supply chains. The increasing effect of these disruptions can affect industry competitiveness, reduce profitability, and force enterprises to adapt by expanding their supplier bases, reconfiguring logistics strategies, and investing in alternative transport routes. The resilience and adaptability of enterprises' supply chains in various industries during political, environmental, or economic crises have become critical factors for maintaining performance stability and growth. The ongoing political and economic turmoil that erupted in Sudan in April 2023 is a clear example of how quickly disruptions can spread beyond national borders to affect neighbouring economies. The conflict in Sudan has disrupted vital trade routes and impacted agricultural output, threatening the stability of supply chains and presenting risks that introduced significant challenges for supplying neighbouring countries, particularly Egypt, which depends partially on input imports from Sudan for its main food industries. Sudan takes second place in Nile basin countries' imports to Egypt with a value of \$504.4 million in 2022, compared to \$336.7 million in 2021, an increase of 30.8%. The food industry in Egypt is likely

facing substantial challenges in sustaining its food industry performance amid such crisis. This research explores how risks emerging from the Sudanese Crisis directly influence food enterprises performance in Egypt, highlighting the impact of supply chain resilience on enterprises' performance within food industries in Egypt and the role of supply chain resilience (SCR) as a potential mitigating factor against these disruptions by investigating how adaptive and resilient supply chain practices can buffer food industry enterprises Egypt from external shocks.

While previous studies have broadly examined the impacts of crises across various sectors, there still needs to be a significant gap in understanding their specific effects on food industry operations, supply chains, and performance metrics. This study seeks to address this gap by analysing the nuanced implications of the Sudanese Crisis on Egypt's food industry enterprises, focusing on supply chain resilience as a mitigating mechanism. By concentrating on the food sector, this research offers a granular perspective on managing industry-specific vulnerabilities amidst regional instability, providing actionable insights into conflict-induced challenges and strategic responses tailored to mitigate these impacts.

The structure of this research is as follows: the next section provides a review of relevant literature, followed by an outline of the research design and methodology; subsequently, the data analysis and results are presented. The findings are then discussed, emphasizing the practical implications. The paper concludes with practical

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recommendations, a discussion of the research's limitations, and suggestions for future research.

2 Literature review

2.1 Supply chain resilience

Supply chain resilience is vital for understanding how logistics networks survive and recover from unexpected disruptions. [1] stated that supply chain resilience is the ability of a supply chain to adapt, prepare to respond to, and recover from unexpected disruptions- geopolitical conflicts or natural disasters- while maintaining continuity of operations. [2] findings underscored that resilient supply chains are characterized by a combination of flexibility, agility, and the integration of technological advancements that enable real-time responses to disruptions. From this perspective, the key factors that enhance supply chain resilience include transparency in operations, collaboration among chain partners, and the ability to quickly adjust operations when needed [3]. These factors contribute to building a culture of prediction and preparedness, enabling organizations to respond effectively in challenging times [4]. [5] emphasized that Resilient supply chains also require proactive strategies, including continuous risk analysis, contingency planning, and developing diverse supplier networks. At the same time, reactive strategies involve quick decision-making, agile response mechanisms, and effective communication [6]. [7] suggested that organizations adopt a holistic view of risks, integrate advanced data analytics, and build resilient structures that can adapt to unexpected challenges. The Dynamic Capabilities Theory, as developed by [8] highlights an organization's ability to renew and adapt its resources and capabilities to respond to rapidly changing environments and maintain competitiveness. Developing these capabilities required significant investments in organizational learning, strategic decision-making, and the alignment of various resources and processes to effectively respond to and exploit environmental changes [9].

2.2 Supply chain resilience and firm performance

[10] stated in their study the role of supply chain flexibility as a moderating factor in mitigation risks which cause uncertainty in supply chains and these risks arising from factors such as demand variability, supply disruptions, and external shocks. These risks can disrupt the flow of goods, increase costs, and negatively impact firm performance. [11] in their study on supply chain resilience and absorptive capacity during the COVID-19 pandemic, highlighted that firms with robust resilience strategies and the ability to absorb external shocks effectively mitigate risks and sustain performance during crises. Also, they emphasize that resilience supports firms in quickly adapting to disruptions. [12] reveal that supply chain resilience (SCR) capabilities positively affect firm performance and competitive advantage within the Sri Lankan apparel industry, especially re-engineering, agility

and collaboration. [13] demonstrated that firms with higher levels of resilience are better equipped to manage disruptions, ensuring continuity and operational efficiency, which leads to enhanced financial and operational outcomes.

2.3 Supply chains and conflicts

The smooth operation of supply chains, which link production, distribution, and consumption across geographies and industries, is crucial to the global economy. Nonetheless, supply networks are highly susceptible to interruptions brought on by several causes, the most important of which is violence. Conflict, whether armed, political instability, or economic sanctions, seriously threatens the movement of products, services, and raw resources [14].

In this essence, the Russia-Ukraine conflict has significantly impacted global supply chains, disrupting existing networks and posing significant challenges for sectors dependent on essential goods. [15] emphasize that the conflict has significantly affected the global food supply chain, given that Russia and Ukraine are prominent exporters of essential products, including wheat, maize, and sunflower oil. This disruption has resulted in considerable price increases, supply deficiencies, and logistical difficulties reverberating across international markets, intensifying pre-existing weaknesses revealed during the COVID-19 pandemic. [16] assert that these disruptions have exacerbated risks to supply chains by impacting not only food but also essential commodities and energy sources, highlighting the interdependent nature of global trade networks. Their analysis demonstrates how these disruptions generate cascade consequences that affect other industries, including manufacturing and transportation, and influence global economic stability.

[17] assert that the combined impacts of the Russia-Ukraine conflict and the pandemic have engendered a double crisis, impacting supply chains beyond food to energy and vital raw resources. This led numerous nations to address systemic vulnerabilities, hastening the shift to alternative energy sources and highlighting inequalities in global supply chain robustness.

2.4 The Sudan Crisis and Egypt's economy

Sudan, the third-largest country in Africa, spans 1,886,068 square kilometres and shares borders with seven neighbouring countries: South Sudan, Ethiopia, Eritrea, Egypt, Libya, Chad, and the Central African Republic [18]. Sudan has enormous agricultural and animal resources, with about 200 million acres of arable land, suitable climate, water sources, and renewable energy. The agricultural sector, with its agricultural and livestock sections, plays a crucial role in Sudan's economy, serving as the primary livelihood for most of its population and accounting for approximately 30% of its GDP. Sudan's agricultural landscape is diverse, encompassing crops such as cereals, horticultural products and valuable cash crops like sesame, ground nuts and gum Arabic, as well as

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livestock, which is one of the largest in the Arab world and Africa, with 103 million heads of cows, sheep, goats and camels, in addition to 45 million poultry and a fish wealth estimated at annual catch of 100 thousand tons. Agriculture employs over 50% of the labour force, especially in rural areas. Additionally, agricultural exports are a critical source of foreign currency, with gum Arabic contributing

to about 80% of the global annual production and substantially supporting Sudan's export economy [19]. Data for 2021 indicate that Sudanese exports were concentrated by 90.5% in certain major markets, including the United Arab Emirates, China, Egypt, and Saudi Arabia ,as shown in Table 1.

Table 1 Major markets for Sudanese exports in the years 2020 and 2021 (USD Million)

Country	Export Value 2020	Export Value 2021	Key Export Commodities
United Arab Emirates	1,637.5	2,203.1	Sesame, Gold
China	752.3	614.5	Sesame, Peanuts
Egypt	363.8	496.4	Live Animals, Sesame
Saudi Arabia	284.9	365.3	Live Animals, Leather

Source: Central Bank of Sudan - Annual Trade and Financial Report for 2021 [20].

The Sudanese Crisis has destroyed the agricultural infrastructure, a situation exacerbated by the disputes over the agricultural resources, particularly land, leading to a significant decline in agricultural production as many farmers have lost their means of production or had to flee their lands; meanwhile the decline in state support

for essential inputs, such as diesel and fertilizers, has also prompted the farmers to reduce their agricultural areas [21] thus exacerbating the food production crisis and increasing costs of basic commodities in Sudan, as shown in Figure 1, and driving higher costs for the exported agricultural products to the neighbouring countries [22].

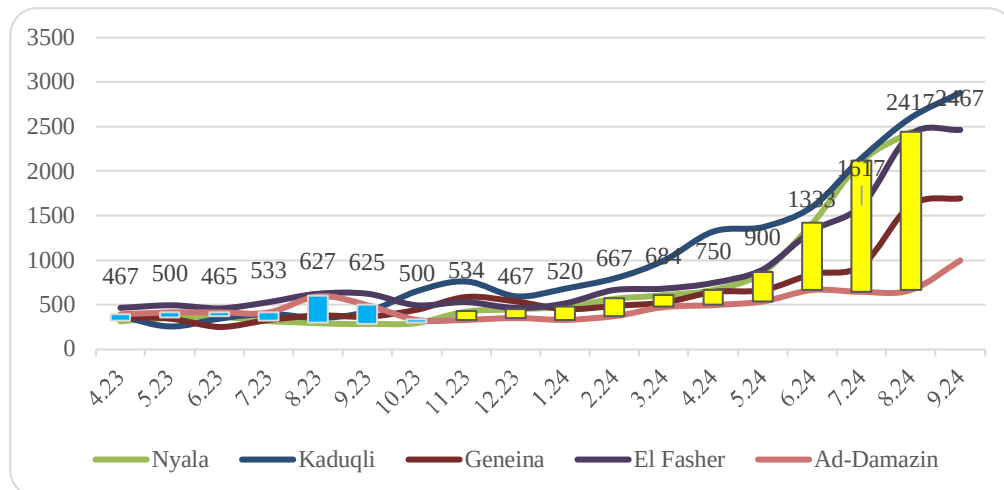


Figure 1 Sorghum retail prices April 2023-September 2024 (Sudanese pound /kilogram)

Source: FEWS NET Food Security Outlook, October 2024 [23].

The Sudanese Crisis has significant spillover effects on neighbouring economies, particularly in food production and supply chains. Sudan's position as a major regional supplier of agricultural products, livestock, and essential goods means that the disruption of its industries has reverberated across borders. Countries like Egypt, Saudi Arabia, South Sudan, Chad, and Ethiopia, which rely on imports of food, livestock, and other commodities from Sudan, have seen reduced trade flows. The closure of key trade routes and infrastructure collapse have further exacerbated the challenges of trade and supply chains. The disruptions in the supply chains, particularly in transportation and logistics, have made it difficult for these countries to secure their stable food imports from Sudan. This regional impact underscores the interconnectedness of Sudan's economy with its neighbours, especially in critical

sectors like food production and supply chain resilience [24].

The Sudanese exports to Egypt (which are mainly raw materials) constitute essential inputs for some Egyptian food industries; the trend in the value of annual Sudanese exports to Egypt shows a significant increase in recent years (especially for groundnuts, livestock, sesame and cotton), but significant fluctuations have also been observed during this period. According to the Central Agency for Public Mobilization and Statistics in Egypt, the value of Egyptian imports from Sudan amounted to \$386.9 million in 2023 compared to \$505.4 million in 2022, a decrease of 23.4%. Meanwhile, the Egyptian exports to Sudan increased to record \$979.9 million in 2023 compared to \$954.3 million in 2022, an increase of 2.7% [25].

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When comparing Sudan's annual exports of agricultural products to Egypt's total import value of the same products, we find that Sudan's export contribution varies across the period of 2019 and 2021, as illustrated in Table 2. For instance, ground nuts showed a high export percentage in 2019 at 77.03%, making it the dominant export category for that year; however, there was a sharp decline in 2020 to 15%, while in 2021, the percentage partially recovered to 35.14%, suggesting fluctuation in demand, or competitive factors. The value of Sudan's traded cotton to Egypt was

relatively steady in 2019 and 2020, at 13.71% and 13.52%, respectively, while a noticeable increase in 2021 was depicted, with cotton exports reaching 25.16% of Egypt's imports, indicating a positive shift in this trade category that can be attributed to the expansion of cotton cultivation while the spinning and weaving industry in Sudan is witnessing several structural and economic constraints that are reflected as a general local reduction demand for cotton [26,27].

Table 2 Percentage of Sudan's exports for total Egypt's imports of some traded commodities

		2019	2020	2021
chickpea	Sudan exports to Egypt	9	9	2057
	Egypt total imports	15675	16952	21853
	Sudan exports per cent of Egypt's total imports	0%	0%	9%
Ground Nuts	Sudan exports to Egypt	7973	7558	13994
	Egypt total imports	10350	49260	39820
	Sudan exports per cent of Egypt's total imports	77%	15%	35%
Cotton	Sudan exports to Egypt	32468	22905	49985
	Egypt total imports	236903	169412	198670
	Sudan exports a per cent of Egypt's total imports	14%	14%	25%
Meat	Sudan exports to Egypt	24814	20921	26989
	Egypt total imports	1984369	1711231	1146391
	Sudan exports a per cent of Egypt's total imports	1%	1%	2%

Source: Calculated from the Arab Agricultural Statistics Yearbook -Vol 42 published by the Arab Organization for Agricultural Development [26], Annual Foreign Trade Digest published by Central Bank of Sudan 2004-2022 [27].

The ongoing conflict will certainly affect trade between the two countries, Egypt and African countries, with a route in Sudan. In October 2024, the paramilitary Rapid Support Forces (RSF) of Sudan imposed an restriction on certain products (including cereals, oil crop seeds, livestock and other products, including gold) from areas under their control to areas controlled by the Sudanese Armed Forces (SAF), where exports are customarily routed to Egypt [28]. Implementing this decree will likely negatively impact on the exports, at least soon. The export decline would likely negatively affect commodity prices in Egypt, especially food and meat, given its reliance on Sudanese imports. [21] stated that as the conflict continued, most economic activities in Sudan stopped, leading to a significant decline in trade volume between the two countries.

The food industry sector in Egypt is considered one of the most prominent economic sectors, as it plays a vital role in meeting the needs of the local market and promoting exports. According to the General Authority for Export and Import Control, imports from the food industry sector recorded about \$6.664 billion in 2021, occupying fifth place in Egyptian imports [29]. Sudan takes second place in Nile basin countries imports to Egypt with a value of \$504.4 million in 2022, compared to \$336.7 million in 2021, an increase of 30.8%, and the most essential items imported [25].

2.5 Literature gap and hypotheses

While research has generally examined the broader effects of crises on various sectors, there needs to be more exploration of how such disruptions affect food industry operations, supply chains, and performance metrics. This research aims to address this deficiency by investigating the nuanced effects of Crisis in Sudan on food industry enterprises in Egypt, emphasizing the role of supply chain resilience as a mitigating factor. By narrowing the scope to the food sector, this research provides more detailed insights into how industry-specific vulnerabilities can be managed amid regional instability, contributing to a more targeted understanding of Crisis impacts and strategic responses. Motivating the following hypothesis:

H1: *Sudanese Crisis Risks negatively impact firm performance in Egyptian food Industries.*

H2: *Supply chain resilience capabilities positively impact firm performance in Egyptian food Industries.*

H3: *Supply chain resilience capabilities moderate the impact of risk caused by the Sudan Crisis on firm performance.*

Figure 2 illustrates the conceptual framework of the research.

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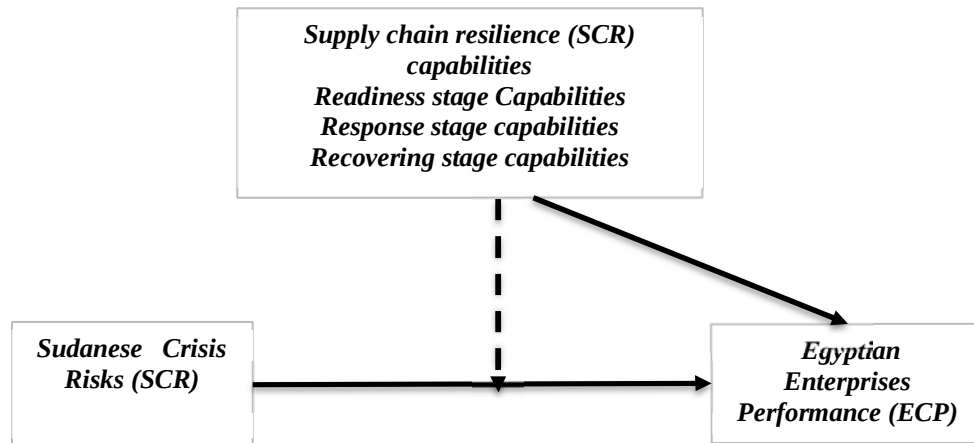


Figure 2 Research conceptual model

3 Methodology

The study population is represented by all enterprises operating in the food industry in the Arab Republic of Egypt. According to statistics published by the Central Agency for Public Mobilization and Statistics during the first quarter of 2024, the total number of enterprises operating in the food industry reached 7,219. The study sample size ($n = 365$) [30]. The calculated sample size was

distributed according to the proportion of each industry in the target population. The tool for the current study was a questionnaire designed for managers of food industry enterprises, which were selected in a stratified simple random sample. The questionnaire was distributed from May to July 2024. Table 3 shows the distribution of the target population and the stratified simple random sample of each stratum.

Table 3 Target population distribution and the sample distribution

Industry (Enterprises')	Population	%	Sample size
Meat, poultry and fish industry	732	10%	37
Manufacture of vegetable oils and fats	1088	15%	55
Dairy products industry	1226	17%	62
Vegetable and fruit industry	2156	30%	109
Manufacture of juices, drinks and water	1661	23%	84
Sugar, candy and chocolate industry	356	5%	18
Total	7219	100%	365

3.1 Multigroup Analysis (MGA)

Multigroup Analysis (MGA) is a statistical method employed to ascertain the presence of significant differences among established groups within a dataset. This method is frequently utilized in structural equation modelling (SEM) and other multivariate analytical techniques to assess the influence of factors across several subpopulations or groupings. The aim is to evaluate if the connections among variables vary significantly between groups, enabling researchers to investigate potential moderating effects and verify the stability of their models across varied samples [31].

3.2 Data analysis and results

The data was analyzed using Partial Least Squares (PLS) path modelling with the SmartPLS software. Smart PLS version 4, developed by Ringle et al. in 2024. It employs a component-based approach to structural equation modelling, making it highly suitable for exploratory research and applicable for confirmatory research [32]. The model has two variables: exogenous

latent variables, which explain other constructs, and endogenous latent variables, which are the investigated constructs [33].

3.2.1 Measurement model

The analysis of the measurement model, as presented in Table 4, demonstrates robust reliability and validity across all constructs: Occupational health and safety, Organizational Resilience, Staff Engagement, and Staff Resilience.

The reliability and validity analysis of the constructions for both animal-based and plant-based products and the complete model shows internal solid consistency and measurement accuracy. Cronbach's Alpha values for all constructs across the three models are above the threshold of 0.7, indicating high internal consistency reliability. For the Egyptian enterprises' performance, the Alpha values for animal-based products, plant-based products, and the complete model are 0.864, 0.795, and 0.813, respectively. Similarly, the Alpha values are consistently above the threshold in the Sudanese crisis risk and supply chain

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resilience constructs, reflecting reliable scales across different categories.

Table 4 The reliability and validity

Items	Animal-based product			Plant-based product			Complete		
	ALPHA	CR	AVE	ALPHA	CR	AVE	ALPHA	CR	AVE
Egyptian Enterprises' Performance	0.864	0.902	0.649	0.795	0.855	0.541	0.813	0.868	0.567
Sudanese Crisis Risk	0.854	0.881	0.600	0.776	0.802	0.458	0.813	0.863	0.559
Supply Chain Resilience	0.799	0.855	0.501	0.848	0.888	0.569	0.837	0.880	0.551

Moreover, Composite Reliability (CR) values for all constructs exceed the critical value of 0.7, which further supports the high reliability of these constructions. For example, the CR for the Egyptian enterprises' performance ranges from 0.855 to 0.902, while the Sudanese crisis risk ranges from 0.802 to 0.881, and supply chain resilience shows a CR between 0.855 and 0.888. These values confirm that the respective items accurately measure the constructions.

All constructs' Average Variance Extracted (AVE) values also exceed 0.5, confirming convergent validity. For instance, the AVE for Egyptian enterprises' performance is 0.649 for animal-based products and 0.541 for plant-based products, while supply chain resilience exhibits AVE values ranging from 0.501 to 0.569. These AVE values

demonstrate that the latent constructs capture a substantial portion of the variance in the observed variables, ensuring good validity. Thus, the reliability and validity of the constructions are well-supported across all models.

3.2.2 Discriminate validity

Discriminant validity was assessed using the Fornell-Larcker criterion, which evaluates whether each construct shares more variance with its indicators than with other constructs. According to the Fornell-Larcker criterion, the square root of the Average Variance Extracted (AVE) of each construct should be greater than the highest correlation it has with any other construct. The results are presented in Table 5 below.

Table 5 Discriminant validity

<u>Fornell-Larcker criterion</u>	Egyptian Enterprises' Performance	Sudanese Crisis Risk	Supply Chain Resilience
Egyptian Enterprises' Performance	0.753		
Sudanese Crisis Risk	-0.115	0.748	
Supply Chain Resilience	0.685	-0.057	0.742

For the Egyptian enterprises' performance, the square root of the AVE is 0.753, which is higher than its correlations with Sudanese crisis risk (-0.115) and supply chain resilience (0.685). Similarly, for the Sudanese crisis risk, the square root of its AVE is 0.748, which exceeds its correlation with Egyptian enterprises' performance and supply chain resilience (-0.057). Lastly, supply chain resilience has a square root of AVE of 0.742, greater than its correlation with the other two constructs. These results indicate that each construct shares more variance with its indicators than others, confirming discriminant validity. This means that Egyptian enterprises' performance, Sudanese crisis risk, and supply chain resilience are distinct and well-differentiated within the model. The results align with the Fornell-Larcker criterion, further supporting the measurement model's validity and ensuring that the constructs accurately represent different aspects of the phenomenon under study.

3.2.3 Structural model measurement

The structural model analysis focuses on assessing the overall explanatory power, path coefficients (β), and significance levels to evaluate the relationships between the constructs. The explanatory power is measured using the R^2 value, which indicates the proportion of variance in the dependent variable explained by the independent variables. High R^2 values suggest a strong explanatory power of the model. Path coefficients (β) represent the strength and direction of the relationships between constructs, while significance levels determine the statistical significance of these relationships as shown in Figures 3 and 4, respectively.

All of these are well below the critical threshold of 5, indicating that multicollinearity is not an issue and that the estimates of the path coefficients are reliable.

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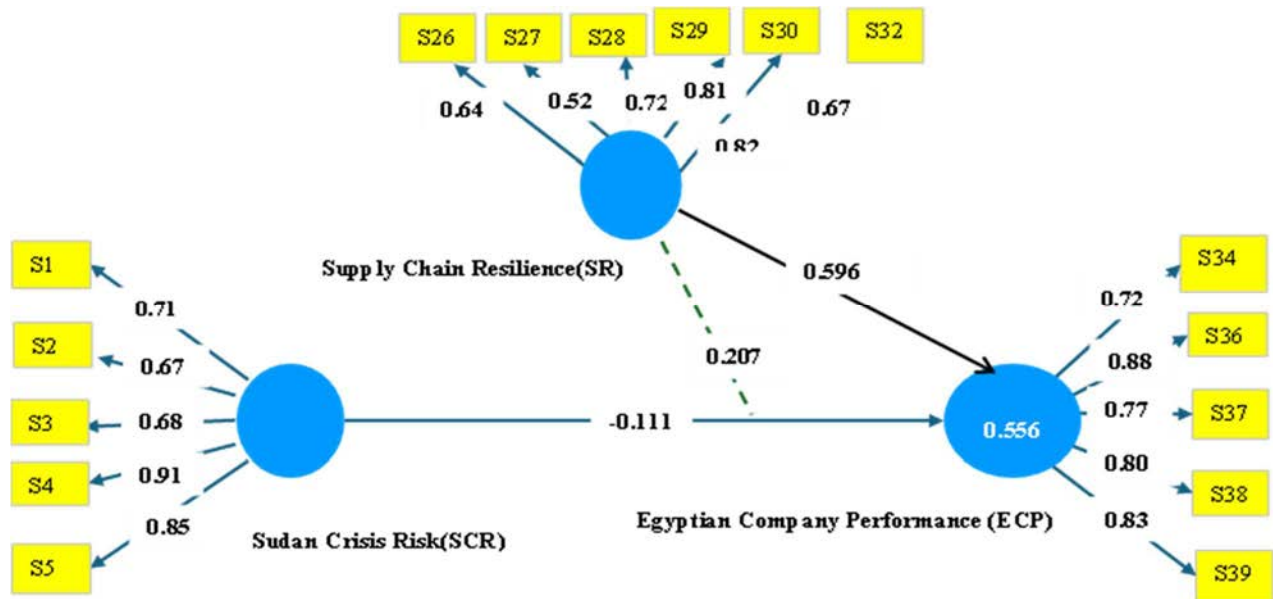


Figure 3 Structural model industry type (Animal-based)

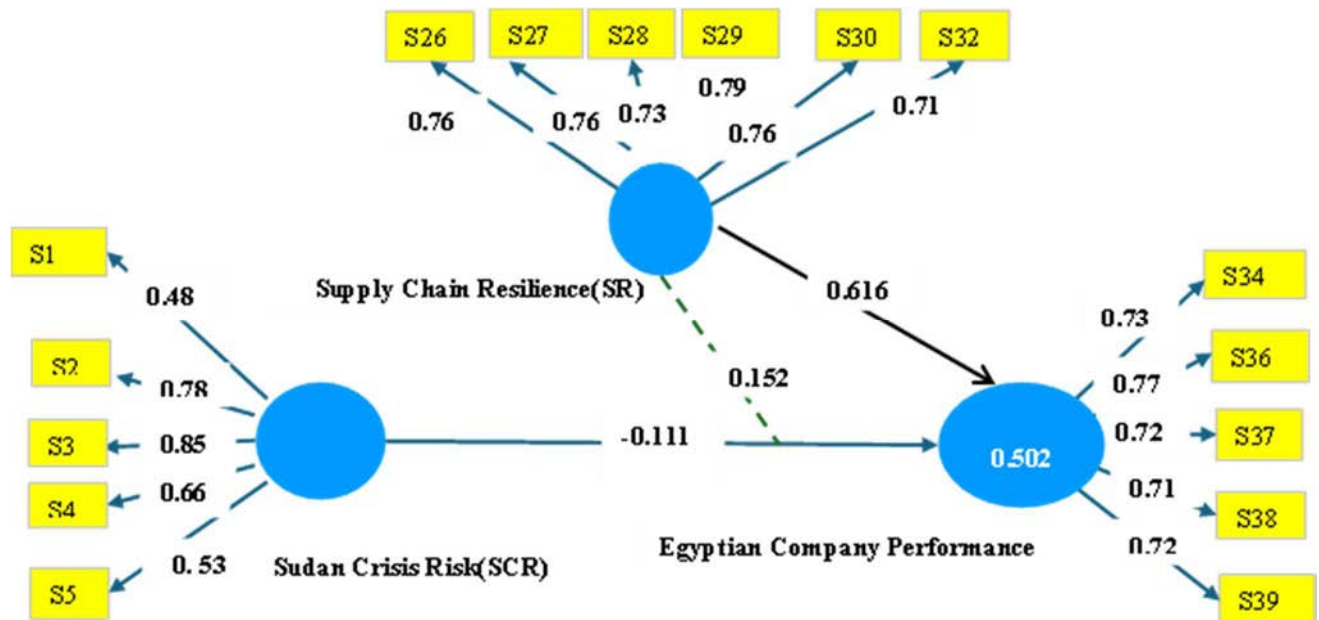


Figure 4 Structural model industry type (Plant-based)

Table 6 Collinearity statistics (VIF)

	VIF
Sudanese Crisis Risk -> Egyptian Enterprises' Performance	1.017
Supply Chain Resilience -> Egyptian Enterprises' Performance	1.305
Supply Chain Resilience x Sudanese Crisis Risk -> Egyptian Enterprises' Performance	1.308

The Variance Inflation Factor (VIF) is used to assess multicollinearity among predictor variables, with a general rule that VIF values below 5 indicate no significant multicollinearity issues. In this model, the VIF values for Sudanese crisis risk (1.017), supply chain resilience (1.305), and the interaction term between supply chain resilience and Sudanese crisis risk (1.308) all fall well

below the threshold of 5, indicating that multicollinearity is not a concern as presented in Table 6. These low VIF values confirm that the predictor variables in the model are independent, allowing for robust and interpretable path coefficients. This reinforces the reliability of the structural model in analyzing the effects of supply chain resilience and Sudanese crisis risk on Egyptian enterprises'

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performance. As a result, the findings suggest that supply chain resilience and Sudanese crisis risk significantly impact enterprises' performance without being distorted by collinearity issues, highlighting their distinct and important roles in the model.

3.2.4 The Model's explanatory power

The model's explanatory power is evaluated using the R-squared and adjusted R-squared values, which indicate the proportion of variance in Egyptian Enterprises' Performance (ECP) explained by the independent variables in both the animal-based and plant-based industries. According to Table 7, the R-squared value for the animal-

based industry, the is 0.56, and the adjusted R-squared is 0.54, indicating that the model explains 56% of the variance in ECP, demonstrating substantial explanatory power. In the plant-based industry, the R-squared and adjusted R-squared values are both 0.50, meaning the model accounts for 50% of the variance in ECP. These values suggest that the model has solid explanatory power in both industry groups, particularly for the animal-based industry, where a slightly higher proportion of variance is captured. This supports the model's robustness in predicting the performance of enterprises across different sectors, contributing valuable insights into the dynamics of these industries.

Table 7 Coefficient of determination (R-Squared)

	R-square	R-square adjusted
Egyptian Enterprises' Performance (ECP)		
Group (1) Animal Based Industry	0.56	0.54
Group (2) Plant-Based Industry	0.50	0.50

3.2.5 Path coefficients and hypotheses testing

Based on the analysis in Table 8, the path coefficients and hypothesis testing provide critical insights into the

relationships between Sudanese crisis risk (SCR), supply chain resilience (SR), and Egyptian enterprises' performance (ECP) across both animal-based and plant-based industries.

Table 8 Path coefficients and hypotheses testing

	Original (Group 1) ANIMAL BASED INDUSTRY	Original (Group 2) PLANT- BASED INDUSTRY	Mean (Group 1) ANIMAL BASED INDUSTRY	Mean (Group 2) PLANT- BASED INDUSTRY	STDEV (Group 1) ANIMAL BASED INDUSTRY	STDEV (Group 2) PLANT- BASED INDUSTRY	p-value (Group 1) ANIMAL BASED INDUSTRY	p-value (Group 2) PLANT BASED INDUSTRY
Sudan crisis risk (SCR) -> Egyptian Enterprises' Performance (ECP)	-0.111	-0.111	-0.116	-0.1	0.096	0.08	0.124	0.081
Supply chain resilience (SR) -> Egyptian Enterprises' Performance (ECP)	0.596	0.616	0.605	0.628	0.086	0.047	0	0
Supply chain resilience (SR) x Sudan crisis risk (SCR) -> Egyptian Enterprises' Performance (ECP)	0.207	0.152	0.18	0.122	0.141	0.08	0.07	0.029

Hypothesis (H1) Sudanese Crisis Risks negatively impact firm performance in Egyptian food industries. The analysis of the relationship between Sudan Crisis Risk (SCR) and Egyptian Enterprises' Performance (ECP) indicates a consistent negative effect across both the animal-based and plant-based industries, with an original sample (O) value of -0.111 for both groups. This suggests a small negative impact of the Sudanese Crisis on firm performance. The p-values of 0.124 (animal-based) and 0.081 (plant-based) are above the 0.05 significance level, meaning the results are not statistically significant. Therefore, H1 is not supported by the data, as the negative impact of the Sudan Crisis on firm performance, though

present, needs to be strong to be considered statistically significant.

The analysis of H2, which examines the impact of Supply Chain Resilience (SR) on Egyptian Enterprises' Performance (ECP), shows a significant and positive relationship across both the animal-based and plant-based industries. The original sample values for SR -> ECP are 0.596 for the animal-based industry and 0.616 for the plant-based industry, indicating a consistent positive influence. The mean values (0.605 for animal-based and 0.628 for plant-based) reinforce this trend, highlighting that SR contributes to enhanced enterprises' performance in both sectors. The standard deviations (0.086 for animal-based

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and 0.047 for plant-based) Notably, the p-values are both 0, confirming that the relationship is highly significant and well below the standard 0.05 threshold, indicating strong evidence against the null hypothesis. This analysis suggests that enhancing supply chain resilience is critical for boosting enterprises' performance. It emphasizes that investments in robust and adaptable supply chains can yield substantial benefits for firms within the Egyptian food industry, regardless of their specific focus on animal- or plant-based products.

Hypothesis (H3) Supply chain resilience (SCR) capabilities moderate the impact of risk caused by the Sudan Crisis on firm performance. The interaction between supply chain resilience (SR) and Sudan Crisis Risk (SCR) was analyzed to determine its moderating effect on Egyptian enterprises' performance. For the animal-based industry, the original sample (O) value is 0.207, but the p-value of 0.07 is slightly above the common threshold of 0.05, indicating marginal significance. In the plant-based industry, however, the original sample (O) value of 0.152 with a p-value of 0.029 shows a statistically significant moderating effect of supply chain resilience. Supply chain resilience plays a more crucial role in mitigating the negative impact of the Sudanese Crisis on the plant-based industry. Therefore, H3 is partially supported as the moderating effect of supply chain resilience is significant in the plant-based industry but not in the animal-based industry.

4 Discussion

The literature presents the role of supply chain resilience in mitigating various disruptions caused by environmental, pandemics and conflict crises. However, most studies in conflict areas address the role on a macro level. The research explores the moderator role of supply chain resilience in Egypt's food sector during the Sudanese crisis. The analysis of the impact of the Sudanese Crisis Risk (SCR) on Egyptian Enterprises' Performance (ECP) demonstrates a negative relationship, though statistically insignificant, impact on firm performance in animal-based and plant-based industries. With an original sample value (O) of -0.111 for both industries, the results suggest a consistent negative effect. However, the t-values (1.153 for animal-based and 1.398 for plant-based) and p-values (0.124 and 0.081, respectively) indicate that these findings do not reach statistical significance, as they do not surpass the significance threshold of p-values at 0.05. This lack of significance implies that while the Sudanese Crisis may cause an obvious negative trend, its spillover effects must be wider and stronger to be definitively concluded as impactful on firm performance within the Egyptian food industry. This result aligns with findings from broader literature that emphasize the compounded nature of crisis impacts. For instance, [34,35] have shown that disruptions caused by crises like pandemics and regional conflicts can strain food security and supply chains but may manifest differently across sectors.

Similarly, [36] highlights that while such crises pose significant risks, the degree of impact often varies based on the affected sectors' resilience and adaptive capacity. These findings suggest that although the Sudanese crisis presents notable challenges, its impact on the performance of food industries in Egypt may be moderated by factors such as supply chain resilience and market adaptability, aspects explored in further research hypotheses. [37] stated that on a macro level, the economic spillover effects of Sudan's intrastate crisis did not significantly impact Egypt's overall economic growth. However, minor possible spillover effects can be detected through capital, labour and trade channels.

The analysis of H2, which demonstrates a significant and positive relationship between Supply Chain Resilience (SR) and Egyptian Enterprises' Performance (ECP) across both animal-based and plant-based industries, p-values (0) for both, aligns with the findings of [11]. Their study on supply chain resilience and absorptive capacity during the COVID-19 pandemic highlights that firms with robust resilience strategies and the ability to absorb external shocks effectively mitigate risks and sustain performance during crises. This complements the current analysis, where high original sample values (0.596 for animal-based and 0.616 for plant-based industries) and significant t-values indicate the strong influence of SR on firm performance. The highly significant p-values (both 0) further validate the importance of SR as a critical factor for maintaining operational success and competitive advantage in volatile environments. [11] emphasize that resilience supports firms in quickly adapting to disruptions; a finding echoed in the Egyptian food industry results shows that investments in adaptable and resilient supply chains can lead to substantial performance improvements. This underscores that SR is essential for crisis response, long-term competitive positioning, and operational stability. Additionally, [12] found that supply chain resilience (SCR) capabilities significantly positively affect firm performance and competitive advantage within the Sri Lankan apparel industry, especially re-engineering, agility and collaboration. [13] demonstrated that firms with higher levels of resilience are better equipped to manage disruptions, ensuring continuity and operational efficiency, which leads to enhanced financial and operational outcomes.

The analysis of H3, which posits that supply chain resilience (SCR) moderates the impact of the Sudan Crisis Risk (SCR) on Egyptian enterprises' performance, reveals differentiated outcomes across industry types. In the animal-based industry, the original sample (O) value of 0.207 suggests an approach towards significance. However, a p-value of 0.07 falls just outside the conventional 0.05 threshold, indicating only marginal significance. This outcome implies that while supply chain resilience has some effect, it is not strong or consistent enough to be considered statistically significant for the animal-based sector. In contrast, the plant-based industry exhibits a more robust moderating effect, with an original

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sample (O) value of 0.152, a t-value of 1.896, and a p-value of 0.029, below the 0.05 significance level. This demonstrates a statistically significant interaction, affirming that supply chain resilience mitigates the adverse impact of the Sudanese Crisis in the plant-based industry. These findings align with insights from [34,35], who emphasize the importance of supply chain adaptability and resilience in safeguarding performance amid disruptions. Also, the findings of [38] highlight that supply chain resilience enables firms to absorb shocks, maintain operational continuity, and recover more effectively.

5 Conclusion

This research aimed to explore the impact of the Sudanese crisis risks on the performance of Egyptian food manufacturing enterprises and to study the impact of supply chain flexibility on the performance of these enterprises. The research results revealed a slight but statistically insignificant negative impact of the Sudanese crisis on the performance of Egyptian enterprises in both sectors, indicating that while the crisis poses challenges, its direct impact on performance alone is not strong. The results also demonstrated that the supply chain's resilience has a positive impact on the performance of enterprises operating in the Egyptian food industry market, particularly in the plant-based industry, thereby mitigating the negative effects of external crises. By examining these results, it was concluded that the Sudanese crisis, despite its negative impact on the performance of enterprises, has not had a tangible impact due to the continued flow of Sudanese exports to Egypt since the outbreak of the conflict in Sudan and due to the effectiveness and resilience of supply chains for enterprises operating in the food industry sector. The hypothesis about the impact of the Sudanese crisis on the performance of enterprises may be realized if it affects the flow of Sudanese exports that are difficult to obtain from other countries. The research recommends that food industry firms invest in building robust and adaptable supply chain resilience capabilities. This could include diversifying suppliers, enhancing logistics resilience, and adopting technologies that increase supply chain visibility and mobility. We encourage policymakers to bolster the food industry's resilience against external shocks by providing resources, incentives, and training. Future research should explore other potential drivers, such as government policy interventions and market adaptability, and assess the long-term impacts of resilience on firm performance across crises and industries.

References

- [1] TUKAMUHABWA, B.R., STEVENSON, M., BUSBY, J., ZORZINI, M.: Supply chain resilience: definition, review and theoretical foundations for further study, *International Journal of Production Research*, Vol. 53, No. 18, pp. 5592-5623, 2015. <https://doi.org/10.1080/00207543.2015.1037934>
- [2] FAGGIONI, F., ROSSI, M.V., SESTINO, A.: Conceptualizing supply chain resilience in exogenous crisis times: Toward a holistic definition, *Journal of the Knowledge Economy*, Vol. 15, pp. 17308-17332, 2024. <https://doi.org/10.1007/s13132-024-01816-0>
- [3] CHOWDHURY, M.M.H., QUADDUS, M.: Supply chain readiness, response and recovery for resilience, *Supply Chain Management*, Vol. 21, No. 6, pp. 709-731, 2016. <https://doi.org/10.1108/SCM-12-2015-0463>
- [4] PONOMAROV, S.Y., HOLCOMB, M.C.: Understanding the concept of supply chain resilience, *The International Journal of Logistics Management*, Vol. 20, No. 1, pp. 124-143, 2009. <https://doi.org/10.1108/09574090910954873>
- [5] PONIS, S.T., KORONIS, E.: Supply chain resilience? Definition of concept and its formative elements, *The Journal of Applied Business Research*, Vol. 28, No. 5, pp. 921-935, 2012. <https://doi.org/10.19030/jabr.v28i5.7234>
- [6] GAUDENZI, B., PELLEGRINO, R., CONFENTE, I.: Achieving supply chain resilience in an era of disruptions: A configuration approach of capacities and strategies, *Supply Chain Management: An International Journal*, Vol. 28, No. 7, pp. 97-111, 2023. <http://dx.doi.org/10.1108/SCM-09-2022-0383>
- [7] MANNERS-BELL, J.: *Supply Chain Risk Management: Understanding Emerging Threats to Global Supply Chains*, London, Kogan Page Publishers, 2017.
- [8] TEECE, D.J., PISANO, G., SHUEN, A.: Dynamic capabilities and strategic management, *Strategic Management Journal*, Vol. 18, No. 7, pp. 509-533, 1997.
- [9] WINTER, S.G.: Understanding dynamic capabilities, *Strategic Management Journal*, Vol. 24, No. 10, pp. 991-995, 2003. <https://doi.org/10.1002/smj.318>
- [10] SREEDEVI, R., SARANGA, H.: Uncertainty and supply chain risk: The moderating role of supply chain flexibility in risk mitigation, *International Journal of Production Economics*, Vol. 193, pp. 332-342, 2017. <https://doi.org/10.1016/j.ijpe.2017.07.024>
- [11] STENTOFT, J., MIKKELSEN, O.S., WICKSTROM, K.A.: Supply chain resilience and absorptive capacity: Crisis mitigation and performance effects during Covid-19, *Supply Chain Management: An International Journal*, Vol. 28, No. 6, pp. 975-992, 2023. <https://doi.org/10.1108/SCM-10-2022-0384>
- [12] ABEYSEKARA, N., WANG, H., KURUPPUARACHCHI, D.: Effect of supply-chain resilience on firm performance and competitive advantage: A study of the Sri Lankan apparel industry, *Business Process Management Journal*, Vol. 25, No. 7, pp. 1673-1695, 2019. <https://doi.org/10.1108/BPMJ-09-2018-0241>
- [13] LIU, C.L., SHANG, K.C., LIRN, T.C., LAI, K.H., LUN, Y.V.: Supply chain resilience, firm performance, and management policies in the liner shipping industry, *Transportation Research Part A*:

Supply chain resilience as a mitigating factor for the impact of the Sudan Crisis on the performance of food manufacturing enterprises in Egypt

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- Policy and Practice*, Vol. 110, pp. 202-219, 2018. <https://doi.org/10.1016/j.tra.2017.02.004>
- [14] TANG, C.S.: Perspectives in supply chain risk management, *International Journal of Production Economics*, Vol. 103, No. 2, pp. 451-488, 2006. <https://doi.org/10.1016/j.ijpe.2005.12.006>
- [15] JAGTAP, S., TROLLMAN, H., TROLLMAN, F., GARCIA-GARCIA, G., PARRA-LÓPEZ, C., DUONG, L., MARTINDALE, W., MUNEKATA, P.E.S., LORENZO, J.M., HDAIFEH, A., HASSOUN, A., SALONITIS, K., AFY-SHARARAH, M.: The Russia-Ukraine conflict: Its implications for the global food supply chains, *Foods*, Vol. 11, No. 14, 2098, pp. 1-23, 2022. <https://doi.org/10.3390/foods11142098>
- [16] NGOC, N.M., VIET, D.T., TIEN, N.H., HIEP, P.M., ANH, N.T., ANH, L.D.H., DUNG, V.T.P.: Russia-Ukraine war and risks to global supply chains, *International Journal of Mechanical Engineering*, Vol. 7, No. 6, pp. 633-640, 2022.
- [17] ALLAM, Z., BIBRI, S.E., SHARPE, S.A.: The rising impacts of the COVID-19 pandemic and the Russia-Ukraine war: Energy transition, climate justice, global inequality, and supply chain disruption, *Resources*, Vol. 11, No. 11, 99, pp. 1-17, 2022. <https://doi.org/10.3390/resources11110099>
- [18] World Atlas, (n.d.), Sudan geography, [Online], Available: <https://www.worldatlas.com> [10 Jan 2025], 2025.
- [19] World Bank, Sudan agriculture value chain analysis, [Online], Available: <https://documents1.worldbank.org/curated/en/731741593616746051/pdf/Sudan-Agriculture-Value-Chain-Analysis.pdf> [10 Jan 2025], 2020.
- [20] Central Bank of Sudan - Annual Trade and Financial Report for 2021, [Online], Available: <https://cbos.gov.sd/en/periodicals-publications> [11 Jan 2025], 2021.
- [21] Pharos Studies: The repercussions of the war on the Sudanese economy and neighbouring countries, [Online], Available: <https://pharostudies.com> [11 Jan 2025], 2023.
- [22] Gulf Research Center: A year of conflict in Sudan: The impact on agricultural activity, [Online], Available: <https://www.grc.net/documents/66323a29a3c49YearconflictSudan2.pd> [11 Jan 2025], 2024.
- [23] Famine Early Warning Systems Network: Sudan food security outlook: June 2024, [Online], Available: <https://fews.net/east-africa/sudan/food-security-outlook/june-2024> [11 Jan 2025], 2024.
- [24] SIDDIG, K., BASHEER, M.: We need to know the economic impacts of Sudan's ongoing conflict, *Nature Human Behaviour*, Vol. 8, pp. 1003-1004, 2024. <https://doi.org/10.1038/s41562-024-01883-y>
- [25] Central Agency for Public Mobilization and Statistics: Trade exchange report between Egypt and the Nile Basin countries for 2022, [Online], Available: <https://www.capmas.gov.eg> [11 Jan 2025], 2022.
- [26] Arab Organization for Agricultural Development: Arab Agricultural Statistics Yearbook, Vol. 42, [Online], Available: <https://www.aoad.org> [11 Jan 2025], 2022.
- [27] Central Bank of Sudan: Foreign Trade Statistical Digest (2004-2022), [Online], Available: <https://cbos.gov.sd/en/periodicals-publications> [11 Jan 2025], 2022.
- [28] Sudan War Monitor: Sudan War Monitor Report, [Online], Available: <https://sudanwarmonitor.com> [11 Jan 2025], 2024.
- [29] General organization for export and import control: Economic Bulletin of Egyptian Exports and Imports for 2021, [Online], Available: <https://www.goeic.gov.eg/ar/news/default/view/id/728/title> [12 Jan 2025], 2021.
- [30] KREJCIE, R.V., MORGAN, D.W.: Determining sample size for research activities, *Educational and Psychological Measurement*, Vol. 30, pp. 607-610, 1970. <https://doi.org/10.1177/001316447003000308>
- [31] HAIR, J.F., JR, HULT, G.M.T., RINGLE, C.M., SARSTEDT, M.: *A Primer on Partial Least Squares Structural Equation Modeling (PLS-SEM)*, 2nd ed., SAGE Publications, 2017.
- [32] HAIR, J.F., JR, SARSTEDT, M., HOPKINS, L., KUPPELWIESER, V.G.: Partial least squares structural equation modeling (PLS-SEM): An emerging tool in business research, *European Business Review*, Vol. 26, No. 2, pp. 106-121, 2014. <http://dx.doi.org/10.1108/EBR-10-2013-0128>
- [33] SARSTEDT, M., RINGLE, C.M., HAIR, J.F.: A Primer on Partial Least Squares Structural Equation Modeling, In: Homburg, C., Klarmann, M., Vomberg, A. (eds) *Handbook of Market Research*, Springer, Cham., pp. 1-40, 2017. http://dx.doi.org/10.1007/978-3-319-05542-8_15-1
- [34] XU, Z., ELOMRI, A., EL OMRI, A., KERBACHE, L., LIU, H.: The compounded effects of COVID-19 pandemic and desert locust outbreak on food security and food supply chain, *Sustainability*, Vol. 13, No. 3, 1063, pp. 1-17, 2021. <https://doi.org/10.3390/su13031063>
- [35] BARAKAT, S., COCHRANE, L., VASEKHA, I.: The humanitarian-development-peace nexus for global food security: Responding to the climate crisis, conflict, and supply chain disruptions, *International Journal of Disaster Risk Reduction*, Vol. 98, 104106, 2023. <https://doi.org/10.1016/j.ijdrr.2023.104106>
- [36] AL-SAIDI, M., SAAD, S.A.G., ELAGIB, N.A.: COVID-19's perils for development and supply security in the Sahel, *Development and Sustainability*, Vol. 25, No. 7, pp. 6295-6318, 2023. <https://doi.org/10.1007/s10668-022-02303-9>
- [37] WELANDER, J.O.: *Bad Neighbors, Conflict and Economic Growth: A qualitative analysis of the economic spillover effects of Sudan's intrastate*

Supply chain resilience as a mitigating factor for the impact of the Sudan Crisis on the performance of food manufacturing enterprises in Egypt

Selma Abdelrahim

conflict on Egypt's economic growth, Master's thesis, Lund University, School of Economics and Management, 2022.

- [38] JÜTTNER, U., MAKLAN, S.: Supply chain resilience in the global financial crisis: An empirical study, *Supply Chain Management: An International*

Journal, Vol. 16, No. 4, pp. 246-259, 2011.
<https://doi.org/10.1108/13598541111139062>

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A comprehensive risk evaluation method for sustainable building construction

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Abstract: Effectively mitigating the risks associated with sustainable development is a key problem when building in developing nations. This method requires businesses to act following moral and ethical standards while balancing financial goals. Stakeholder consensus is critical for executing sustainable risk management, which strives to reduce risks while increasing possibilities. The research focuses on sustainability concerns in Iraqi construction projects, with the primary goal of identifying reasons causing project delays using a comprehensive framework and rigorous methodology. The initial stage of the approach is gathering data from several construction sites. To assess project risks, the weighted product approach was employed, which included factor scores from prior research to create structured questionnaires that were then used to study the influence of various aspects. To establish the significance of each aspect, the relative relevance index was used, and Delphi expert consultations were held to provide additional insights. Historically, Iraq's construction sector has disregarded risk management and restrictions of finance. The project hazards were assessed using surveys, expert comments, and exploratory research. Logistic challenges were also considered in the assessment process. Microsoft Excel made performance evaluations easier, and MAT F5 obtained the highest rating for sustainable materials in WPM's risk assessment. Furthermore, equipment output has emerged as a critical aspect in guaranteeing technical compliance. This study introduces a structured risk evaluation approach for improving sustainable construction practices in developing countries.

1 Introduction

The identification and resolution of the root causes of a risk can often prevent the occurrence of a risk event or an unwanted consequence. Furthermore, it is imperative to enhance the efficiency of the scheme by guaranteeing that any remaining risks are recovered by the members. To achieve these objectives, it is recommended to follow a systematic approach: first, identify potential sources of danger; then, assess and analyze the impact of these sources through risk assessment; next, develop a management response to the risks; and finally, include any remaining risks in the scheme's estimations [1-3]. The definitions of risk and uncertainty are as stated below: Risk arises when a decision is made with multiple possible outcomes, each of which has a quantifiable probability attached to it. Uncertainty arises when having knowledge of the probability of several potential outcomes is not enough to make an educated decision [4]. The primary goal of project management is to guarantee the effective culmination of a project while minimizing the probability of its failure by implementing specified procedures, frameworks, knowledge, and proficiency [5-6]. A multitude of technologies have been developed to assist managers in effectively managing project control and assuring compliance with specified budgets, scopes, and

schedules due to the complex nature of modern projects. In the coming years, effective, durable, and environmentally friendly handling of intricate projects will require the adoption of related fiscal strategies [7-8]. Multiple factors can lead to a project experiencing delays. Hence, it is imperative to closely monitor the progress of the project and assess the potential impact of any changes on the schedule or budget. If any component were to malfunction, we would be able to implement preventive steps. The Earned Value Method is considered the standard for monitoring the development of a project over a specific duration. The main duties [9] of this role involve overseeing the project's advancement and producing reliable projections about time and expense. Hence, it is imperative for cost models to possess adequate adaptability in order to accommodate user specifications, produce reliable projections, and effectively handle various cost factors. The model's course of action should be determined by management's actions, aiming to achieve a balanced state of cost-effectiveness and excellent product quality [10-13]. Imports consist of reinforcing bars, concrete and cement, which are fundamental constituents of reinforced concrete. The employment of reinforced concrete framed structures in the stone pulverizing mills in the Besparmak highlands leads to environmental damage, dust emission,

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and noise pollution [14]. The lack of recycling or export options for the imported construction materials has resulted in an excessive accumulation of construction sector waste in landfills [15]. Other factors that contribute to the issue include the supervisor's lack of care and attention, incorrect accounting practices, poor inventory management, a high rate of deterioration due to prolonged storage on the job site, an excessive amount of materials issued from central stores, and the lack of returns for unused surplus materials [16].

2 Literature review

2.1 Risk management strategy

Typically, the strategic documents and excellence management system include the comprehensive risk management policy and strategy of the client or project owner, which might be a corporation or organization. The primary concerns in project owners' risk management approaches are risk ownership and risk backing [17]. The significance of the past lies solely in its ability to influence our future expectations through historical occurrences or prior demonstrations. The likelihood of control diminishes as the strategy advances. You have control over two significant occurrences [18]. This suggests that before these two commitments, clients have a strong probability of exerting influence. They ascertain the necessary actions and devise the most efficient plan for project implementation. These decisions have an impact on the obligations of the parties involved; they influence the manner in which design, construction, commissioning, change, and risk are handled; ultimately, they influence the cost, schedule, and quality [19]. Risk identification should take place during the preconstruction phase of the project [20] to address potential hazards before accepting them with a certain level of tolerance. Convening the project team and stakeholders for brainstorming sessions is an effective approach to examining dangers. Following the brainstorming session, it is necessary for the project team to convene frequently. This will facilitate the examination of current risk management strategies and the categorization of any potential future hazards. The user's text is [21]. An additional crucial measure is to transfer the risk. Ultimately, this approach can prove to be more cost-effective than assuming the risk. In order to alleviate the load, the contractor has the option to shift the risk to the insurance provider or establish a contractual agreement with a supplier before engaging the subcontractor [36]. Furthermore, when contractors mitigate risk, they also develop tactics to lower it. To illustrate, the contractor can mitigate safety threats by imparting essential training and equipping workers accordingly [22].

2.2 The effective risk factors

The contractor's reaction strategy will be contingent upon their ability to adapt to risks and potential benefits following the completion of the project. The potential risk

may be deemed reasonable if the contractor has the potential to achieve greater benefits in the future, such as the chance to penetrate an untapped market or secure a loyal repeat customer [23]. The study's findings elucidate the distinctive traits that differentiate the perspectives of green project managers. Given these factors, it is highly recommended for project managers to emphasize using assessment and identification methods to promote the production of eco-friendly products that minimize environmental harm. Self-sufficient program administrators have numerous challenges, including the volatility of resource expenses and the complexities of job hunting. This section assesses the competencies and capabilities of the project administrators and emphasizes the factors that the individuals in charge should take into account to fulfill this need. The bulk of the research sample, comprising green project leaders and construction administrators, exhibit a significant inclination to enhance their environmental consciousness by actively engaging in conservation initiatives [24].

2.3 Sustainable material factors

Considering the appropriate materials is essential when creating anything. It is imperative to identify cost-effective alternatives that nevertheless meet the objectives of the created product. Recently, there has been a growing realization of the importance of using environmentally friendly items in this particular situation. The longevity of a structure is greatly reduced by the deterioration of its quality. Long-term exposure to environmental factors and the gradual deterioration of building materials lead to slow degradation (Table 1). The longevity of a structure is typically considered a gauge of its success, which can be attributed to the materials used in its construction.

Table 1 Material risk factors for sustainable buildings

Material risk factors	
MAT F1	Designing waste collection units that facilitate sorting waste for recycling purposes to reduce the negative impact on the environment.
MAT F2	Study the quantities of materials needed by the project to reduce transportation.
MAT F3	Choose recyclable materials so that we can recycle or reuse them in the future.
MAT F4	Choose materials with low VOC emission (such as wood panels containing urea formaldehyde resin) to preserve the environment.
MAT F5	Support the use of locally available materials.
MAT F6	Using sustainable materials for buildings is financially costly.
MAT F7	There is a social demand for the use of sustainable materials for buildings as society realizes their strategic importance.

3 Methodology

3.1 Sustainable management factors

The scope of managerial responsibility can be influenced by several things. Supervisors depend on them to strategize, coordinate, guide, and manage. Furthermore, globalization, technology, variety, and integrity are crucial contributing variables (Table 2). Extensive research has been conducted on several factors that impact the efficiency of educators' teaching construction. In contrast, the predominant body of academic research has primarily examined the impact of management and human variables, such as incentives, resources, and the work environment, on teachers' research productivity [25].

Table 2 Management risk factors for sustainable buildings

	Management risk factors
ADM F1	Weak supervision causes major financial losses to the project.
ADM F2	Weak supervision causes delays in the project work schedule.
ADM F3	Weak supervision may not be a reason for obstructing work according to plans.
ADM F4	Projects managed by a specialized road engineering contractor are characterized by good performance.
ADM F5	Good decision-making depends on the project manager.
ADM F6	Good decision-making depends on the contractor's experience.
ADM F7	The administrative structure of the project is a critical factor for its success.
ADM F8	The project management structure depends on the project manager.
ADM F9	The project's administrative structure depends on the contractor's experience.
ADM F10	Increasing the number of supervisors causes confusion in work management.
ADM F11	Weak project management structure causes project loss.
ADM F12	The weak administrative structure of the project caused the project to be delayed
ADM F13	Weak staff consultation is a direct reason for project disruption.
ADM F14	The weakness of the consulting staff is determined by resolving the obstacles during the implementation of the work
ADM F15	The weakness of the consulting staff extends from project design until the completion of work implementation.
ADM F16	Weak supervision by the project beneficiary is one of the biggest reasons for project delays.
ADM F17	The precision of the beneficiary's staff is a success factor for the project.
ADM F18	Poor management of beneficiary cadres is a major reason for project delays.

ADM F19	Slow decision-making by the beneficiaries causes the project significant financial consequences.
ADM F20	The number of supervisors is proportional to the size of the project.

3.2 Equipment risk factors

Several scholars have extensively examined several facets of effective project management. The primary differentiation lies in the fact that while conventional performance metrics such as financial resources, time, and quality are associated with effective project management, project success is contingent upon evaluations of whether all project objectives have been achieved. There are other models that can be utilized for project management and completion (Table 3). Nevertheless, discerning between these models can prove to be difficult because of their interconnectedness [26].

Table 3 Equipment risk factors for sustainable buildings

	Equipment Risk Factors
EQ F1	The type of equipment used is a significant reason for the success of the project.
EQ F2	The efficiency of the equipment must be proportional to the type of work and the time required to complete the work.
EQ F3	Equipment productivity is the primary factor for implementing technical specifications.
EQ F4	The equipment used must be completely new.
EQ F5	Old equipment cannot be used.
EQ F6	The size of the project is proportional to the type of equipment used.
EQ F7	The cost of equipment is a factor in the success of the project.
EQ F8	The equipment must be owned by the implementing company for the project to be successful.
EQ F9	Delayed arrival of equipment causes loss to the project.
EQ F10	There is a direct relationship between the type of equipment, the size of the machinery, and the time the equipment arrives to the project.
EQ F11	The most productive machines are the ones with the highest technology.
EQ F12	The size and number of machines are determined according to the planned productivity in the work progress schedule.
EQ F13	Balancing the number of machines for each paragraph of the contractual bill of quantities is the basis for the success of the work.
EQ F14	The skill of workers in using machinery is a decisive factor in increasing productivity.
EQ F15	The skill of the worker depends on the type of equipment and its techniques.

EQ F16	Market inflation is a major reason for companies' reluctance to offer competitive prices.
EQ F17	Cost inflation can be contained by reducing the number of workers.
EQ F18	Cost inflation relates to materials only and not to labor wages.
EQ F19	Cost inflation is dealt with by the contractor with the amount of capital invested.
EQ F20	Increasing the financial capacity of the contractor increases profits.

3.3 The Delphi method

The Delphi technique is employed when many written questions are received from subject-matter experts. The individual supervising the procedure will gather the responses from each specialist and furnish them with a succinct summary after they have completed a set of inquiries. The assessor's subsequent duty is to evaluate the extent to which the executive summary of the report reinforces its conclusions. After finishing the executive summary, participants are requested to provide further details on their latest viewpoints in a subsequent question. In order for the Delphi technique to be effective, it is imperative to have complete unanimity regarding future estimates [27]. Prior to commencing any actual building, it is feasible to calculate the whole cost of a project, establish administrative protocols, and carry out surveys. Expert selection can commence once a well-defined process outline has been established. The process is reiterated until a consensus is reached among all members of the group over the interpretation of the results [28].

3.4 Relative important index (Rii)

The decisions made at each level of cost management are influenced by the decision-makers particular cost threshold, as well as the magnitude and nature of the expenditure. Assessing the level of acceptability of the risks is the subsequent stage after their evaluation. The entities in question can be more accurately described by utilizing the surety equivalent, which refers to the anticipated alteration in value of a specific amount of resources in both risk-free and hazardous situations [29]. The following equation (1) was utilized to calculate the Relative Importance Index (RII).

$$RII = \sum \frac{P_i U_i}{Nn} \quad (1)$$

RII = relative importance index

P_i = respondent's rating of cost

U_i = number of respondents placing identical weighting/rating on the cost

N = sample sized people responded to the survey

n = the highest attainable score for each cost

3.5 Weighted product method

The weighted product model (WPM) is a widely recognized approach used in multi-criteria decision analysis (MCDA) and multi-criteria decision-making (MCDM). The Weighted Product (WP) approach is a component of the decision-making framework that connects attribute ratings by means of multiplication. When characteristics are multiplied together, weight and rating assign a negative rank and a positive rank, respectively, to the cost attributes [30]. Like other MCDA/MCDM procedures, a limited number of option choices are provided, each defined by a set of decision criteria. In order to evaluate different options for a decision, various ratios are multiplied, with each ratio corresponding to a certain criterion for choice. Each ratio is multiplied by the corresponding weight of each condition. Let's assume that there are m possible solutions to a given Multiple Criteria Decision Analysis (MCDA) problem and n options to consider as criteria. Additionally, let us assume that each criterion represents a utility function for the purpose of argumentation. In other words, the greater the values, the more favorable the outcome. The calculations of this technique are illustrated in the subsequent basic numerical illustration. We employ identical numerical values for our data as those utilized in the numerical illustration of the weighted sum model. The numerical data provided below has been replicated for your convenience. The computing steps of the WPM method are as follows [31]:

1. List the criteria used in the computation based on the weight and category.
2. Calculate the relative weight of j -th criteria to the total weight of all criteria using the following equation (2).

$$\bar{W}_j = \frac{W_j}{\sum_{j=1}^N W_j} \quad (2)$$

$$\text{Where } \sum_{j=1}^N W_j = 1$$

3. Calculate the preference value of every i -th alternative using equation (3).

$$S_i = \prod_{j=1}^N x_{ij}^{\bar{W}_j} \quad (3)$$

Where the value of w is positive if the criteria is a benefit, otherwise its value is negative.

4. Calculate relative preference value of each alternative to all alternatives using equation (4).

$$V_i = \frac{S_i}{\sum_{i=1}^M S_i} \quad (4)$$

5. The higher the V value the better the alternative.

4 Results and discussion

One of the challenges that sustainable construction initiatives in poor countries have is the requirement to efficiently handle the risks associated with these projects. This business approach aims to maximize financial returns by considering the enterprise's influence on various aspects of society, the environment, and the government. The objective of risk management in the context of sustainability is to attain an optimal equilibrium between mitigating adverse impacts and enhancing favorable outcomes. This thesis has highlighted several potential hazards that could impede the sustained progress of Iraqi construction projects. Implementing this approach decreases the probability of supply chain disruptions caused by occurrences such as natural calamities or labor conflicts. Ensuring that suppliers adhere to optimal labor and waste management protocols is crucial. This guarantees the continuity of operations in the event of

pollution or labor disruptions. The primary objective of risk management is to mitigate the likelihood of losses and minimize their consequences in the event that they do transpire. Investors with a focus on capital preservation may opt to invest in construction projects. There is a growing apprehension that politicians may be influenced by money interests, resulting in this prevailing trend. The primary objectives of this business strategy are to optimize financial gains while minimizing adverse effects on society, the environment, and corporate governance. Sustainability risk management aims to enhance the alignment between sustainability objectives and risk management practices in order to efficiently address possible risks and leverage opportunities related to sustainability. This thesis focuses on the sustainable aspect of construction projects in Iraq, specifically addressing risk issues. It offers a thorough framework for understanding and managing these risks.

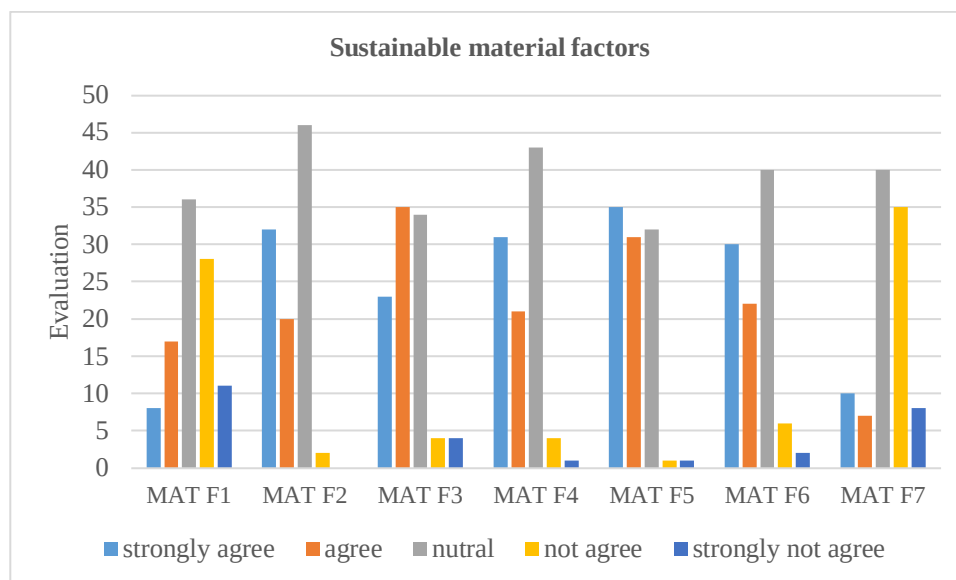


Figure 1 Evaluation of sustainable material risk factors

The risk appetite and tolerance of management play a crucial role in assessing the significance of a matter, as depicted in Figure 1. An in-depth analysis of both quantitative and qualitative factors is required to assess materiality. These motivations may encompass the desire to adhere to societal norms or the apprehension of jeopardizing one's reputation. The notion of materiality is crucial in sustainability reporting as it enables firms to identify and prioritize the most pertinent sustainability issues to incorporate in their reports. Consequently, stakeholders can receive more substantial and pertinent flow of information. Various categories of assets and types of investments require specific approaches to effectively manage the risk associated with sustainability. Quintet will

implement the procedures specified below if they are deemed necessary to effectively reduce sustainability risk. Adherence to international standards set by relevant international organizations Quintet's business operations and investment strategy conform to a diverse array of global standards. Quintet's active ownership strategy encompasses investments in single-line equities, fixed income, and externally managed investments. The quintet asserts that controversy monitoring is a viable instrument for tackling the obstacles to sustainable development. Quintet employs a comprehensive technique for monitoring disputes, encompassing both fixed-income markets and individual stocks. This technique relies on data obtained from external sources.

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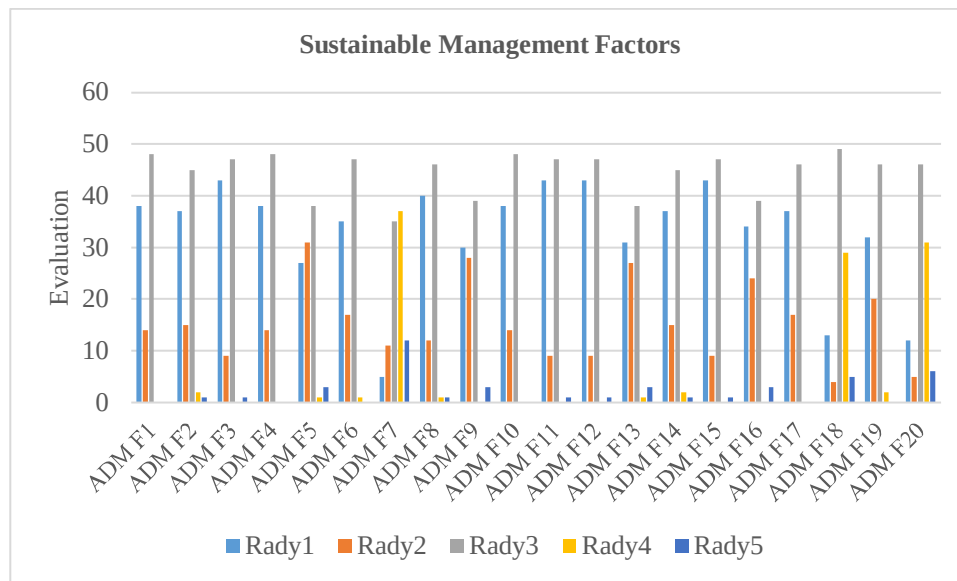


Figure 2 Evaluation of sustainable management risk factors

Quintet strategically combines specialized assets at the portfolio level using three sustainable perspectives: leader, improver, and theme. The sustainable lens can be used for a diverse array of assets, akin to growth and value investment theories. Micro-finance and green bonds are

key components of sustainable development. These methods expose many things to common sustainability-related causes and risks, rendering them vulnerable (Figure 2).

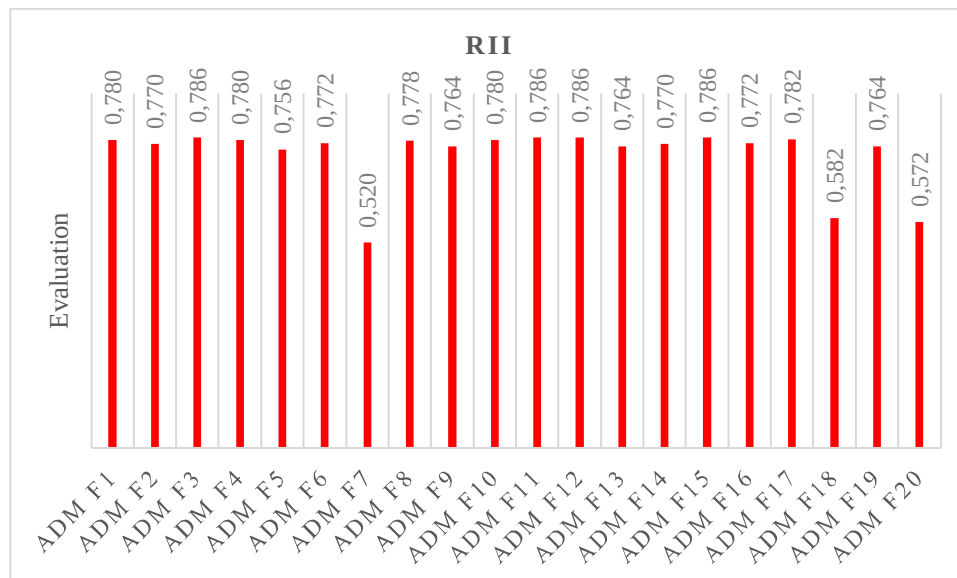


Figure 3 RII of sustainable management risk factors

The RII results shown in Figure 3 indicate that the following issues were ranked as the most significant: (ADM F11) Delays are attributed to an inadequate project management framework; (ADM F12) An inadequate project management framework results in project failure; and (ADM F15) Achieving sustainable development is challenging due to the consulting staff's lack of proficiency

in all aspects of project planning, execution, and implementation. Quintet provides a comprehensive approach to monitoring conflicts that encompasses several markets, such as individual equities and fixed-income assets. This plan is derived from data obtained from external sources.

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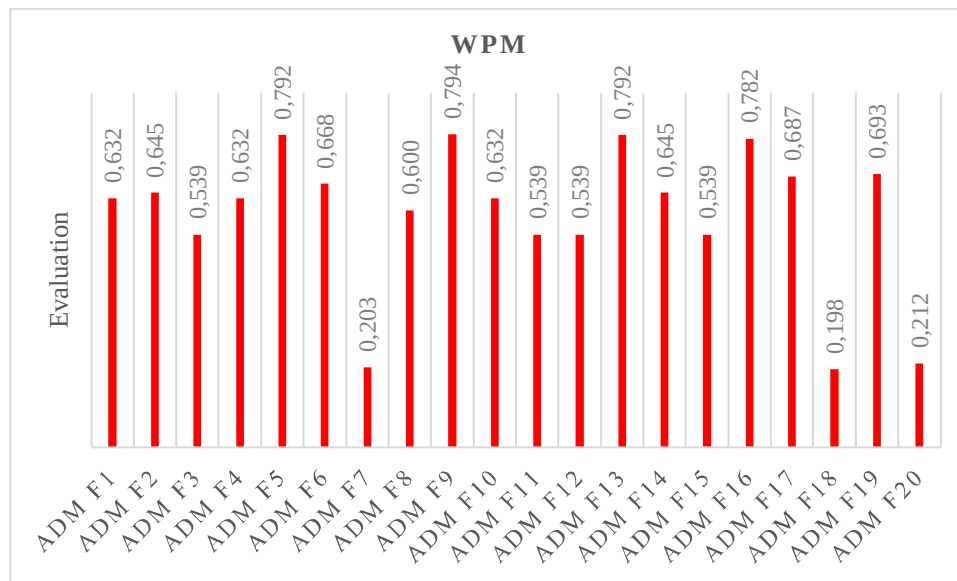


Figure 4 WPM of sustainable management risk factors

ADM F9 receives flow of information from the WPM's report regarding risk factors in sustainable management, shown in Figure 4. The job's administrative structure will be determined by the contractor's level of proficiency. In order to integrate a strategic sustainability viewpoint into product creation, leaders must effectively establish a direct correlation between measurable short- and long-term advantages of finance and sustainability criteria. Only individuals who possess genuine motivation to employ ethically sound manufacturing processes will be the ones who actually implement them.

All forms of construction equipment have the capacity to present difficulties. Individuals are accountable for any harm caused by using a device without knowing its possible hazards. Every occupation necessitates some form of machine engagement. Engaging in risk management without the requisite tools is unwise. Equipment management is an essential component of every aspect of a construction project, spanning from concept to execution. Inadequate planning for ventures utilizing expensive equipment often leads to the most significant financial losses.

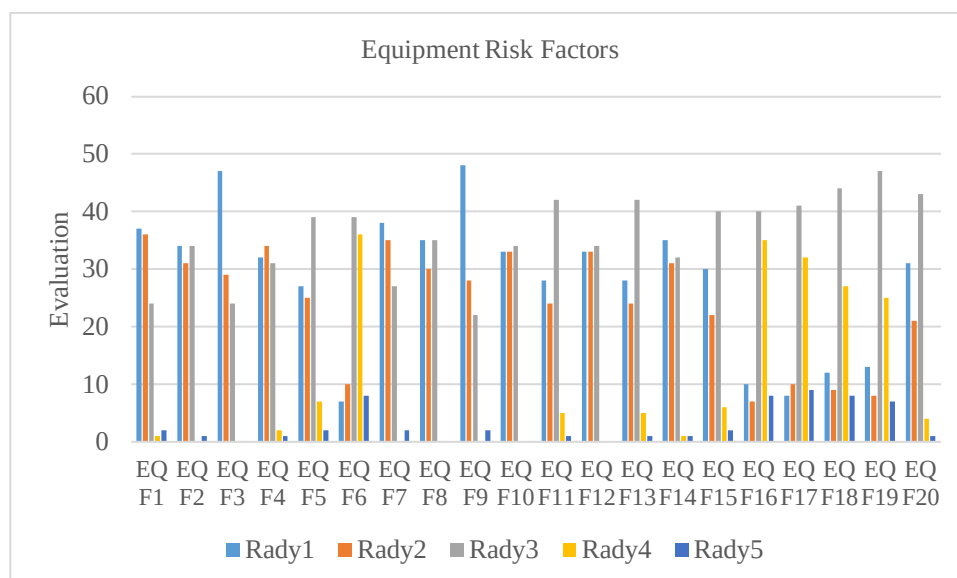


Figure 5 Evaluation of equipment risk factors

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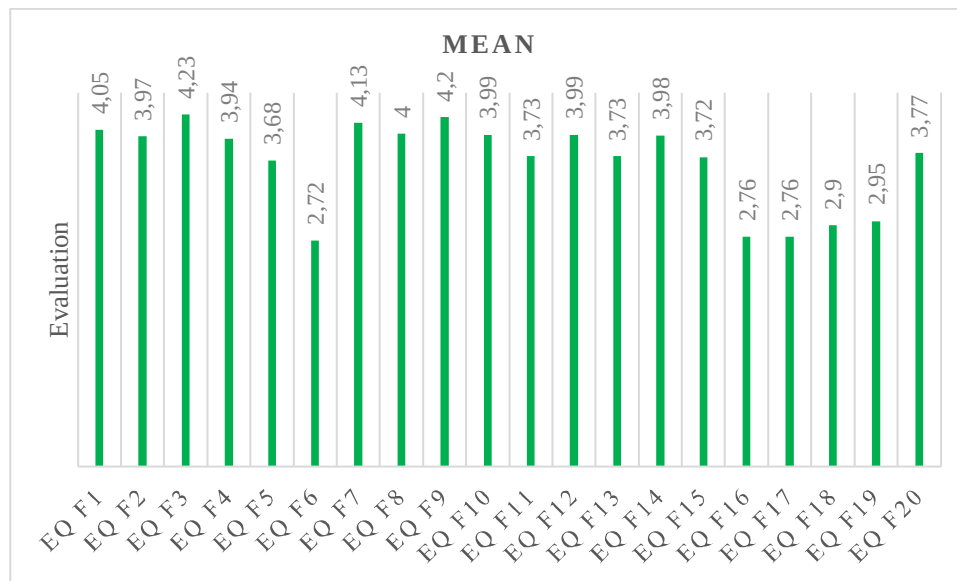


Figure 6 Mean of equipment risk factors

Given these concerns, contractors must meticulously evaluate the instruments they select and employ risk mitigation strategies. The findings indicate that the productivity of equipment is the paramount aspect of fulfilling technical criteria. Additionally, they demonstrate

that both equipment risk and financial risk have had a role in the occurrence of EQ F3, as shown in Figures 5 and 6. The RII results demonstrate that both equipment risk and financial risk significantly influence EQ F3.

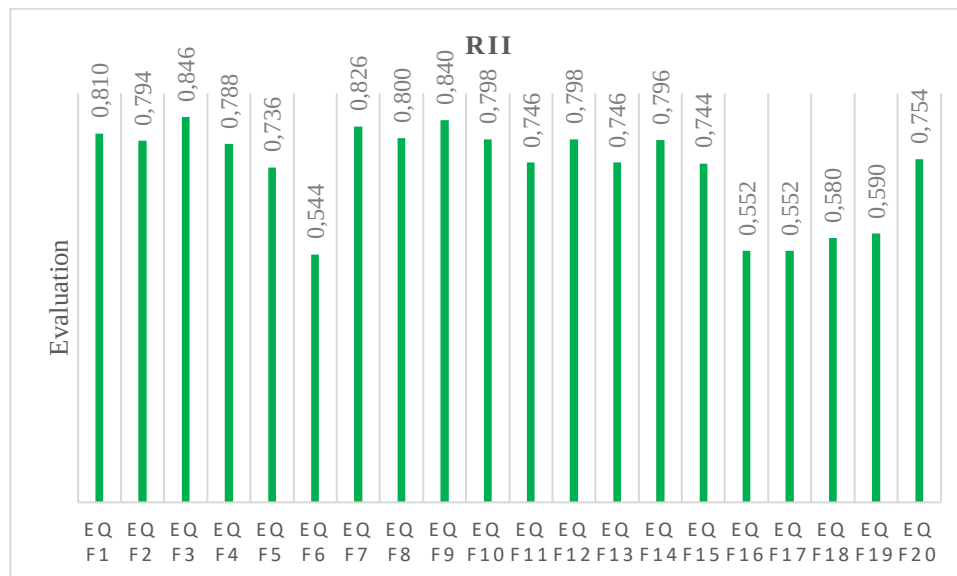


Figure 7 RII of equipment risk factors

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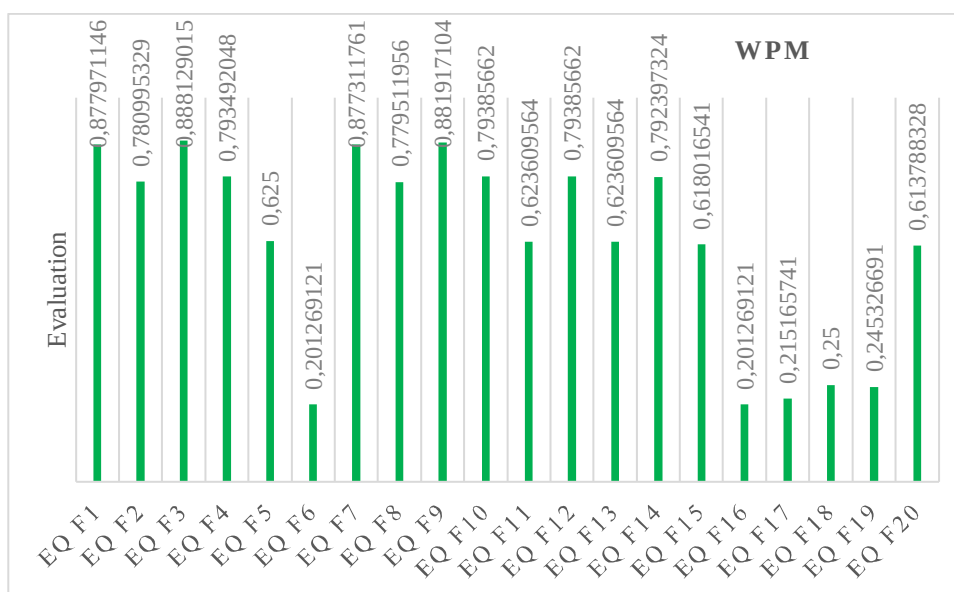


Figure 8 WPM of equipment risk factors

The efficiency of the equipment depicted in Figure 7 and 8 is the primary determinant of implementing technical standards. The findings of the WPM analysis on Equipment Risk Factors indicate that both financial risk and equipment risk significantly influence the EQ F3 Equipment Productivity, which is the paramount factor in fulfilling technical specifications.

5 Conclusions

There is a notable gap in the existing literature regarding the relationship between the benefits and drawbacks of a solution for a company's operations and competitiveness and how it aligns or diverges from strategic sustainable growth. Examining this connection is crucial for understanding the significance of integrating sustainability issues into decision-making and determining the causes of different events. The assessment of sustainability is based on an organization's capacity to effectively control and manage its expenditures. The building sector in Iraq has a long history of not following risk management rules and budgetary limitations. Extensive research has focused on the causation of project hazards. The aim of this thesis is to identify and evaluate the root causes of dangers at building sites. The current inquiry utilized a wide range of approaches and procedures to achieve its objectives. The initial study examined the operation and effects of performance criteria by utilizing a blend of surveys, expert comments, interviews, and exploratory research based on previous studies of building projects. Reformatting the user's content in an academic style is not possible because it is extremely compact. The first step of the RII extrapolation procedures entailed the choice of suitable modelling software. Microsoft Excel was chosen for its efficient performance evaluations because of its intuitive interface and robust analytical capabilities. Consequently, we were able to determine the

weight of different types of achievements with enhanced accuracy. MAT F5 has the highest rating in WPM's risk assessment when it comes to sustainable materials. The user's input cannot be completely altered. The data supplied illustrates the results that were deliberated upon at the World Congress on Risk Factors in Sustainable Management. The level of proficiency demonstrated by an employee will determine the organizational framework that supports the project. Moreover, according to the analysis of Equipment Risk Factors, the equipment's output is the primary factor that determines compliance with technical standards. The prevalence of dangers linked with the use of technologies and financial transactions could have a substantial impact on this.

References

- [1] SU, G., KHALLAF, R.: Research on the Influence of Risk on Construction Project Performance: A Systematic Review, *Sustainability*, Vol. 14, No. 11, pp. 1-19, 2022. <https://doi.org/10.3390/su14116412>
- [2] SERPELLA, A.F., FERRADA, X., HOWARD, R., RUBIO, L.: Risk Management in Construction Projects: A Knowledge-based Approach, *Procedia - Social and Behavioral Sciences*, Vol. 119, pp. 653-662, 2014. <https://doi.org/10.1016/j.sbspro.2014.03.073>
- [3] MISHRA, M., DAS, D., LAURINAVICIUS, A., LAURINAVICIUS, A., CHANG, B.H.: Sectorial Analysis of Foreign Direct Investment and Trade Openness on Carbon Emissions: A Threshold Regression Approach, *Journal of International Commerce, Economics and Policy*, Vol. 16, No. 1, 2550003, 2025. <https://doi.org/10.1142/s1793993325500036>
- [4] TWOREK, P.: Plan Risk Response as a Stage of Risk Management in Investment Projects in Polish and U.S. Construction - Methods, Research, *Scientific Annals of*

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Sepanta Naimi, Amar Abdulwahid Jassem Al-Sudani, Yaqoob Saif

- Economics and Business*, Vol. 59, No. 1, pp. 201-212 2012. <https://doi.org/10.2478/v10316-012-0014-9>
- [5] ALSAFFAR, A.K.K., ALQUZWEENI, S.S., AL-AMEER, L.R., ALI, A.H., MOHAMED, A., ALDAIHANI, H.M., REHAM, A., AL-ANSARI, N., AL-HASHIMI, O., SHUBBAR, A., KHAN, M.A., HASHIM, K.: Development of eco-friendly wall insulation layer utilising the wastes of the packing industry, *Heliyon*, Vol. 9, No. 11, pp. 1-9, 2023. <https://doi.org/10.1016/j.heliyon.2023.e21799>
- [6] MISHRA, M., KESHAVARZZADEH, V., NOSHADRAVAN, A.: Reliability-based lifecycle management for corroding pipelines, *Structural Safety*, Vol. 76, pp. 1-14, 2019. <https://doi.org/10.1016/j.strusafe.2018.06.007>
- [7] MISHRA, M.: Quantifying compressive strength in limestone powder incorporated concrete with incorporating various machine learning algorithms with SHAP analysis, *Asian Journal of Civil Engineering*, Vol. 26, pp. 731-749, 2025. <https://doi.org/10.1007/s42107-024-01219-1>
- [8] AL-TAWAL, D.R., ARAFAH, M., SWEIS, G.J.: A model utilizing the artificial neural network in cost estimation of construction projects in Jordan, *Engineering, Construction and Architectural Management*, Vol. 28, No. 9, pp. 2466-2488, 2021. <https://doi.org/10.1108/ECAM-06-2020-0402>
- [9] POLYANKIN, A.G., POTOKINA, A., KULIKOVA, E.Y.: *Geotechnical risk assessment during the construction of international crossing under the runways of Sheremetyevo airport*, IOP Conference Series: Materials Science and Engineering, Vol. 962, International Conference on Construction, Architecture and Technosphere Safety (ICCATS 2020), 6-12 September 2020, Sochi, Russia, pp. 1-9, 2020. <https://doi.org/10.1088/1757-899X/962/3/032017>
- [10] NGUYEN, H.D., MACCHION, L.: A comprehensive risk assessment model based on a fuzzy synthetic evaluation approach for green building projects: the case of Vietnam, *Engineering, Construction and Architectural Management*, Vol. 30, No. 7, pp. 2837-2861, 2023. <https://doi.org/10.1108/ECAM-09-2021-0824>
- [11] SUN, Y., ZHOU, Z., LI, Q., HE, H.: A novel risk assessment method for advanced and environmentally friendly construction technologies integrating RBM and I-OPA, *Alexandria Engineering Journal*, Vol. 113, pp. 648-660, 2025. <https://doi.org/10.1016/j.aej.2024.11.059>
- [12] TABASI, N., FERESHTEHPOUR, M., ROGHANI, B.: A review of flood risk assessment frameworks and the development of hierarchical structures for risk components, *Discover Water*, Vol. 5, No. 10, pp. 1-20, 2025. <https://doi.org/10.1007/s43832-025-00193-2>
- [13] DATTA, S.D., SOBUZ, M.H.R., AKID, A.S.M., ISLAM, S.: Influence of coarse aggregate size and content on the properties of recycled aggregate concrete using non-destructive testing methods, *Journal of Building Engineering*, Vol. 61, 105249, pp. 1-17, 2022. <https://doi.org/10.1016/j.jobbe.2022.105249>
- [14] ABDULWAHHAB, R., NAIMI, S., ABDULLAH, R.: Managing Cost and Schedule Evaluation of a Construction Project via BIM Technology and Experts' Points of View, *Mathematical Modelling of Engineering Problems*, Vol. 9, No. 6, pp. 1515-1522, 2022. <https://doi.org/10.18280/mmep.090611>
- [15] BAI, L., LI, Y., DU, Q., XU, Y.: A Fuzzy Comprehensive Evaluation Model for Sustainability Risk Evaluation of PPP Projects, *Sustainability*, Vol. 9, No. 10, pp. 1-22, 2017. <https://doi.org/10.3390/su9101890>
- [16] SHARMA, S., GUPTA, A.K.: Risk Identification and Management in Construction Projects: Literature Review, *International Journal of Humanities, Arts & Social Sciences*, Vol. 5, No. 6, pp. 224-231, 2019. <https://dx.doi.org/10.20469/ijhss.5.20002-6>
- [17] DZIADOSZ, A., REJMENT, M.: Risk Analysis in Construction Project - Chosen Methods, *Procedia Engineering*, Vol. 122, pp. 258-265, 2015. <https://doi.org/10.1016/j.proeng.2015.10.034>
- [18] IQBAL, S., CHOUDHRY, R.M., HOLSCHEMACHER, K., ALI, A., TAMOŠAITIENĖ, J.: Risk management in construction projects, *Technological and Economic Development of Economy*, Vol. 21, No. 1, pp. 65-78, 2015. <https://doi.org/10.3846/20294913.2014.994582>
- [19] KRECHOWICZ, M.: *Effective Risk Management in Innovative Projects: A Case Study of the Construction of Energy-efficient, Sustainable Building of the Laboratory of Intelligent Building in Cracow*, IOP Conference Series: Materials Science and Engineering, Vol. 245, No. 6, pp. 1-11, 2017. <https://doi.org/10.1088/1757-899X/245/6/062006>
- [20] ZHANG, C., ZHANG, J., JIANG, P.: Assessing the risk of green building materials certification using the back-propagation neural network, *Environment, Development and Sustainability*, Vol. 24, pp. 6925-6952, 2022. <https://doi.org/10.1007/s10668-021-01734-0>
- [21] ELIWA, H.K., JELODAR, M.B., POSHDAR, M.: Information and Communication Technology (ICT) Utilization and Infrastructure Alignment in Construction Organizations, *Buildings*, Vol. 12, No. 3, pp. 1-19, 2022. <https://doi.org/10.3390/buildings12030281>
- [22] ALYAMI, S.H., REZGUI, Y.: Sustainable building assessment tool development approach, *Sustainable Cities and Society*, Vol. 5, pp. 52-62, 2012. <https://doi.org/10.1016/j.scs.2012.05.004>
- [23] RAMLEE, N., TAMMY, N.J., RAJA MOHD NOOR, R.N.H., AINUN MUSIR, A., ABDUL KARIM, N.,

A comprehensive risk evaluation method for sustainable building construction

Sepanta Naimi, Amar Abdulwahid Jassem Al-Sudani, Yaqoob Saif

- CHAN, H.B., MOHD NASIR, S.R.: *Critical success factors for construction project*, In: AIP Conference Proceedings, Vol. 1774, No. 1, pp. 030011-1-030011-6, 2016. <https://doi.org/10.1063/1.4965067>
- [24] TAMOŠAITIENĖ, J., KHOSRAVI, M., CRISTOFARO, M., CHAN, D.W.M., SARVARI, H.: Identification and Prioritization of Critical Risk Factors of Commercial and Recreational Complex Building Projects: A Delphi Study Using the TOPSIS Method, *Applied Sciences*, Vol. 11, No. 17, pp. 1-24, 2021. <https://doi.org/10.3390/app11177906>
- [25] NGUYEN, H.D., MACCHION, L.: Risk management in green building: a review of the current state of research and future directions, *Environment, Development and Sustainability*, Vol. 25, pp. 2136-2172, 2023. <https://doi.org/10.1007/s10668-022-02168-y>
- [26] DÍAZ-LÓPEZ, C., CARPIO, M., MARTÍN-MORALES, M., ZAMORANO, M.: Analysis of the scientific evolution of sustainable building assessment methods, *Sustainable Cities and Society*, Vol. 49, 101610, pp. 1-13, 2019. <https://doi.org/10.1016/j.scs.2019.101610>
- [27] ÖZDEMİR, M.: *A probabilistic schedule delay analysis in construction projects by using fuzzy logic incorporated with relative importance index (RII) method*, Middle East Technical University, Turkey, 2010.
- [28] BARI, N.A.A., YUSUFF, R., ISMAIL, N., JAAPAR, A., AHMAD, R.: Factors Influencing the Construction Cost of Industrialised Building System (IBS) Projects, *Procedia - Social and Behavioral Sciences*, Vol. 35, pp. 689-696, 2012. <https://doi.org/10.1016/j.sbspro.2012.02.138>
- [29] SINAGA, A., MAULANA, D.: Implementation of weighted product method for evaluating performance of technicians, *International Journal of Modern Education and Computer Science*, Vol. 11, No. 4, pp. 30-42, 2022. <https://doi.org/10.5815/ijmecs.2022.04.03>
- [30] SUPRIYONO, H., SARI, C.P.: *Developing decision support systems using the weighted product method for house selection*, In: AIP conference proceedings, Vol. 1977, No. 1, pp. 020049-1-020049-7, 2018. <https://doi.org/10.1063/1.5042905>
- [31] HASSAN ALI, A., FAROUK KINEBER, A., ELSHABOURY, N., ARASHPOUR, M., OSAMA DAOUD, A.: Analysing multifaceted barriers to modular construction in sustainable building projects: a comprehensive evaluation using multi-criteria decision making, *International Journal of Construction Management*, Vol. 25, No. 1, pp. 1-17, 2024. <https://doi.org/10.1080/15623599.2023.2299557>

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Commuting versus e-flexibility: the workforce's choice

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Abstract: Covid-19 changed people's mobility and lifestyles. An ad hoc Google Forms questionnaire was sent to N=843 Austrian e-commuters across the tertiary sector to capture the impact of the commute on the workforce's e-flexibility inclination. The findings show that, where possible e-flexibility may help to reduce the general reliance on commuting. All hypotheses were supported: the data show that the proportion of satisfied people working remotely increases as commuting time increases; interestingly, the ideal e-working model is a hybrid one of commuting 3-4 times a week (41.4%); the debate on whether or not to return to the office is far from settled, 73% of respondents are reluctant to give up the 9-5 space, the workforce living further from the office prefers to work remotely more often, and, not surprisingly, the workforce living not far from the organisation prefers to keep working in the office; coworking space seems to be on the rise (72%) among employees in shared work environments. Employees who live further from the office do not want the coworking possibility. Overall, spending some of the week working from home is a boon for employees in many circumstances, especially those who live far from the office.

1 Introduction

Mobility is one of the daily stressors faced by the global workforce. We live in a society of commuting. Commuting to and from work builds consequential changes. Commuting changes the workforce's relationship with work and the workplace in many ways - especially how and where the workforce works and does work-related activities every day. In simple terms, commuting is the shifting of the workforce in terms of where it works and lives. Many negative factors are associated with commuting, e.g. cost, time consumed, frequent stops, delays, congested traffic, discomfort, noise and pollution. According to Hernandez-Tamurejo et al. [1] data there is a decrease of the number of trips in urban settings when working remotely, but the effectiveness on traffic in the city of Madrid during the rush hour is limited.

Under workforce e-flexibility we understand the enabling of the workforce with different modern technologies and in different places to adjust the ability to work in line with the demand of control over when, where and how the work is done. One of the perks of this flexibility is spending less time commuting. E-working 3 days a week is interlinked with less travel distance [2]. E-working "leads to reduced travel demand, more use of active transport modes, and congestion relief" [3, p. 8]. Generally, a commuter is a person who travels regularly between private and business premises using private or public transport. More precisely, an e-commuter is a person who travels digitally between private and business premises. We can divide commuters into three groups: 1)

zero commuters where cubicles are close to their homes and no commuting is done, 2) short commuters where cubicles are close to their homes and are reached on foot or by bicycle, and 3) long commuters where cubicles are not close to their homes and are reached by car or other transport mode. "Coworking spaces are shared workplaces utilised by different sorts of knowledge professionals, mostly freelancers, working in various degrees of specialisation in the vast domain of the knowledge industry" [4, p. 194]. The true meaning of the commute can only be understood in the context of how it relates to workforce e-flexibility. Business and private life seep into the commute in many ways, and vice versa. Workers commonly commute on a daily basis. Commuting is equal to a significant ratio of the workers' daily routine and has a major influence on the workers' well-being [5]. More precisely, e-flexibility has had a greater impact on the workforce (their job satisfaction, motivation and performance), especially on the freight forwarding workforce [6]. But "feelings of loneliness affect employees' flow levels when working remotely" [7, p. 7]. Thus, an engaged workforce was able to leverage a higher flow for better performance [8]. According to Demirhan and Bulgur [9, p. 73] "remote work has an effect on the workflow experience and the psychological well-being of the employees plays a mediating role in this relationship." COVID-19 accelerated many existing trends, including those related to the supply chain [10]. "Logistics companies were forced to digitalize and automate processes, work remotely, and based on e-commerce" (sic) [10, p. 92]. Therefore, it requires a reconsideration of the

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supply and demand of the transport mode. This flexibility represents a possible way of decreasing mobility.

Despite its importance in everyday life, commuting in relation to e-flexibility has been studied in detail in only a few papers. An ad hoc Google Forms questionnaire was sent to N=843 Austrian e-commuters across the tertiary sector to capture the impact of the commute on the workforce's e-flexibility inclination. In the next section, we hypothesise that the data obtained can be used to assess the impact of commuting on workplace e-flexibility inclination. We then present the methodology used in this investigation, followed by an empirical section. Then follows a discussion of the results, and the final section gives the authors' conclusions and ideas about possible future directions of research.

2 Methodology

Austria, as the surveyed country, provides valuable insights and data for various reasons. Firstly, the Austrian economy is dominated by the service sector in which many workers favour e-working. Secondly, there is an extensive transport infrastructure, including information and communication technologies. Moreover, Austrians tend to be attached to their place of residence, because only 2.3 million commute to work [11].

The authors followed Beño et al.'s [12] methodology using an ad hoc Google Forms questionnaire to collect data in the period 1 to 31 August 2024. As highlighted by Jenn [13, p. 32], "a good questionnaire should be valid, reliable, clear, interesting and succinct," and the authors followed these guidelines. Close-ended Likert scale questions (agreement, periodicity) were used. Due to the specific research area in which data were collected at one point in time from one sample, the following questions were designed: 1) Overall, how do you feel about working remotely? 2) What is the ideal number of times to work remotely? 3) Should your organisation keep a cubicle of some kind? and 4) Would you use a coworking space if offered and paid for by the employer?

We analysed the responses of a sample of 843 Austrian workers who commuted and experienced working

remotely. First the authors contacted the organisations by telephone for the initial step of gathering potential respondents. After this approval had been obtained, the next step was to send an email with an invitation to participate in the questionnaire, with a Google Forms link.

One research question was formulated for this survey, namely: Does the workforce appreciate the e-flexibility that comes with no commuting? While the research question determines what the authors are trying to find out, the following hypotheses are the predicted answers to that question:

- H1: There is a relationship between commuting time and e-work satisfaction.
- H2: Increased distance from the cubicle results in increased inclination to work remotely.
- H3: A workforce working close to the cubicle is more likely to keep the cubicle.
- H4: Decreased distance from the cubicle results in decreased inclination to use a coworking space.

A descriptive statistical method was used to analyse and describe the basic features of the data. All respondents were informed about the aims of the survey. Participation was voluntary, and anonymity was guaranteed.

3 Results

Although e-working existed much earlier, workforce e-flexibility numbers increased significantly during the Covid-19 pandemic. In general, one of the key assets of e-working is the absence of commuting. In this study, the authors investigate the impact of commuting on the workforce's e-flexibility inclination.

All hypotheses were tested using Pearson's chi-square test of independence. The strength of the proved dependence was described in each case by a suitable contingency or association coefficient.

- H1: There is a relationship between commuting time and e-work satisfaction.

Table 1 There is a relationship between commuting time and e-work satisfaction

Overall, how do you feel about working remotely?		Commuting time per day					Total
		under 15 min	15 - 30 min	31 - 60 min	61 - 120 min	121+ min	
Positive	n	183	176	84	64	33	540
	%	56.3%	63.5%	69.4%	79.0%	84.6%	64.1%
Negative	n	50	28	7	3	1	89
	%	15.4%	10.1%	5.8%	3.7%	2.6%	10.6%
Neutral	n	92	73	30	14	5	214
	%	28.3%	26.4%	24.8%	17.3%	12.8%	25.4%
Total	n	325	277	121	81	39	843
	%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

$\chi^2=30.536$; $p<0.001$; Kendall's tau-c=-0.143

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Our findings suggest that the workforce has enjoyed the modern aspect of working remotely (64.1% positive). In Table 1, the data show that the proportion of satisfied people working remotely increases as commuting time increases. At the same time, as the commuting time increases, the proportion of dissatisfied employees working remotely decreases. Looking at the respondents' commuting time (under 15 mins, 15-30 mins, 31-60 mins, 61-120 mins or 121+ mins), the authors found that there is

a direct correlation between the workforce's commuting time and the enjoyment of e-flexibility. According to the p-value of the test ($p < 0.001$), this relationship is statistically significant. The hypothesis was confirmed. However, the correlation between e-employees and commuting time is very weak ($\tau = -0.143$).

- H2: Increased distance from the cubicle results in increased inclination to work remotely.

Table 2 Increased distance from the cubicle results in increased inclination to work remotely

What is the ideal number of times to work remotely?		Commuting time per day					Total
		under 15 min	15 - 30 min	31 - 60 min	61 - 120 min	121+ min	
Not at all	n	12	11	1	0	0	24
	%	3.7%	4.0%	0.8%	0.0%	0.0%	2.9%
Seldom	n	54	29	4	2	0	89
	%	16.6%	10.5%	3.4%	2.9%	0.0%	10.8%
1 - 2 per week	n	101	111	47	9	3	271
	%	31.1%	40.4%	39.8%	13.0%	7.7%	32.8%
3 - 4 per week	n	128	101	51	45	17	342
	%	39.4%	36.7%	43.2%	65.2%	43.6%	41.4%
Daily	n	30	23	15	13	19	100
	%	9.2%	8.4%	12.7%	18.8%	48.7%	12.1%
Total	n	325	275	118	69	39	826
	%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

$\chi^2=116.268$; $p < 0.001$; Kendall's tau-b=0.198

Interestingly, the ideal e-working model is a hybrid one of 3-4 times a week (41.4%). Employees with a commuting time of up to 15 minutes would most often work remotely 3-4 times a week (39.4%) or 1-2 times a week (31.1%). The same applies to those who commute for 15 - 30 min and 31 - 60 min (all around 40%). For employees with a commuting time of 61-120 minutes, it is ideal to work remotely 3-4 times a week in 65.2% of cases. For employees with a commuting time of more than 120 minutes, it would be ideal to work remotely 3-4 times a

week in 43.6% of cases, and even daily in 48.7% of cases. A preference to work remotely daily or at least 3-4 times a week is higher among employees with a commuting time of 61 min. According to the p-value of the test ($p < 0.001$), this relationship is statistically significant. The hypothesis was confirmed. However, the strength of the dependence of the frequency is very weak ($\tau = 0.198$).

- H3: A workforce working close to the cubicle is more likely to keep the cubicle.

Table 3 A workforce working close to the cubicle is more likely to keep the cubicle

Should your organisation keep a cubicle of some kind?		Commuting time per day					Total
		under 15 min	15 - 30 min	31 - 60 min	61 - 120 min	121+ min	
Yes	n	245	210	87	53	20	615
	%	75.4%	75.8%	71.9%	65.4%	51.3%	73.0%
No	n	17	12	9	7	19	64
	%	5.2%	4.3%	7.4%	8.6%	48.7%	7.6%
Don't know	n	63	55	25	21	0	164
	%	19.4%	19.9%	20.7%	25.9%	0.0%	19.5%
Total	n	325	277	121	81	39	843
	%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

$\chi^2=106.446$; $p < 0.001$; Cramer's V=0.355

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The debate on whether or not to return to the office is far from settled; 73% of respondents are reluctant to give up the 9-5 space. But the workforce living further from the office more often prefers to work remotely. Not surprisingly, the workforce living not far from the organisation prefers to keep working in the office. According to the p-value of the test ($p < 0.001$), this

relationship is statistically significant. The hypothesis was confirmed. However, the strength of the dependence is rather weak ($V = 0.355$).

- H4: Decreased distance from the cubicle results in decreased inclination to use a coworking space.

Table 4 Decreased distance from the cubicle results in decreased inclination to use a coworking space

Would you use a coworking space if offered and paid for by the employer?		Commuting time per day					Total
		under 15 min	15 - 30 min	31 - 60 min	61 - 120 min	121+ min	
Yes	n	216	220	97	58	16	607
	%	66.5%	79.4%	80.2%	71.6%	41.0%	72.0%
No	n	92	45	17	11	19	184
	%	28.3%	16.2%	14.0%	13.6%	48.7%	21.8%
Don't know	n	17	12	7	12	4	52
	%	5.2%	4.3%	5.8%	14.8%	10.3%	6.2%
Total	n	325	277	121	81	39	843
	%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

$\chi^2 = 51.707$; $p < 0.001$; Cramer's $V = 0.248$

Coworking space seems to be on the rise (72%) among employees in shared work environments. Employees who live further from the office do not want the coworking possibility. According to the data obtained, the share of employees with a commute of 15 to 60 minutes do want to use a coworking space (around 80%). According to the p-value of the test ($p < 0.001$), this relationship is statistically significant. The hypothesis was confirmed. However, the strength of the dependence is rather weak ($V = 0.248$).

4 Discussion

As commuting undergoes a modern revival, shaped by modern technology and a global shift in the work environment, the traditional commute is being reevaluated. Commuting by driving is among the most stressful and least productive means of commuting, while also the most prevalent. Data in this study show that the proportion of satisfied people working remotely increases with the rise of commuting time. This is in the vein of the European Environment Agency's finding that "new ways of working could reduce commuting" [14]. It can be argued that the key motivators for choosing to work from home include saving on commuting costs and reducing travel time [15]. Caldarola and Sorrell [2] remark that teleworking 3 days a week means less commuting distance. To some extent, this corresponds with data obtained about the ideal e-working model, namely a hybrid one of 3-4 times a week, except in the case of 15-30 minutes commuting time (1-2 days) and, not surprisingly, 121+ minutes (daily). De Vos et al. describe this practice of working from the office for some days a week and from home for some days as telecommuting [16, p. 375]. De Vos et al. [16, p. 391] conclude that "telecommuting significantly affects

commuting time" and overall "the effect of telecommuting on commuting time remains positive and significant" [16, p. 393]. The results in this paper conform to the statement: "workers' commute time is the most important personal characteristic determining WFH preference" [17]. Based on our data, the workforce living further from the office prefers to work remotely more often. Not surprisingly, the workforce not far away from the organisation prefers to keep the office. Appel-Meulenbroek et al.'s [18 p. 7] findings confirm the similar outcome that "the employee-workplace alignment mechanism is not a one-size-fits-all solution, but also because they show the need to keep a diverse office workplace available to satisfy needs of all employees if hybrid working policies are introduced". Employees who live further from the office do not want the coworking possibility. In contrast, various studies highlight that perceived social isolation constitutes an important predictor of employees' intention to telework in a coworking space [19-22]. A recent study exclusively on teleworkers revealed that the intention to use a coworking space for telework is also strongly influenced by the cost of a coworking space and concerns about increased commuting time [23], which is similar to our data that the share of employees with a commuting time of 15 to 60 minutes do want to use a coworking space (around 80%).

5 Conclusions

As commuting undergoes a modern revival, shaped by modern technology and a global shift in the work environment, traditional commuting is being reevaluated. The authors tried to find the answer to the following research question: Does the workforce appreciate the e-flexibility that comes with no commuting?

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- Although trends in the data can be found, preferences around e-flexibility can vary from person to person. Based on the findings, where possible e-flexibility may help to reduce the general reliance on commuting. It seems that commuting patterns of the past will start changing because the spaces and modes in this study offer the possibility of separating the home and workplace while still allowing people to work from a place (ideally) closer to the home, which will mean less reliance on commuting. The data show that the proportion of satisfied people working remotely increases as commuting time increases; interestingly, the ideal e-working model is a hybrid one of 3-4 times a week (41.4%); the debate on whether or not to return to the office is far from settled, 73% of respondents are reluctant to give up the 9-5 space, a workforce living further from the office prefers to work remotely more often, and, not surprisingly, the workforce that lives not far from the organisation prefers to keep working in the office; coworking space seems to be on the rise (72%) among employees in shared work environments. Employees who live further from the office do not want the coworking possibility. Overall, spending some of the week working from home is a boon for employees in many circumstances, especially those who live far from the office.

One problem in the way of work-life balance is a simple one, namely distance. On the basis on the data, it appears that Austrian organisations understand that the key to allowing employees to reclaim a better work-life balance is to offer commuting flexibility

There are some limitations to the research approach in this paper that could inspire further research directions. First, the authors only analyse commuting time, and not commuting distance. Secondly, to combat geographical problems, businesses take advantage of the rise of coworking spaces, as shown in this study, but the incidence of this being refused, for psychological reasons, has not been examined. The best-designed commuting plans should take into account both what employees want (via surveys and behaviour metrics) and what they need (via route tracking and mode data). It is important to understand where the workforce is coming from, how often the workforce commutes, the modes the workforce relies on and what alternative options exist. The behaviour and preferences of different age groups in regard to commuting affect the nature of the workforce and are important issues for the employer. These are further topics to be investigated. While this study explores dimensions of commuting time, it was limited to only the commute to the office itself. There are numerous incidental issues, such as means of commuting, how easy it is to reach a convenient railway station or bus stop for example, the role played by

weather conditions, the possibility of encountering criminal elements. These kinds of issues, as well as commuting distance, were not considered, which is therefore a limitation. The sample size for this research is adequate (843 respondents), but larger sample sizes from different countries in future work would be beneficial for characterising (or at least confirming) the effects of the variables found in the current study. Moreover, a questionnaire in English might have affected the responses of Austrian respondents. Therefore, a questionnaire in German was chosen, but because of this the authors' interpretation could have influenced the generalisability of the outcomes. Despite these limitations, this study provides a methodical approach to explore the involved and intricate interplay between e-flexibility arrangements and commuting.

Acknowledgement

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References

- [1] HERNANDEZ-TAMUREJO, A., HERRAEZ, B., AGUDO, M.: Telework and the limited impact on traffic reduction – Case study Madrid (Spain), *Acta logistica*, Vol. 10, No. 3, pp. 423-434, 2023. <https://doi.org/10.22306/al.v10i3.411>
- [2] CALDAROLA, B., SORRELL, S.: Does teleworking encourage longer commute? Pre-pandemic evidence from the English National Travel Survey, *Travel Behaviour and Society*, Vol. 37, 100822, pp. 1-13, 2024. <https://doi.org/10.1016/j.tbs.2024.100822>
- [3] ELLDÉR, E.: Telework and daily travel: New evidence from Sweden, *Journal of Transport Geography*, Vol. 86, 102777, pp. 1-9, 2020. <https://doi.org/10.1016/j.jtrangeo.2020.102777>
- [4] GANDINI, A.: The rise of coworking spaces: A literature review, *Ephemera Journal*, Vol. 15, No. 1, pp. 193-205, 2015.
- [5] MAHESHWARI, R., VAN ACKER, V., GERBER, P.: Commuting vs teleworking: How does it impact the relationship between commuting satisfaction and subjective well-being, *Transportation Research Part A*

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- Policy and Practice*, Vol. 182, 104041, pp. 1-16, 2024. <https://doi.org/10.1016/j.tra.2024.104041>
- [6] TÜRKİSTANLI, T.T., TUĞDEMİR KÖK, G.: The impact of remote work arrangements on freight forwarders job performance, satisfaction, and motivation, *Dokuz Eylül Üniversitesi Denizcilik Fakültesi Dergisi*, Vol. 16, No. 1, pp. 71-100, 2024. <https://doi.org/10.18613/deudfd.1459049>
- [7] TASER, D., AYDIN, E., TORGALOZ, A.O., ROFCANIN, Y.: An examination of remote e-working and flow experience: The role of technostress and loneliness. *Computers in Human Behavior*, Vol. 127, 107020, pp. 1-10, 2021. <https://doi.org/10.1016/j.chb.2021.107020>
- [8] AITKEN, J.A., KAPLAN, S.A., KUYKENDALL, L.: Going with(out) the flow at home: day-to-day variability in flow and performance while teleworking, *European Journal of Work and Organizational Psychology*, Vol. 32, No. 5, pp. 662-677, 2023. <https://doi.org/10.1080/1359432x.2023.2211271>
- [9] DEMIRHAN, A., BULGUR, N.E.: How does remote working enhance flow experience? the role of employees' psychological well-being, *Management Research and Practice*, Vol. 15, No. 2, pp. 65-76, 2023.
- [10] BINDA, J., BOLIBRUKH, L.: Pandemic covid-19 as a catalyst of the global logistic crisis and digitalization system, *ASEJ-Scientific Journal of Bielsko-Biala School of Finance and Law*, Vol. 26, No. 4, pp. 91-95, 2022. <https://doi.org/10.19192/wsfp.sj4.2022.14>
- [11] STATISTICS AUSTRIA: Commuters (place of work), [Online], Available: <https://www.statistik.at/en/statistics/labour-market/employment/commuters-place-of-work> [4 Oct 2024], 2024.
- [12] BEŇO, M., HVORECKÝ, J., JENEŠOVÁ, Š.: On-site workforce shortening the week in favour of flexibility, *Journal of Eastern European and Central Asian Research*, Vol. 9, No. 6, pp. 1034-1045, 2022. <https://doi.org/10.15549/jeecar.v9i6.1044>
- [13] JENN, N.CH.: Designing a Questionnaire, *Malaysian Family Physician*, Vol. 1, No. 1, pp. 32-35, 2006.
- [14] EEA: From the daily office commute to flexible working patterns — teleworking and sustainability, [Online], Available: <https://www.eea.europa.eu/publications/from-the-daily-office-commute> [4 Oct 2024], 2023.
- [15] CHALABI, G., DIA, H.: The impacts of remote work and attitudinal shifts on commuting reductions in Post-COVID Melbourne, Australia, *Sustainability*, Vol. 16, No. 17, 7289, pp. 1-30, 2024. <https://doi.org/10.3390/su16177289>
- [16] DE VOS, D., MEIJERS, E., VAN HAM, M.: Working from home and the willingness to accept a longer commute, *The Annals of Regional Science*, Vol. 61, pp. 375-398, 2018. <https://doi.org/10.1007/s00168-018-0873-6>
- [17] DIAS, D.S.A., GEORGARAKOS, D., WEIßLER, M.: How people want to work – preferences for remote work after the pandemic, [Online], Available: https://www.ecb.europa.eu/press/economic-bulletin/focus/2023/html/ecb.ebbox202301_04~1b73ef4872.en.html [4 Oct 2024], 2023.
- [18] APPEL-MEULENBROEK, R., KEMPERMAN, A., VAN DE WATER, A., WEIJS-PERRÉE, M., VERHAEGH, J.: How to attract employees back to the office? A stated choice study on hybrid working preferences, *Journal of Environmental Psychology*, Vol. 81, 101784, pp. 1-12, 2022. <https://doi.org/10.1016/j.jenvp.2022.101784>
- [19] GERDENITSCH, C., SCHEEL, T.E., ANDORFER, J., KORUNKA, C.: Coworking spaces: a source of social support for independent professionals, *Frontiers in Psychology*, Vol. 7, 581, pp. 1-12, 2016. <https://doi.org/10.3389/fpsyg.2016.00581>
- [20] LASHANI, E., ZACHER, H.: Do we have a match? Assessing the role of community in coworking spaces based on a person-environment fit framework, *Frontiers in Psychology*, Vol. 12, 620794, pp. 1-15, 2021. <https://doi.org/10.3389/fpsyg.2021.620794>
- [21] RADMAN, E., JOHANSSON, E., BOSCH-SIJTSEMA, P., RAHARJO, H.: In search of member needs in coworking spaces, *Review of Managerial Science*, Vol. 17, No. 3, pp. 881-907, 2022. <https://doi.org/10.1007/s11846-022-00546-4>
- [22] WRIGHT, A., MARSH, D., WIBBERLEY, G.: Favours within “the tribe”: Social support in coworking spaces, *New Technology Work and Employment*, Vol. 37, No. 1, pp. 59-78, 2021. <https://doi.org/10.1111/ntwe.12214>
- [23] LESCARRET, C., LEMERCIER, C., FLOCH, V.L.: Coworking spaces vs. home: Does employees' experience of the negative aspects of working from home predict their intention to telework in a coworking space?, *Frontiers in Psychology*, Vol. 13, pp. 1-15, 2022. <https://doi.org/10.3389/fpsyg.2022.1079691>

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The evolution of international logistics in the era of globalisation: opportunities and challenges for business operations

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Keywords: international logistics, logistics performance, globalization, logistics operations, international trade.

Abstract: The state of international logistics is closely related to political, economic, and technological changes that take place in the context of dynamic technological development, military threats, and, at the same time, integration of countries in search of partners. The article aims to highlight the main aspects and features of the international logistic development in the globalization context. The methodology included general scientific methods of studying the chosen research object (analysis, synthesis, grouping). The logistics productivity index is considered the leading indicator of the global logistics sector development in 2018-2023. The study's results demonstrate the dependence of logistics development on several factors. In the leading countries, according to the Logistics Performance Index, the drivers of change are investments in infrastructure, transport networks, IT communications, technology, digital networks, logistics centres and hubs; logistics education and competence; government support and incentives for the sector; and a stable political and economic environment that fosters investment and innovation. The article highlights the main aspects and features of the international logistics development in globalization condition. The practical value of the study lies in highlighting the challenges faced by the logistics sector on a global scale in the context of technological shifts and military threats (the need for investment in maintaining logistics sustainability, changing supply chains, and rising delivery costs).

1 Introduction

International logistics, as a component of global supply chain management, is becoming increasingly important in the economic development of countries in the context of globalisation. Logistics ensures the efficient movement of goods, services and information between countries, regions and companies. Growing demand for efficient supply chains, changing requirements for the speed of transportation of products, rising transportation costs, and the need to consider environmental aspects – all these factors significantly impact the dynamics of international logistics.

On the one hand, the sector has undergone significant changes due to developed countries' governments' trade, investment, innovation international policies. The increased openness of the economies of developed and developing countries has led to an increase in international trade, which has had an impact on international logistics. The sector has significantly strengthened its position, which was also facilitated by technological factors, the development of railway, maritime infrastructure, and highways. On the other hand, political and economic

vulnerability and military threats significantly hinder the development of the industry. The rise in energy prices as a result of the war in Ukraine, geopolitical risks and threats affect various sectors of the economy on a global scale, including the need to change supply chains, find new ways to manage logistics. In this context, the state and commercial enterprises face new prospects and challenges related to the factors affecting their dynamics. Despite these threats, logistics companies are evolving and developing thanks to technology, scaling up their operations.

The article aims to highlight the main aspects and peculiarities of the development of international logistics in the context of globalisation.

The study's objectives are the state of international logistics development and the level of its efficiency in different countries of the world, factors and drivers of international logistics development, and opportunities and challenges for the development of international logistics in the context of globalisation.

2 Literature review

In the literature, logistics is defined as a component of Supply Chain Management (SCM) that ensures the planning, implementation, and effective control of the flow of goods and services and allows for the communication of information about these flows between companies, partners, and customers to meet customer requirements [1].

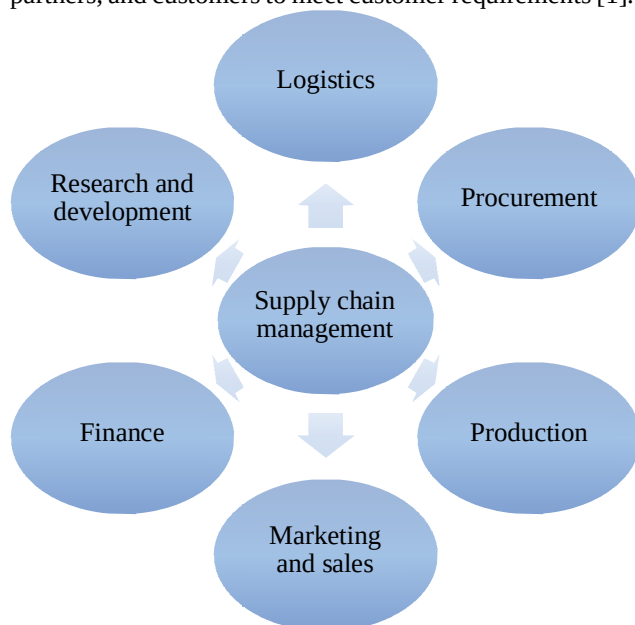


Figure 1 Logistics as a component of supply chain management

Source: Kozma et al. [1]

The critical dimensions of logistics are the system of management, financial flows, material flows, and information flows. Thus, the management system is the basis of logistics, which in today's highly competitive environment is focused on the customer and his needs. Therefore, the management of materials, resources, and information flows is aimed at 1) understanding the range of goods and services required by customers; 2) obtaining information and data about customers, their needs and behaviour; 3) understanding the income and potential expenditures of customers for goods and services.

Logistics is also defined as the organization, planning, and coordination of the materials, resources, information, energy, and values within an enterprise logistic system to meet satisfy customer needs in a timely and cost-effective manner [2]. This definition considers the critical goal of logistics - customer satisfaction, which aligns with the modern concept of customer-centric marketing. At the same time, the objects of logistics are the movement of material, resource, information, financial, and technological flows. The subject of logistics is the purposeful management of material, financial, information and technological flows from suppliers to end users.

The primary tasks of logistics include optimisation of the processes of documenting logistics operations (contract

logistics) since this process has a regulatory impact on the information flow, and contract agreements are the information base for a logistics operation, i.e. they determine the conditions for the movement of material flow and the volume of financial flow [3].

Logistics as a system can be divided into interconnected subsystems, namely procurement logistics, production logistics, warehousing and distribution logistics, and after-sales (service) logistics.

International logistics goes beyond the internal borders of a country, involving the crossing of flows of tangible and intangible assets across the borders of other countries. International logistics is a field of specialists' theoretical and practical knowledge and skills focused on organising and implementing technologies and equipment to improve logistics processes, managing and controlling interconnected flows, and servicing the international exchange of material flows, innovations, and services in time and space.

In the literature, the main areas of research on the peculiarities of international logistics development are as follows:

- 1) the relationship between the logistic sector development and macroeconomic growth (macro level) [3-8];
- 2) the role of logistics in the activities of enterprises;
- 3) "sustainability" and logistics, its impact on the environment [9-14].

Hayaloglu [4], based on a panel analysis of data and indicators of international logistics development in OECD countries for 1994-2011, concludes that it has an impact on international trade and, consequently, on economic growth. Similar conclusions are drawn in Wiederer [7] and Gani [6], which find a significant link between logistics productivity and trade. Chua et al. [8] find a relationship between the state of transport and logistics infrastructure and international trade between China and its main trading partners in the textile sector. Saidi et al. [15] found significant causal relationships between transport, logistics, foreign direct investment, and economic growth in developing countries in 2000-2016. Transport and logistics infrastructure is a factor in the inflow of foreign investment. At the same time, Blyde and Molina [5] found that a developed logistics infrastructure facilitates investment in logistics service-dependent industries.

3 Research methodology

The article uses the analysis and synthesis methods to characterise the peculiarities of international logistics development in the context of globalisation. The World Bank data are used to assess the development and state of international logistics of countries, namely the Logistic Performance Index and indicators of the level of globalisation (share of trade in GDP). Table 1 shows the six components of the Logistic Performance Index and their brief description.

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Table 1 Logistic Performance Index components

Component	World Bank explanation
Customs	The efficiency of border and customs management clearance.
Transport infrastructure	The quality of transport and trade infrastructure in country.
Services quality	The quality and competence of logistics services.
Timeliness	The frequency with which shipments reach consignees within the expected delivery times.
Tracing and tracking.	The ability to trace and track consignments.
International shipments	The ease of arranging competitively priced shipments.

Source: based on [16,17]

The LPI is an interactive tool for conducting a comparative analysis of countries' existing problems, challenges and opportunities for developing the international logistics sector. The Index also provides a more detailed and comprehensive picture of supply chain performance and constraints in more than 100 countries across the globe based on the following parameters: time, distance, reliability, quality of domestic infrastructure, services, customs and related services. Experts are surveyed in eight countries to calculate the Index and

assign scores to the above components from 1 to 5 (1 – low productivity, 5 – high logistics productivity). The survey is conducted among respondents who are experts in international transport and logistics.

We used information from UN Trade and Development [18], European Security and Defence [19], European Parliament [20], and International Transport Forum [21] to highlight the challenges of international logistics development.

4 Results

The development of logistics is closely interconnected with various factors that stimulate the development of infrastructure (ports, roads, railways) and support its continuous operation. The most developed European countries generally have a high degree of efficiency in logistics activities, which is associated with economic stability, government programmes supporting the sector, and investment and innovation policy.

In 2018, the countries with the highest logistics efficiency were Germany, Sweden, Belgium, Austria, Japan, and the Netherlands (Table 2). By comparison,

in 2023, the leaders are Singapore, Finland, Denmark, Germany, the Netherlands, and Switzerland, which achieved greater efficiency by improving infrastructure, logistics competences and quality of logistics, tracking of material flows, timeliness of logistics, and customs. At the same time, GDP growth rates in these countries were below average in 2018-2019 (less than 2%), and in 2020 they declined (the average for countries was 3.59%) [22]. In 2021-2022, the average GDP growth rate was 4.06% [22], but the economies of the leading countries in the Logistics Productivity Index demonstrated the ability to recover from the crisis.

Table 2 Grouping of countries by Logistics Productivity Index in 2018, 2023

LPI score	Countries 2018	Countries 2023
More than 4	Germany, Sweden, Belgium, Austria, Japan, Netherlands	Singapore, Finland, Denmark, Germany, Netherlands, Switzerland
3 - 4	Singapore, Denmark, United Kingdom, Finland, United Arab Emirates, Hong Kong SAR, China, Switzerland, United States, New Zealand, France, Spain, Australia, Italy, Canada, Norway, Czech Republic, Portugal, Luxembourg, Korea, Rep, China, Taiwan, China, Poland, Ireland, Qatar, Hungary, Thailand, South Africa, Chile, Slovenia, Estonia, Israel, Panama, Vietnam, Iceland, Malaysia, Greece, Oman, India, Cyprus, Indonesia, Turkey, Romania, Croatia, Côte d'Ivoire, Mexico, Bulgaria, Slovak Republic, Lithuania, Saudi Arabia	Austria, Belgium, Canada, Hong Kong SAR, China, France, Japan, Spain, Taiwan, China, Korea, Rep, United States, Australia, China, Greece, Italy, Norway, South Africa, United Kingdom, Estonia, Iceland, Ireland, Israel, Luxembourg, Malaysia, New Zealand, Poland, Bahrain, Latvia, Qatar, Thailand, India, Lithuania, Portugal, Saudi Arabia, Turkey, Croatia, Czech Republic, Malta, Oman, Philippines, Slovak Republic, Slovenia, Vietnam, Brazil, Bulgaria, Cyprus, Hungary, Kuwait, Romania, Botswana, Egypt, Arab Rep, North Macedonia, Panama, Bosnia and Herzegovina, Chile, Indonesia, Peru, Sweden, Uruguay, United Arab Emirates

Source: compiled by the author according to Logistic Performance Index [17]

Germany is a leader in Europe, ahead of France, the UK and the Netherlands, in terms of international logistics development. Several factors contributed to this:

innovation, technology and quality logistics services; development of a logistics hub and a comprehensive, extensive infrastructure that combines transport networks

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with IT communications; leadership in the quality of logistics education; stimulation of the sector's development at the state level by the Federal Ministry of Digitalisation and Transport, development of industry incentive and support programmes; politically and economically stable investment environment that promotes logistics sustainability and competitiveness [23]. The volume of investments in transport infrastructure and its support in Germany amounted to EUR 271.6 billion in 2018-2022 (land transport, rail, roads, water transport, maritime transport, aviation) [24].

The factors behind the high level of logistics productivity in the Netherlands include high-quality air transport, efficient seaports, the high availability of logistics infrastructure within Europe, and new technologies, digital networks, and solutions. The country's average GDP growth rate for 2018-2023 was 1.85% [22]. The volume of investments in transport infrastructure and its support in the Netherlands amounted to 92.7 billion euros in 2018-2022 [24]. More than 10% of the country's specialists are employed in the logistics sector, which helps to develop its innovative component [25]. Therefore, the country has significant opportunities for distributing material flows and a reliable supply chain. Following the UK's exit from the EU, the level of investment in Dutch logistics is growing, particularly in distribution networks and logistics centres, which greatly simplify trade operations in global markets. The growing interest of foreign freight carriers in Dutch logistics has also stimulated the industry development. More than 1000 American and Asian companies have centralised their distribution activities in the country by investing in logistics projects [25].

In Finland, logistics development is driven by economic growth, which has allowed the government to invest in road infrastructure and a favourable geographical location [26]. According to the World Bank, the average annual GDP growth rate was 0.524% in 2018-2023 [22].

The volume of investments in transport infrastructure and its maintenance in Finland amounted to €24.4 billion in 2018-2022 [24]. Accordingly, these factors also led to an increase in private investment in the logistics sector. In addition, due to the high share of small and medium-sized businesses, the country's economy remains stable, which positively impacts logistics. In addition, the country is also developing green logistics, with the logistics infrastructure transitioning to a more environmentally friendly one. For example, the country has zero-carbon airports and electrified ports and is transitioning to electric transport [27].

Favourable geographical location, developed infrastructure, including port infrastructure, and economic growth have contributed to the development of the Danish logistics sector. From 2018 to 2023, the country's average GDP growth rate is estimated to be 2.08%. The volume of investments in transport infrastructure and its support in Denmark amounted to EUR 5.4 billion in 2018-2022 [24]. The Port of Aarhus handles 70% of the country's total container sales. The electricity grid's reliability is also one of the country's strategic advantages [26].

Austria, Belgium, Canada, Hong Kong SAR, China, Sweden, the United Arab Emirates, France, Japan, and Spain recorded a relatively high level of logistics efficiency in 2023. However, globally, most countries are either in the middle of the logistics productivity spectrum (3-4 points) or in the lower middle (2-3 points).

As shown in Figure 2, there is a direct, low correlation between the Logistics Productivity Index and the level of economic openness, expressed as the share of trade in GDP. It should be noted that a predominantly open economy characterises countries with a logistics productivity score of 2-3, expressed as a share of trade in GDP, of 50% to 100%. At the same time, countries with logistics productivity scores of 3-4 and above are generally characterised by a tendency to have a higher share of trade in GDP.

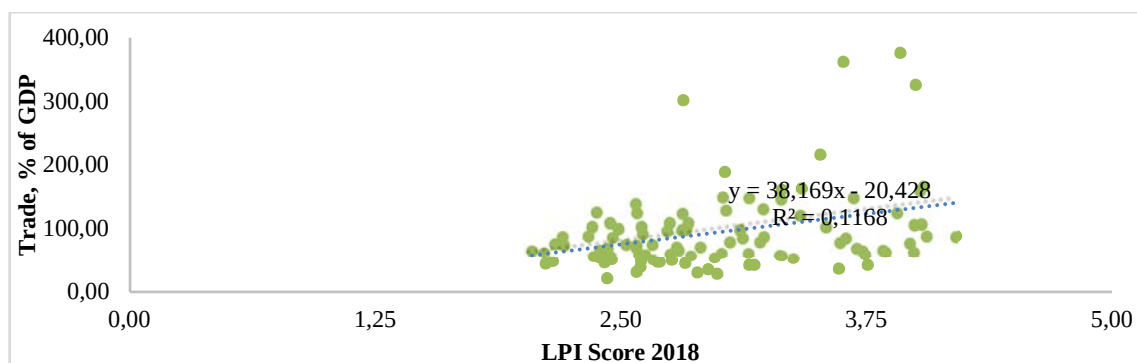


Figure 2 Correlation between the Index and the share of trade in GDP in different countries in 2018

Source: compiled by the author based on [17,22]

In 2023, this correlation is still relatively low despite a slight increase in the correlation between the Logistics Productivity Index and the share of trade in GDP in different countries. This is due to significant variation

between countries, both in the trade development, and growth with other countries and in the presence of other export and import growth drivers.

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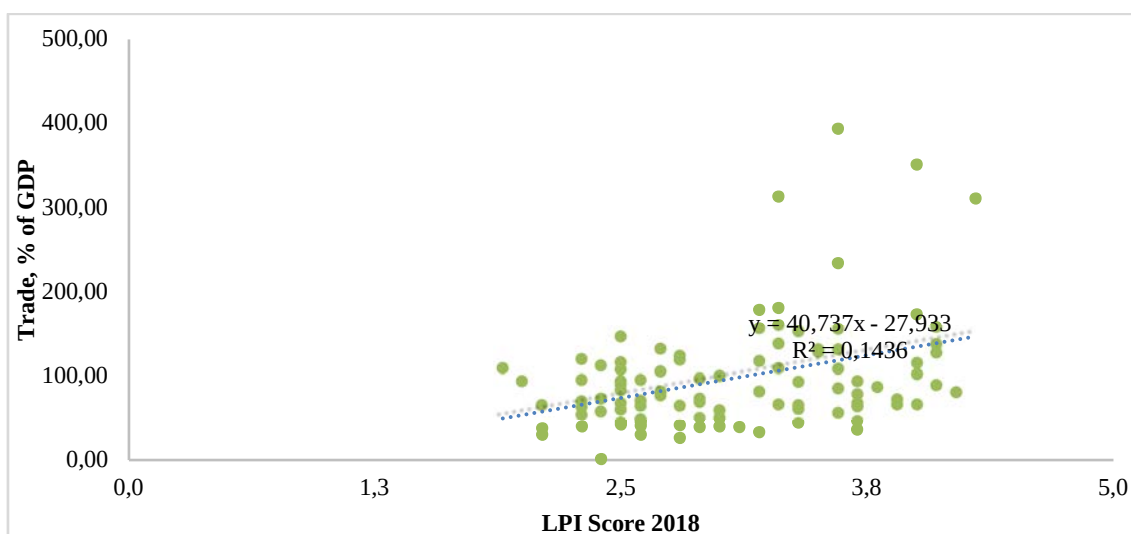


Figure 3 The relationship between the Logistics Productivity Index and the share of trade in GDP in different countries in 2023
Source: compiled by the author based on [17,22]

The development of international logistics depends on political, economic, geographical and technological factors. The sector dynamics have been particularly affected by technological changes, such as the Fourth Industrial Revolution, which has contributed to the automation of logistics operations and processes. Industry 5.0 focuses on automation of logistics businesses: large organizations automate processes to increase flexibility and respond quickly to customer demands. However, the desire to meet market needs will become a challenge for international logistics [28]. Digitalisation has created challenges and needs to restructure logistics operations,

processes and functions. This will require significant investment from both national governments and leading service providers. Additionally, the industry needs to ensure resilience during the war in Ukraine and the disruption of logistics links. The ports and transport links in the Black Sea region have been particularly affected by the invasion, which has led to increased demands on maritime and land transport infrastructure and services. Global demand for ships and shipping costs have increased significantly. The main challenges in developing international logistics in the context of globalisation are shown in Figure 4.



Figure 4 Key challenges in the development of international logistics in the context of globalisation
Source: compiled by the author [18,20,21]

The war in Ukraine has led to difficulties with the availability of technology and equipment, both in the

security and defence sectors and the energy, transport, and warehousing sectors. The destruction of seaports has hurt

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food security globally, as 90% of agricultural exports were exported through the Black Sea before the war. As a result, European supply chains were disrupted [21].

5 Discussion

In general, the study's findings demonstrate the emergence of new challenges in the logistics sector, which correlates with the conclusions presented by scholars who have studied this issue. The digitalisation of the logistics sector in the context of globalisation is changing supply chains. In addition, such changes are influenced by customer requirements, product characteristics, and a new philosophy of production and service [29]. Traditional mass production is being replaced by serial, unique, personalised production [4,30]. Technological development and individual use of information and communication technologies have created new challenges and opportunities for logistics on a global scale [31,32].

At the same time, the research results indicate specific differences compared to the works of scholars in this area. The study results indicate a direct low correlation between logistics and trade efficiency in different countries. Gani [6] shows a positive, statistically significant impact on overall logistics productivity with exports and imports (mainly exports), and continuous investment in logistics infrastructure positively impacts international trade. Bensassi et al. [33] also conclude that logistics significantly impacts a country's exports (based on the case of Spain). In particular, this impact is due to geographical location, transport infrastructure and accessibility. Munim and Schramm [34] prove the importance of continuously improving the quality of port infrastructure through investment to ensure the growth of logistics productivity, which increases international trade and economic growth. Bugarčić et al. [35] show a positive statistically significant relationship and impact of international logistics, measured by the Logistics Productivity Index for 2007 and 2018 in Central and Eastern Europe, on trade between countries. Thus, in general, our results align with the findings of studies on the importance of investment and development of transport infrastructure for improving logistics productivity.

6 Conclusion

International logistics is developing in a challenging political and economic environment. The experience of the leading countries in the Logistics Productivity Index shows that positive changes in the efficiency of the logistics sector are driven by economic sustainability, investment in infrastructure and transport networks, expanding the availability of infrastructure, research and development, and the development of education and competences. The experience of logistics development in developed European countries demonstrates the importance of combining several factors to ensure positive changes in the industry. The experience of Germany, the Netherlands, Finland, and Denmark shows that governments have

chosen different strategies and policies for logistics development. Germany has achieved a high level of productivity in the sector due to government programs, the development of high-quality logistics services, innovation, technology, investment, and the development of an extensive infrastructure network. In the Netherlands, the volume of public investment in transport infrastructure is somewhat lower, and the industry is driven by the quality of transport, the efficiency of port infrastructure, technology, and digital networks. Finland and Denmark also have lower levels of investment in transport infrastructure, and in these countries, the government focuses on sustainable economic development and environmental friendliness. Thus, government incentives and infrastructure development programs are creating new opportunities for logistics development, which vary significantly from country to country. The openness of the economy and the level of globalization are interconnected with the state of logistics productivity. In general, the productivity of this sector has a positive impact on a country's export opportunities. In the context of growing military risks and threats, there is a need to move to sustainable logistics. This practice is most typical in Denmark. In most countries, logistics development is average or below average. There is a low degree of direct correlation between logistics efficiency and trade. A higher level of trade integration characterises countries with average logistics efficiency. In contrast, a lower share of trade in GDP characterises countries with below-average logistics productivity. In the context of globalisation, the development of the international logistics sector is characterised by its dependence on political, economic, and technological factors, challenges, and the level of political and economic integration of countries. Further research should focus on identifying the relationship between these factors and the state of the international logistics sector.

References

- [1] KOZMA, D., VARGA, P., HEGEDÜS, C.: *Supply chain management and logistics 4.0-A study on Arrowhead framework integration*, In: 2019 8th International Conference on Industrial Technology and Management (ICITM), Cambridge, UK, pp. 12-16, 2019. <https://doi.org/10.1109/ICITM.2019.8710670>
- [2] GUBÁN, M., KOVÁCS, G.: Industry 4.0 conception, *Acta Technica Corviniensis-Bulletin of Engineering*, Vol. 10, No. 1, pp. 111-114, 2017.
- [3] HAYALOĞLU, P.: The impact of developments in the logistics sector on economic growth: The case of OECD countries, *International Journal of Economics and Financial Issues*, Vol. 5, No. 2, pp. 523-530, 2015.
- [4] KOVÁCS, G., KOT, S.: New logistics and production trends as the effect of global economic changes, *Polish Journal of Management Studies*, Vol. 14, No. 2, pp. 115-126, 2016. <https://doi.org/10.17512/pjms.2016.14.2.11>

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- [5] BLYDE, J., MOLINA, D.: Logistics infrastructure and the international location of fragmented production, *Journal of International Economics*, Vol. 95, No. 2, pp. 319-332, 2015.
<https://doi.org/10.1016/j.jinteco.2014.11.010>
- [6] GANI, A.: The logistics performance effect in international trade, *The Asian Journal of Shipping and Logistics*, Vol. 33, No. 4, pp. 279-288, 2017.
<https://doi.org/10.1016/j.ajsl.2017.12.012>
- [7] WIEDERER, C.: The role of logistics in supporting international trade and development – A literature review, *Trade, Law and Development*, Vol. 11, No. 1, 111, 2019.
- [8] CHUA, W.C.A., CHANA, M.H.E., CHEUNGA, J., NGUYENB, H.O.: International logistics and trade, *Journal of International Logistics and Trade*, Vol. 17, No. 1, pp. 21-32, 2019.
<http://dx.doi.org/10.24006/jilt.2019.17.1.003>
- [9] CENIGA, P., SUKALOVA, V.: Future of logistics management in the process of globalisation, *Procedia Economics and Finance*, Vol. 26, pp. 160-166, 2015.
[https://doi.org/10.1016/S2212-5671\(15\)00908-9](https://doi.org/10.1016/S2212-5671(15)00908-9)
- [10] BÎZOI, C., POPESCU, A., SIPOS, G., SIPOS, C.: The transportation and logistics sector's performance and the social development—a comparison within the European Union, *Studia Universitatis Babes-Bolyai*, Vol. 60, No. 1, pp. 68-81, 2015.
- [11] KHAN, S.A.R., QIANLI, D., SONGBO, W., ZAMAN, K., ZHANG, Y.: Environmental logistics performance indicators affecting per capita income and sectoral growth: Evidence from a panel of selected global ranked logistics countries, *Environmental Science and Pollution Research*, Vol. 24, pp. 1518-1531, 2017.
<https://doi.org/10.1007/s11356-016-7916-2>
- [12] RODRIGUE, J.P., SLACK, B., COMTOIS, C.: Green logistics, *Handbook of Logistics and Supply-Chain Management*, Emerald Group Publishing Limited, Vol. 2, pp. 339-350, 2017.
- [13] LIU, J., YUAN, C., HAFEEZ, M., YUAN, Q.: The relationship between environment and logistics performance: Evidence from Asian countries, *Journal of Cleaner Production*, Vol. 204, pp. 282-291, 2018.
<https://doi.org/10.1016/j.jclepro.2018.08.310>Get rights and content
- [14] KHAN, S.A.R., SHARIF, A., GOLPÎRA, H., KUMAR, A.: A green ideology in Asian emerging economies: From environmental policy and sustainable development, *Sustainable Development*, Vol. 27, No. 6, pp. 1063-1075, 2019.
<https://doi.org/10.1002/sd.1958>
- [15] SAIDI, S., MANI, V., MEFTEH, H., SHAHBAZ, M., AKHTAR, P.: Dynamic linkages between transport, logistics, foreign direct investment, and economic growth: Empirical evidence from developing countries, *Transportation Research Part A: Policy and Practice*, Vol. 141, pp. 277-293, 2020.
<https://doi.org/10.1016/j.tra.2020.09.020>
- [16] VAN ROEKEL, W.S.: *Improving international logistics performance measurement*, Master Thesis, Delft University of Technology, [Online], Available: <http://resolver.tudelft.nl/uuid:bbec46b9-c6bc-475f-ba61-2f3404bc7178> [20 Jan 2025], 2017.
- [17] LOGISTIC PERFORMANCE INDEX: 2024, [Online], Available: <https://lpi.worldbank.org/international/scorecard> [20 Jan 2025], 2024.
- [18] UN TRADE AND DEVELOPMENT: Maritime trade disrupted: The war in Ukraine and its effects on maritime trade logistics, 2024, [Online], Available: <https://unctad.org/es/isar/publication/maritime-trade-disrupted-war-ukraine-and-its-effects-maritime-trade-logistics> [20 Jan 2025], 2024.
- [19] EUROPEAN SECURITY AND DEFENCE: Lessons learned from Ukraine: Logistics, 2023, [Online], Available: <https://euro-sd.com/2023/06/articles/31845/lessons-learned-from-ukraine-logistics/> [20 Jan 2025], 2023.
- [20] EUROPEAN PARLIAMENT: Russia's war on Ukraine: Maritime logistics and connectivity, 2022, [Online], Available: [https://www.europarl.europa.eu/RegData/etudes/ATAG/2022/733603/EPRS_ATA\(2022\)733603_EN.pdf](https://www.europarl.europa.eu/RegData/etudes/ATAG/2022/733603/EPRS_ATA(2022)733603_EN.pdf) [20 Jan 2025], 2022.
- [21] INTERNATIONAL TRANSPORT FORUM: Transport and the war in Ukraine, 2024, [Online], Available: <https://www.itf-oecd.org/transport-and-war-ukraine> [20 Jan 2025], 2024.
- [22] WORLD DEVELOPMENT INDICATORS: 2024, [Online], Available: <https://databank.worldbank.org/source/world-development-indicators#> [21 Jan 2025], 2024.
- [23] JONES LANG LASALLE COMPANY: Logistics and Industrial Market Overview Germany, 2022, [Online], Available: <https://stage-de.jll.com/content/dam/jll-com/images/emea/Germany/trends-and-insights/research/de-industriemarktueberblick/Logistics-and-Industrial-Market-Overview-JLL-Germany.pdf> [21 Jan 2025], 2022.
- [24] OECD: Transport infrastructure investment and maintenance spending, 2024, [Online], Available: [https://data-explorer.oecd.org/vis?lc=en&fs\[0\]=Topic%2C0%7CTransport%23TRA%23&fs\[1\]=Topic%2C1%7CTransport%23TRA%23%7CInfrastructure%20investment%20and%20maintenance%20spending%23TRA_IMS%23&pg=0&fc=Topic&snb=1&vw=tb&df\[ds\]=dsDisseminateFinalDMZ&df\[id\]=DSD_INFRINV%40DF_INFRINV&df\[ag\]=OECD.ITF&df\[vs\]=1.0&dq=.A.INV.EUR.V&lom=LASTNPERIODS&lo=5&to\[TIME_PERIOD\]=false&ly\[cl\]=TIME_PERIOD&ly\[rs\]=TRANSPORT_MODE&ly\[rw\]=REF_AR_EA](https://data-explorer.oecd.org/vis?lc=en&fs[0]=Topic%2C0%7CTransport%23TRA%23&fs[1]=Topic%2C1%7CTransport%23TRA%23%7CInfrastructure%20investment%20and%20maintenance%20spending%23TRA_IMS%23&pg=0&fc=Topic&snb=1&vw=tb&df[ds]=dsDisseminateFinalDMZ&df[id]=DSD_INFRINV%40DF_INFRINV&df[ag]=OECD.ITF&df[vs]=1.0&dq=.A.INV.EUR.V&lom=LASTNPERIODS&lo=5&to[TIME_PERIOD]=false&ly[cl]=TIME_PERIOD&ly[rs]=TRANSPORT_MODE&ly[rw]=REF_AR_EA) [21 Jan 2025], 2024.

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- [25] SCOTTISH DEVELOPMENT INTERNATIONAL: The Netherlands as a logistics leader, 2021, [Online], Available: https://thehague.com/businessagency/sites/thcb_thba/files/2021-06/The%20Netherlands%20as%20a%20logistics%20leader_260521_0.pdf [20 Jan 2025], 2021.
- [26] MAIL BOXES ETC, (2024): Unlocking prosperity: Why Finland's logistics market is a must-invest destination, [Online], Available: <https://mbefranchise.com/unlocking-prosperity-why-finlands-logistics-market-is-a-must-invest-destination/> [21 Jan 2025], 2024.
- [27] BUSINESS FINLAND: Finland, making a difference with green logistics, 2023, [Online], Available: <https://www.businessfinland.com/news/2023/making-a-difference-with-green-logistics/> [20 Jan 2025], 2023.
- [28] OSIECZKO-POTOCZNA, K. Reasons, benefits and challenges on the road to automated internal transportation, *Acta logistica*, Vol. Vol. 11, No. 4, pp. 605-613, 2024. <https://doi.org/10.22306/al.v11i4.557>
- [29] WINKELHAUS, S., GROSSE, E.H.: Logistics 4.0: A systematic review towards a new logistics system, *International Journal of Production Research*, Vol. 58, No. 1, pp. 18-43, 2020. <https://doi.org/10.1080/00207543.2019.1612964>
- [30] GOVINDAN, K., KILIC, M., UYAR, A., KARAMAN, A.S.: Drivers and value-relevance of CSR performance in the logistics sector: A cross-country firm-level investigation, *International Journal of Production Economics*, Vol. 231, 107835, pp. 1-14, 2021. <https://doi.org/10.1016/j.ijpe.2020.107835>
- [31] SPERANZA, M.G.: Trends in transport and logistics, *European Journal of Operational Research*, Vol. 264, No. 3, pp. 830-836, 2018. <https://doi.org/10.1016/j.ejor.2016.08.032>
- [32] BILGIN, C.: *The concept of logistics performance in international trade framework: An empirical evaluation of logistics performance index*, In: I. Management Association (Ed.), *Research Anthology on Macroeconomics and the Achievement of Global Stability*, IGI Global Scientific Publishing, pp. 345-369, 2023. <https://doi.org/10.4018/978-1-6684-7460-0.ch020>
- [33] BENSASSI, S., MÁRQUEZ-RAMOS, L., MARTÍNEZ-ZARZOSO, I., SUÁREZ-BURGUET, C.: The relationship between logistics infrastructure and trade: Evidence from Spanish regional exports, *Transportation Research Part A: Policy and Practice*, Vol. 72, pp. 47-61, 2015. <https://doi.org/10.1016/j.tra.2014.11.007>
- [34] MUNIM, Z.H., SCHRAMM, H.J.: The impacts of port infrastructure and logistics performance on economic growth: The mediating role of seaborne trade, *Journal of Shipping and Trade*, Vol. 3, No. 1, pp. 1-19, 2018. <https://doi.org/10.1186/s41072-018-0027-0>
- [35] BUGARČIĆ, F.Ž., SKVARCIANY, V., STANIŠIĆ, N.: Logistics performance index in international trade: The case of Central and Eastern European and Western Balkan countries, *Business: Theory and Practice*, Vol. 21, No. 2, pp. 452-459, 2020.

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Optimising process flow in manufacturing: a study on standardisation and equipment capacity

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Keywords: flow of processes, optimalization, theory of constraints, equipment capacity, standardization.

Abstract: The main goal of a manufacturing company is to make a profit, which requires efficient in-house processes and smooth process flow. The key tools for increasing productivity and optimizing production are process standardization, workflow efficiency, and the application of the theory of constraints (TOC). Process standardisation leads to the standardisation of workflows and the elimination of variability. TOC focuses on identifying bottlenecks in the process and optimizing them, resulting in cost reduction, increased productivity, and improved enterprise profitability by enhancing process flow. The presented paper describes a case study aimed at analysing selected processes at robotic welding workstations in a selected industrial enterprise. The aim of the paper is to identify opportunities to improve production efficiency at robotic welding workplaces, focusing on standardization of work procedures, more efficient use of production equipment capacity, and improvement of the remuneration system, which has a direct impact on workflow efficiency, process optimization, and the financial performance of the enterprise. The results of the research point to a lack of standardisation of working practices, low utilisation of the equipment capacity (30% below the planned value) and limitations in the remuneration system that hinder the achievement of the full productivity potential. The combination of inefficient use of equipment and working time increases financial costs and limits profitability. An effective bonus system can increase employee motivation, support productivity improvements and contribute to cost reduction. To address these issues, the implementation of standardised work practices, optimisation of equipment utilisation and effective workforce management are needed.

1 Introduction

The main goal of every enterprise is to make a profit. In order to achieve this, it is necessary to establish the right and efficient processes across various areas. All processes within a company are interconnected and essential, whether they relate to production, ergonomics, logistics, material flow, or even remuneration and flow of management of financial. Effective supply chain management also plays a crucial role in ensuring smooth operations and optimizing resource utilization. Continuous process improvement should lead to enhanced workflow efficiency, resulting in greater operational effectiveness in terms of productivity, cost reduction, increased competitiveness, and, most importantly, improved profitability. Without regular profit generation, an enterprise cannot sustain itself. Increasing the enterprise's profitability is possible through the implementation of various philosophies, theories, and tools, all of which are closely linked to optimizing internal company processes to

reduce operating costs and maximize productivity and profits.

An enterprise, like any other system, is made up of interdependent activities and processes, forming a complex process flow. The analogy is a chain—to increase the strength of the chain, it is necessary to strengthen its weakest link. Strengthening any other link has no effect on the overall strength and represents a loss. The only way to improve the entire system is to identify and optimize the weakest link, which requires a focus on all flows within the enterprise. To effectively enhance flow management, it is first necessary to standardize processes, eliminating unnecessary variations and inconsistencies. Standardization does not aim to establish the ultimate best practice but rather to unify workflows, creating a solid foundation for continuous process flow improvement. These tools are also used to eliminate the process variations and possible wastage that occur, which are a very common cause of reduced profitability in companies. Unless a standard is in place, too much variation occurs in the

process, and it is almost impossible to improve such a process [1-3]. One of the metrics to improve processes in an enterprise is the Theory of Constraints - TOC. Theory of Constraints is concerned with uncovering bottlenecks in a business and its profitability. In manufacturing, TOC focuses on identifying bottlenecks and by analysing of the material and information flow [3,4]. TOC can also help to identify and improve ergonomically challenging tasks within the manufacturing process, leading to higher efficiency and reduced absenteeism [5]. TOC also influences the reward system by motivating employees to achieve goals. A properly set reward system leads to increased productivity and employee engagement [6]. Lost EBITDA (Earnings Before Interest, Taxes, Depreciation and Amortization) and lost wages are related to a well-set reward system. EBITDA and lost wages are among the key indicators that need to be analysed in process improvement. Removing constraints in processes improves performance, which directly affects EBITDA. Lost wages, which result from inefficiencies, are also reduced when workforce and process utilization are improved [7].

2 Theoretical background

Modern manufacturing process management requires a systematic approach to optimising activities, identifying constraints and improving productivity. In this context, process standardisation and more efficient capacity utilisation of production facilities are key tools to improve production efficiency and resource management. The following section describes the basic concepts related to the presented paper. In addition to these concepts, the chapter also describes an analysis of the number of publications that focus on topics such as process standardization, process optimization, theory of constraints and more efficient use of the capacity of production facilities. The analysis of the number of publications is processed using the Web of Science - WOS citation database, in order to demonstrate the relevance and topicality of the given problem solution.

2.1 The process, its standardisation and the theory of constraints

The term process can be understood as the transformation of inputs into outputs, with a clearly defined beginning and end, according to defined regulators and using allocated resources, with a strong customer orientation. The individual activities within the process are important, but none of them as a stand-alone are meaningful to the customer if the whole process does not lead to the delivery of the desired output [8]. Process standardization creates processes that are consistent or permanent. The same operations or tasks are performed in the same manner and procedure [9]. Standardization helps in companies to create efficient processes and thus reduce costs. In its essence, standardization works as a guide that defines the procedures and flow that should be followed to

achieve the desired results in a specified time [1,10]. Process standardization has many benefits, which mainly include eliminating work randomness and confusion, reducing operating costs, increasing productivity, and improving process automation [11]. Standardization is also important within the theory of constraints because it allows organizations to define best practices and performance standards. By implementing standardized workflows, organizations can reduce variability and optimize performance in bottleneck areas [12].

Theory of Constraints is a concept that is closely related to business process management and focuses on the identification and elimination of "constraints" or bottlenecks in a process [13]. Constraints are defined as any factors that limit the performance of the overall system and prevent the achievement of higher levels of efficiency or productivity [14]. If we have a work activity that has multiple steps, not every step can be performed equally efficiently. The lower performance of any step causes a bottleneck in which work accumulates waiting to be processed and moved to the next step. At the same time, if the next steps beyond the constraint are more efficient, they do not receive enough work and go partially idle, thus h optimising material flow and information flow aying unnecessary downtime. As a result, the productivity of the entire work chain suffers from the constraint in one step [3,15,16]. When we analyse the process, we are likely to find that there are several constraints in the process. The challenge is to find the constraint that limits the efficiency of the process the most and solving it will have the greatest positive impact on the productivity of the entire process. It is important to analyse the process and find out where the constraint arises, i.e., where the most work accumulates, and which part of the work process does not keep up with the rest [17]. In general, constraints can be found in several places: in production resources - insufficient machine capacity, inefficient use of equipment capacity, lack of staff, lack of finance, lack of materials/parts for production; in marketing - you can have a perfectly fine-tuned production process, but if there are just few orders, it does not help to the enterprise; in time; in people's attitudes; and in management, directives and organization [3,17].

In the next part of the paper, we will focus on TOC, which has been widely applied to manufacturing process improvement, standardization and rewarding, and is also closely linked to financial analysis. TOC focuses on identifying and removing bottlenecks in the production process. By analysing the material and information flow, organizations can increase equipment capacity and reduce costs and improve production efficiency [18]. In Lean manufacturing and Industry 4.0 [19], TOC is applied to improve overall productivity and efficiency. By improving and automating processes using Industry 4.0 technologies, it has been possible to increase productivity by 20-30% compared to traditional practices [4,20]. In the context of TOC, it is also important to analyse the normalization in manufacturing - the recalculation of the norm, which must

take into account the actual capacity constraints. TOC helps in defining realistic and achievable standards, leading to more efficient planning and optimization of processes [21]. Standard setting is crucial for measuring of efficiency and resource allocation in manufacturing. In the context of TOC, standards adapt to process improvements after bottlenecks are removed, resulting in higher accuracy and fairer evaluation of worker performance and reward systems [22,23]. TOC in the context of reward emphasizes the need to align employee goals with the goals of the organization. If a constraint that slows down production is removed, there will be an increase in efficiency, which can be linked to performance bonuses and improvements in the reward system [23]. The reward system should be set to motivate employees [24]. In assessing the financial impact of production constraints, the lost EBITDA and lost wages are also analysed. If the constraint causes lower output, this has a direct impact on reduced EBITDA, which means

untapped potential profit. Once the constraints are removed and the production rate is increased, an EBITDA increase of more than 10-15% can be achieved [25]. Similarly, lost wages, which reflect inefficient use of working time, are reduced when restrictions are removed, leading to a fairer distribution of financial rewards. Constraint theory [26,27] provides a powerful framework for optimizing production processes and improving efficiency in different areas of the enterprise [28,29].

2.2 Literature review

As part of the theoretical background analysis, we also focused on examining the number of publications that focus on topics such as "process and optimization", "standardization", "theory of constraints" and "capacity utilization rate" in the WOS - Web of Science citation database from 2014 to 2025 (Figure 1).

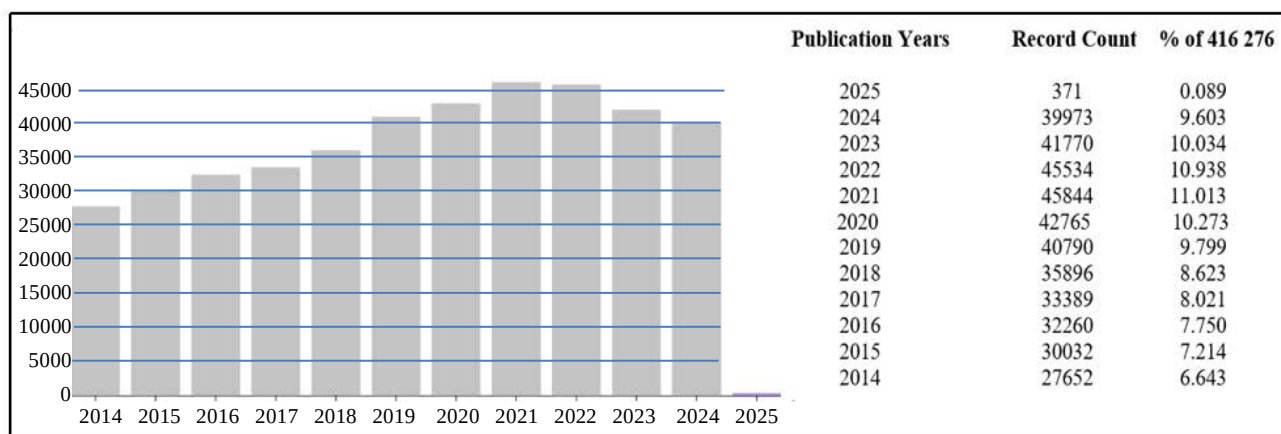


Figure 1 The topics: "processes, optimisation, theory of constraints, equipment capacity" in world database WOS in the years 2014 – 2025 (Own processing)

The aim of the analysis was to show the relevance of the areas. Figure 1 shows an increasing trend of articles in the different databases until 2023. The year 2024 is not yet complete, but we assume an increasing trend in that year as well.

The second point of the analysis of the theoretical background was the bibliometric analysis performed using VOSviewer software [30]. That database uses files also

created in the WOS citation database. For this analysis a dataset was created from the database, focusing on the keyword "processes, optimisation, theory of constraints, equipment capacity". A total of 416 276 documents were found.

Documents were converted into an MS Excel file and processed in VOSviewer (Figure 2, Figure 3).

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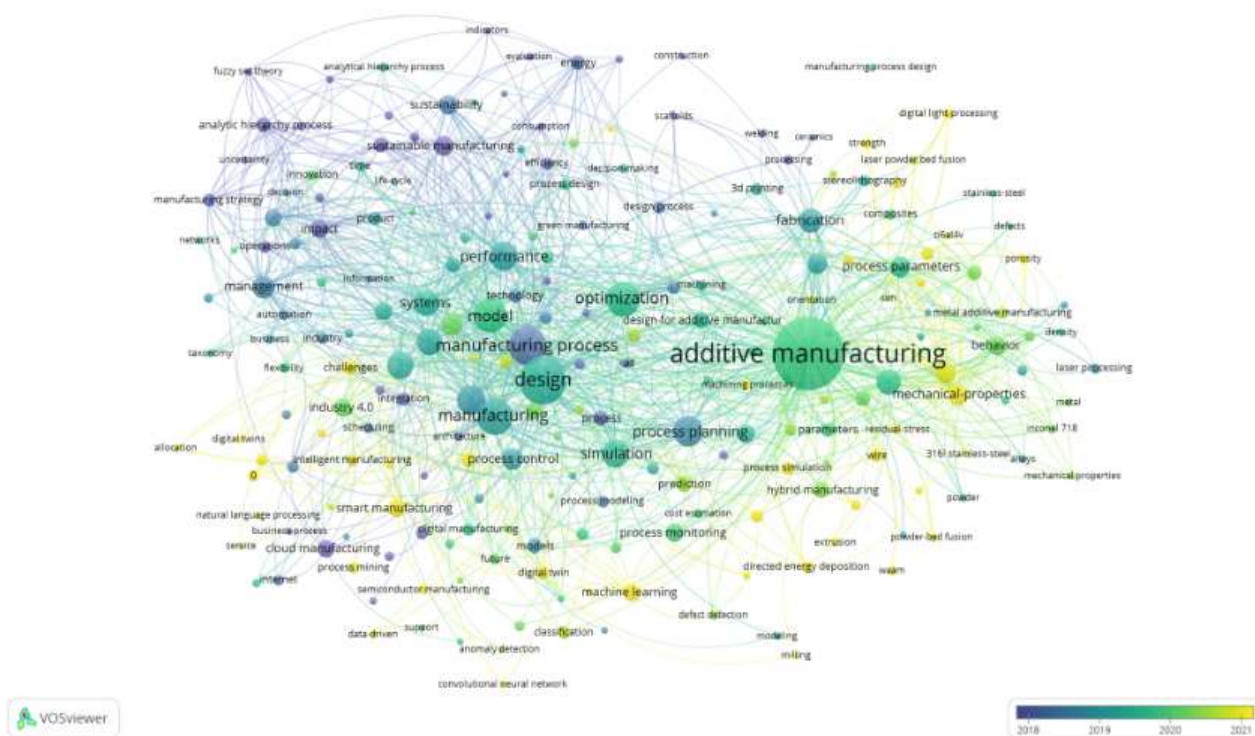


Figure 2 Bibliographic analysis – keywords: “processes, optimisation, theory of constraints, equipment capacity“ in WOS in the years 2014 – 2025 (Own processing)

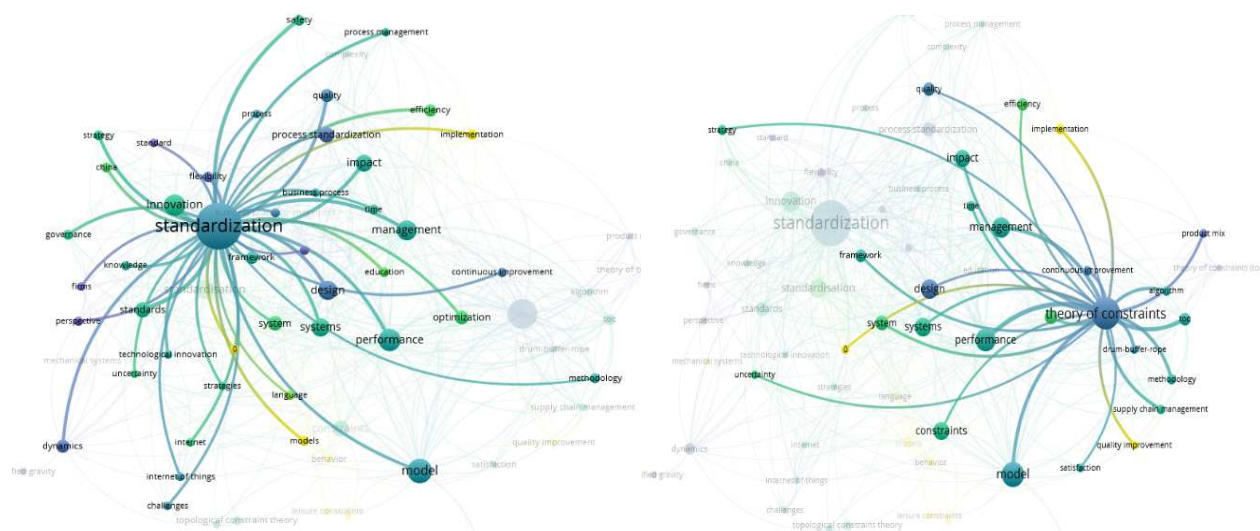


Figure 3 Bibliographic analysis – keyword: “standardization and theory of constraints (details)” in WOS in the years 2014 – 2025
(Own processing)

3 Methodology of research

The paper used a case study as one of the basic research methods of qualitative research. A case study is "*an idiographic investigation of a single individual, family, group, organization, community, or society and its main purpose is description; attempts at explanations are also acceptable*" [27]. The case study was chosen to examine selected enterprise processes in depth because it allows for detailed information to be obtained about specific practices

in the enterprise under analysis. In the presented paper, a case study of an organization is described in which the robotic welding workplaces are analysed in detail.

3.1 Qualitative research using a case study

- **Research questions:** Three research questions have been identified in the presented paper:

- **RQ1:** How does the low level of standardization affect the efficiency and quality of production in robotic welding workplaces?
- **RQ2:** What factors contribute to the underutilisation of production equipment capacity and what are their implications for production flexibility and product delivery times?
- **RQ3:** What are the main causes of financial losses in robotic welding workplaces?
- **Aim of the case study:** The aim of the present case study is to identify opportunities to improve the efficiency of the production process, with a focus on standardisation of working procedures, more efficient use of the capacity of production facilities and improvement of the remuneration system, which will have a direct impact on the optimisation of the processes and financial management of the company.
- **Characteristics of robotic welding workplaces:** As part of the research, 7 robotic welding workstations were analysed to produce column footing products. Two of the seven workplaces are dedicated only to the production of semi-finished products and the remaining five workplaces are also dedicated to the production of finished products. Each of these five workstations is staffed by one operator for the production of the semi-finished product and one operator for the production of the finished product.
- **Selection criteria:** The process selected for the research was the production of a product of the column footing group, which is produced in two steps, that is, the production of the semi-finished product and the production of the finished product. In this production process, the analysis of work instructions at the robotic welding workstations, standard calculation, equipment utilization and productivity analysis, remuneration system and basic financial analysis of the enterprise were carried out. These listed areas represent key processes for robotic welding workplaces and provide the necessary data for a thorough efficiency analysis.
- **Data collection methods, instruments and timeframe:** Multiple data collection methods were used in the research, which lasted 11 months:
 - Observation of operators in the workplace, which gives insight into the work habits of employees and work efficiency;
 - Interviews with operators at robotic welding workplaces;
 - Document analysis: production documentation, financial statements, shift foreman reports;
 - PDCA cycle tool, which we have chosen as an effective tool for incremental improvement, through which we can measure bottlenecks and improve them incrementally;
 - KAIZEN philosophy to identify and implement improvements.

- **Data analysis:** The research used the MachineTrack software solution, which is able to track and record the real equipment usage in robotic welding workplaces.

3.2 Description of the company and the robotic welding workplace (RW)

The analysed company supplies a wide range of products such as precast concrete bolted joints, reinforcing elements and interlocking steel beams for thin ceilings. Currently, the analyzed robotic welding workplaces produce the products of the column footing group (for the purpose of this article they are referred to as: product X and product Y). These are used in the manufacture of precast reinforced concrete columns which, together with anchor bolts, form the basis for bolted connection solutions. With this solution, it is possible to replace the conventional cup solution, which in many cases can bring considerable savings and there is also the possibility of reusing the columns. Another key advantage of such columns is the smaller footprint while handling the same load. Both products (X and Y) are manufactured in two steps, namely the production of a semi-finished product called "SFP" and the production of the finished product.

4 Results and discussion

The following chapter analyses selected processes in manufacturing, focusing on standardisation, standard calculation and equipment availability determination, remuneration and financial analysis.

4.1 Analysis of the production processes for the representative product "X"

Within the analysis of the production processes, the most sold and therefore also produced product "X" from the group of column footings will be analysed and described. The production consists of two steps, first the semi-finished product and then the finished product. Due to the need for the welded plate to cool naturally before bending, these two steps are not coordinated in any way and there is usually a large quantity of already welded semi-finished products in stock, as the production of the semi-finished products proceeds faster than the production of the finished product. The volume of orders is therefore greater than the capacity of the RW facilities. However, during the analysis it was not possible to determine by how many percent the orders exceeded this capacity during the period in question. It is for this reason that one workplace was allocated on a 24-hour basis only to the production of product "X" and, where possible, if an additional workplace became available, this product was also produced on two workplaces simultaneously. This was also possible because two sets of fixtures were available on the workplaces. However, the production process itself was not unified in any way and it could be said that each of the operators had his own way of preparing and producing the

products. The stacking of the fixture products was admittedly dictated by the fixture itself, and thus the manufactured pieces were stacked correctly. However, the way in which the operators transferred the pieces to the place varied. The same was true in the process of making the semi-finished product "SFP" as well as in the process of making the finished product or the bending part of the product. At the time of the analysis, the company's internal rule was that only 1 operator was dedicated to the production of the semi-finished product and only 1 operator was dedicated to the production of the finished product. Probably the most common production method was one in which the worker tried to unload and reload the product in the shortest possible time. In doing so, however, he often made unnecessary movements and performed unnecessary handling of the load. For example, in the production of the "SFP", instead of removing and directly placing the weldment on the pallet of finished products, the worker first placed the piece on the ground in order to release the fixture as soon as possible. In this way, he removed all the welded "SFP" from the fixture and proceeded to load the parts destined for the welding of the new "SFP". Only after they had been placed and secured in the fixtures did he put the already welded pieces on the pallet with the finished "SFP". However, this was wasteful in terms of handling the load. Similar wastage was also visible during the observation in the production of the finished products. Workers were mostly preparing the material ahead of time or putting it aside for a period of time when it was not necessary. Thus, it was necessary to check whether the procedures and rules for production were clearly built. Significant differences then also occurred in the output, i.e. the number of pieces produced per shift. The more skilled operators were able to produce more pieces of product per shift, the less skilled less so. Standards were set before the analysis period, but their achievement was not regular. It could be said that a smaller group of workers were able to achieve them, but not all. It was therefore clear that they were achievable, it was just that the method of production was probably not sufficiently and correctly standardised.

4.2 Analysis of work instructions at RW workplaces - standardisation

At the time of the research, one workflow was in place for all RW workplaces and for all products that were produced at the workplaces, regardless of whether it was for the production of a semi-finished product or for the production of a finished product. It was available as an internal document in the quality section of the ERP system used by the company and also at the RW workplaces. The last update of the document part that specified the production process was made in 2012. Having analysed the entire workflow, we can assess that each of the employees working at the RW workplaces followed this workflow, although each of them has their own way and sequence of actions they follow. The procedure did not specify the

individual tasks separately, nor was their sequence developed in detail. The part of the workflow focusing on the actions to be performed for the production of the products consisted of only three simple steps: fit the fixtures, unload the fixtures and place the pieces on the workbench, check the pieces, repair if necessary, place on the pallet and return to step one. The developed workflow did not provide a single standard of product manufacture from a process point of view that could be worked with in the future and could be improved over time. In the absence of a single standard for the workers to follow and adhere to, there were too many variations and unforeseen problems or constraints that were difficult to predict and influence. Another shortcoming of the workflow is that it was applicable to all types and sizes of products, whether finished or semi-finished. At the time of the analysis, it was a rule that for certain types of products two workers were assigned to production and for others only one.

4.3 Calculation of the standard and usability of the equipment

In order to analyse the individual processes in the following parts of the paper, it is first necessary to analyse the calculation of the standards that determine the quantity of products that need to be and are planned to be produced in one working shift. The times involved in the calculation of the standards may vary slightly depending on the workplace for which the standard is calculated. Therefore, we will set a recent robotic welding workplace as a representative example. For this workplace, the times given below are valid. The individual times have been accurately measured and recalculated and have been found to be correct on analysis.

1. **Shift length** - total duration of one shift - 8 hours.
2. **Break time** - total duration of breaks - 50 minutes.
3. **Time required for consumables change** - total time required for welding spike change during one work shift - 5 minutes.
4. **Cleaning time and TPM (Total Productive Maintenance)** - time to clean the work area at the end of the shift and activities associated with TPM - 15 minutes.
5. **Welding nozzle cleaning time per shift** - total time required for continuous manual cleaning of the welding nozzle on welding robots per work shift - 16 minutes.
6. **Failure rate** - one of the KPIs is 95% availability of robotic welding equipment. This KPI has been met for a long time and thus a failure rate of 5% is assumed.
7. **Tact in minutes** - the production tact of one cycle of the RW equipment. If the machine cycle tact is shorter than the operator cycle tact, i.e. the time required to load and unload the machine, the operator cycle tact is given as the tact, and 1 min. is added as the time required for resting.
8. **Number of pieces per tact** - the number of pieces of products in one welding cycle.

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For the calculation of the norm, we have all the input data except the tact and the number of pieces in the tact. These had already had their values determined and when re-measured, the tact and pieces were found to be correct,

$$\frac{\text{Takt time}}{\text{Number of pieces in a measure}} = \frac{\text{Production time 1 pc}}{6} = \frac{9.25}{6} = 1.54 \text{ min/pc} \quad (1)$$

The quantity of pieces (equation (2)) produced in 1 hour is calculated:

$$\frac{1 \text{ hour}}{\text{Production time 1 piece}} = \frac{60}{1.54} \approx 39 \text{ pcs/h} \quad (2)$$

The net working time in hours (equation (3)) is then calculated, taking into account the failure rate:

$$\text{Net working time} = \left(8 - \left(\frac{50}{60} \right) - \left(\frac{5}{60} \right) - \left(\frac{15}{60} \right) - \left(\frac{16}{60} \right) \right) \times 0.95 = 6.24 \text{ h} \quad (3)$$

Calculate the quantity of pieces for 1 shift, expressed equation (4):

$$\text{Number of pieces per shift} = 39 \times 6.24 = 243 \text{ pcs/shift} \quad (4)$$

with the tact measured at 9.25 minutes and 6 pieces being welded in one cycle. The actual calculation then begins by recalculating the time required to produce one piece of product (as expressed in equation (1)).

The resulting standard is therefore equal to the number of pieces per shift and in the case of product "X" this is 243 pieces per shift.

The planned availability on the RW workplaces is calculated as the ratio of net working time to the duration of the working shift and is given in% (equation (5)):

$$\text{Planned utilization} = \left(\frac{\text{Net wrking time}}{8\text{-hour shift}} \right) \times 100 = \left(\frac{6.24}{8} \right) \times 100 = 78\% \quad (5)$$

The analysed company has been using a software solution for a long time, which is able to monitor and record the real usage of the equipment at the RW workplaces. The system was called MachineTrack. The period monitored was 11 months (6 milestones), i.e. eleven months of data on how much time the equipment produced, how much downtime it had and how many breakdowns there were. The analysis showed (Figure 4) that the equipment was used at 48,92%, which corresponds to a time of 3,91 hours per 8-hour shift. The real utilisation is therefore 30% lower than it should be when achieving 100% of the standard on the equipment. Only the shifts on which production was planned were monitored. Thus, weekend shifts and shifts that were not scheduled are not counted in Figure 4.

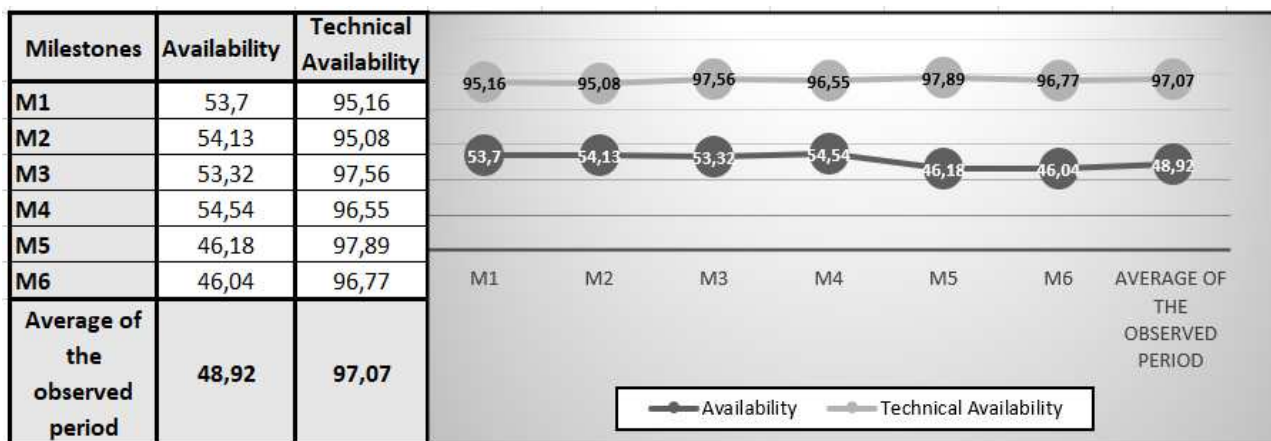


Figure 4 Utilisation and failure rate of RW equipment (Own processing)

4.4 Analysis of the remuneration processes

In addition to the hourly rate, workers employed at robotic welding workstations had the opportunity for increased earnings if they achieved sufficient performance on the job. This performance was measured in terms of the number of pieces produced per shift, as a percentage of planned pieces/produced pieces (equation (6)). The formula for calculating the productivity was as follows:

$$\text{Productivity} = \frac{\text{Planned production}}{\text{Actual production}} \times 100 \quad (6)$$

The bonus system had different levels set, with productivity thresholds being graduated and when a certain level of productivity was reached, the worker was rewarded with the appropriate amount of financial resources when the salary was paid. The different levels along with the values a worker could earn are shown in Table 1 - Part A.

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Table 1 Productivity and bonus system (Own processing)

A – Bonus system		B – Conversion of productivity to equipment availability		C – Proposal for a change to the reward system	
Productivity	Bonus	Productivity	Equipment Utilization	Productivity	Bonus
< 50%	20 EUR	50%	39.0%	< 70%	0 EUR
50% - 55%	40 EUR	55%	42.9%	70% - 75%	80 EUR
55% - 60%	60 EUR	60%	46.8%	75% - 80%	160 EUR
60% - 65%	80 EUR	65%	50.7%	80% - 85%	240 EUR
65% - 70%	120 EUR	70%	54.6%	85% - 90%	300 EUR
70% - 75%	160 EUR	75%	58.5%	90% - 95%	360 EUR
75% - 80%	200 EUR	80%	62.4%	> 100%	440 EUR
80% - 85%	240 EUR	85%	66.3%		
> 85%	280 EUR	90%	70.2%		
		95%	74.1%		
		100%	78.0%		

As shown in Table 1-A, remuneration started as early as the 50% of the norm threshold. If we analyse the norm for product "X", which is 243 units per shift, then if a worker produced 122 pieces per shift, he was credited with a productivity value of 50% for that shift in addition to his hourly wage. The monthly remuneration is calculated as an average of the whole month and an aliquot amount is paid based on the actual number of days worked on the job. Thus, if a worker achieved 50% productivity every day, he would receive a reward of 20 EUR at the end of the month. If his average was 66%, which is 160 pieces "X", he would receive a remuneration of 120 EUR per month. In contrast, the upper limit of the bonus system is set at 85% and above. Here, the worker has the possibility to receive a 280 EUR bonus per month if he exceeds this threshold. However, at this threshold, workers have no incentive to reach 100% productivity and thus achieve the planned quantity of units produced, as they only need to stay at the 90% threshold. The workers were able to keep track of the productivity themselves on a screen in the production area, where this information was also continuously updated during the month.

In the analysis of the remuneration processes, the data from the equipment availability and the data from the reports of the shift masters, who recorded the productivity achieved for each worker, were compared, while the observation period remains the same as in the equipment availability section. The average productivity value, when converted to equipment availability, should be approximately equal to the actual availability for the period under review. The formula for converting productivity into equipment availability is as follows (equation (7)):

$$\text{Converting productivity to equipment availability} = \frac{\left(\frac{\text{Net working time}}{\text{Productivity achieved}} \right) \left(\frac{8}{100} \right)}{\left(\frac{8}{100} \right)} \llbracket \% \rrbracket \quad (7)$$

Table 1 - Part B shows the conversion of the productivity achieved from 50% and above into plant availability. The average productivity obtained from the shift foremen's reports was 86,71% for the period under review. This means that after the formula conversion, the equipment availability should be 67,63% (as expressed in equation (8)). However, in the previous analysis, it was found that the equipment utilization was 48,92% during the period under review (Figure 4). Again, we can back-calculate this figure to the actual productivity achieved using the formula:

$$\begin{aligned} \text{Converting equipment availability to productivity} &= (\text{Converting equipment availability to productivity}) \\ &\times \left(\frac{8}{100} \right) = \left(\frac{48.92}{6.24} \right) \times \left(\frac{8}{100} \right) = 62.71 \llbracket \% \rrbracket \quad (8) \end{aligned}$$

After converting the equipment availability into real productivity, we get a value of 62.71%. The difference between the reported productivity and the real productivity was 24%. A summary of this data is given in Table 2.

Table 2 Conversion of productivity to plant availability and back conversion to productivity (Own processing)

Productivity	Equipment Utilisation
62.71%	48.92%
86.71%	67.63%

As the analysis revealed, one important aspect of performance is the company's remuneration system, which at the time of the analysis did not sufficiently motivate workers to achieve full productivity in the workplace. For this reason, the company proposes to change both the boundaries of each level of remuneration and the amount at each level. The proposed change is shown in Table 1 - Part C.

4.5 Financial analysis

One of the most important analyses during process improvement is financial analysis, because the goal of every enterprise is to make a profit. In this analysis we will discuss the lost EBIDTA, lost wages, but also the overall loss due to inefficient processes.

Lost EBITDA: The above analysis can also be used for financial analysis of the process at RW workplaces. As already defined, the real availability was 30% lower than it would have been in achieving 100% of standards. We have financial data from the company's finance department on the products sold that are produced at the RW workplaces. The data are for a period when sales were high and production was directly to order, not to stock. It is clear from the results that the main reason for this was the under-utilisation of the facilities and if they were used more it

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would also be possible to produce and sell more products. It is therefore possible to calculate EBITDA as one of the fairly accurate indicators of financial performance. The total EBITDA for the period under review for the products manufactured at the RW workplaces and sold was 2 972 206 EUR. Furthermore, the data necessary to calculate the EBITDA, such as invoiced amounts, direct, indirect, fixed and variable costs, sales margin, etc., were also available. On the basis of these data, it was possible to calculate what EBITDA would have been achieved in the event of higher equipment utilisation and thus higher staff productivity. The calculations have been made starting from an increase of 15% and are summarised in Table 3.

Table 3 EBITDA conversion table for productivity increase (Own Processing)

Increase	Number of units	EBITDA (EUR)	Difference (EUR)
TOTAL	402 055	2 972 206	
15% increase	462 363	3 535 337	563 131
20% increase	482 466	3 723 047	750 841
25% increase	502 569	3 910 757	938 551
30% increase	522 672	4 098 467	1 126 262

The difference between the EBITDA achieved and the EBITDA with the increase in utilisation can be considered as the EBITDA foregone that would have been achieved if productivity had been increased.

Lost wages - In addition to the lost EBITDA, the lost wages paid to workers for time they did not actually work should also be treated in the financial analysis. In the section where equipment utilization was analyzed, it was found that the average time worked per 8-hour shift was 3,91 hours. In order to achieve the required productivity, 6,24 hours were required. The difference in this case is 2,33 hours. This means that 2,33 hours of the 8-hour shift were unworked and unused wages were paid for this time. For privacy reasons, this part of the analysis has been carried out on the basis of information from the Human Resources Department. The average cost per employee was 25 000 EUR/year. During the year, an average of 34 employees worked at the RW workplaces. The resulting amount of wages paid is therefore 850 000 EUR /year.

Table 4 shows the individual figures for the different degrees of productivity loss and also the difference in wages paid, which can be considered as an indication of the foregone staff costs.

Table 4 Foregone personnel costs (Own processing)

Decrease in productivity	Wages paid (EUR)	Difference (EUR)
TOTAL	850 000	
15% decrease	722 500	127 500
20% decrease	680 000	170 000
25% decrease	637 500	212 500
30% decrease	595 000	255 000

Total loss - The total loss for each level of decline can be quantified as the sum of lost EBITDA and lost wages per employee. The individual amounts are summarized in Table 5. These losses include the cost of weekend labor. The latter was mainly due to the fact that it was not possible to produce sufficient quantities during the working week. In doing so, however, additional costs are incurred, which arise from the law and which are paid by the company under analysis even in excess of the law at a higher percentage than is necessary.

Table 5 Total loss at different levels of productivity loss (Own processing)

Decrease in productivity	Difference (EUR)	Difference (EUR)	TOTAL
15% increase	563 131	127 500	-690 631
20% increase	750 841	170 000	-920 841
25% increase	938 551	212 500	-1 151 051
30% increase	1 126 262	255 000	-1 381 262

5 Conclusions

There is a lot of waste that is overlooked on robotic welding workplaces. Overlooking is also aided by increased inventories of input material and semi-finished products, which can disrupt logistics and obscure real problems. In the event of an issue, these excess materials can replace rejects, allowing production to continue without addressing the root cause. A positive finding is the system for calculating standards, where all planned and necessary downtime during production is taken into account, ensuring a balanced process flow. The set standards are achievable and also consider possible minor equipment failures. If the equipment is tacted too fast, the norm is adjusted based on the operator's clock, allowing for sufficient rest between cycles, contributing to more sustainable human flows in the workplace. As a positive assessment for the company, there is sufficient room for future process improvements, as well as increased capacity and profit, even without the additional cost of purchasing new equipment or making other costly investments. The main shortcomings can be considered as:

- Low level of standardisation in the workplaces, especially in the area of work instructions. Workers carry out different tasks in different ways. This way of production makes it significantly more difficult to identify and correct process deficiencies.
- Under-utilisation of equipment capacity. Utilisation was found to be 30% below planned capacity. This has a negative impact on both production flexibility and delivery times for finished products.
- A pay system based on stepped productivity provides clear incentives for employees to improve performance, but does not sufficiently support the achievement of maximum productivity potential. Setting an upper limit on rewards at 85% of productivity creates a barrier to motivating

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employees to go beyond this and achieve the planned production of 100%.

- Financial losses due to under-utilisation of equipment capacity and incorrect use of staff time.

The above findings can be generalised as they have major negative consequences for production, which can be summarised as follows:

- The lack of standardisation of workplace procedures, particularly in the area of work instructions, causes a high degree of variability in the performance of individual tasks. This significantly complicates the systematic analysis of processes, the identification of the root causes of deficiencies and their subsequent elimination. In addition, the lack of a uniform standard weakens the implementation of improvement measures and makes it impossible to ensure consistent production quality.
- Inefficient capacity utilisation of production facilities compared to their planned output results in a significant reduction in overall production productivity. This inefficiency leads to limitations in the flexibility of the production process, which means that the company is unable to respond adequately to changes in demand, unexpected variations in production or the need to shorten delivery times. Such a situation weakens the ability to compete in the market.
- The combination of inefficient capacity utilisation of production facilities and misallocation of employee time generates significant financial losses. These losses result from increased fixed costs per unit of production, unproductive staff time and unused potential of production facilities. These inefficiencies not only reduce the overall profitability of production but also limit the ability of the enterprise to allocate resources to innovative and strategic projects.
- Optimal remuneration not only increases employee motivation, but also directly contributes to the achievement of production plans, cost reduction and the long-term competitiveness of the enterprise. When designing bonus systems, it is necessary to create reward structures that promote continuous productivity improvement without introducing disincentive ceilings. The bonus system should be set up in such a way that employees have a clear incentive to achieve and exceed targets, while ensuring that targets are realistic and fair. The transparency of performance information provided by the production system should be supported by feedback and opportunities for further productivity improvements.

To address these shortcomings, it is necessary to implement standardised working practices, optimise the

use of equipment and manage the workforce effectively and use effective remuneration.

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References

- [1] RUSNÁKOVÁ, D.: Ako na štandardizáciu procesov a pracovných postupov, How to standardize processes and workflows, [Online], Available: <https://dianarusnakova.sk/blog/ako-na-%C5%A1tandardiz%C3%A1ci-procesov-a-pracovn%C3%BDch-postupov> [11 Oct 2024], 2020. (Original in Slovak)
- [2] MEDYNSKI, D., BONARSKI, P., MOTYKA, P., WYSOCZAŃSKI, A., GNITECKA, R., KOLBUSZ, K., DĄBROWSKA, M., BURDUK, A., PAWELEC, Z., MACHADO, J.: Digital Standardization of Lean Manufacturing Tools According to Industry 4.0 Concept, *Applied Sciences*, Vol. 13, No. 10, 6259, pp. 1-16, 2023. <https://doi.org/10.3390/app13106259>
- [3] KRIŠŤAK, J.: Teória obmedzení, Theory of Constraints, *IPA Slovakia*, [Online], Available: <https://www.ipaslovakia.sk/clanok/teoria-obmedzeni> [01 Oct 2024], 2017. (Original in Slovak)
- [4] GUPTA, M., DIGALWAR, A., GUPTA, A., GOYAL, A.: Integrating Theory of Constraints, Lean and Six Sigma: a framework development and its application, *Production Planning & Control*, Vol. 35, No. 3, pp. 238-261, 2024. <https://doi.org/10.1080/09537287.2022.2071351>
- [5] URBAN, W., ROGOWSKA, P.: *Systematic Literature Review of Theory of Constraints*, In: Hamrol, A., Kujawińska, A., Barraza, M. (eds) *Advances in Manufacturing II*, MANUFACTURING 2019, Lecture Notes in Mechanical Engineering, Springer, Cham, pp. 203-215, 2019. https://doi.org/10.1007/978-3-030-18789-7_12
- [6] MURA, L., GONTKOVICOVA, B., DULOVÁ SPIŠÁKOVÁ, E., HAJDUOVA, Z.: Position of Employee Benefits in Remuneration Structure, *Transformations in Business and Economics*, Vol. 18, No. 2, pp. 156-173, 2019.
- [7] KRÓLIKOWSKA, E., SIERPINSKA-SAWICZ, A.: The Types of Covenants in Bond Issuance Programs of Mining Industry Companies, *Gospodarka Surowcami Mineralnymi*, Vol. 32, No. 2, pp. 135-152, 2016. <https://doi.org/10.1515/gospo-2016-0014>
- [8] PAPULOVA, Z., GAŽOVÁ, A., ŠLENKER, M., PAPULA, J.: Performance Measurement System: Implementation Process in SMEs, *Sustainability*, Vol. 13, No. 9, 4794, pp. 1-19, 2021. <https://doi.org/10.3390/su13094794>

- [9] WURM, B., MENDLING, J.: *A Theoretical Model for Business Process Standardization*, Business Process Management Forum, BPM 2020, Seville, Spain, September 13–18, Vol. 392, Springer, Proceedings, pp. 281-296, 2020.
https://doi.org/10.1007/978-3-030-58638-6_17
- [10] KIRCHMER, M.: *Realizing Appropriate Process Standardization – Basis for Effective Digital Transformation*, In: Shishkov, B. (eds) Business Modeling and Software Design, BMSD 2023, Lecture Notes in Business Information Processing, Vol. 483, Springer, Cham, pp. 18-31, 2023.
https://doi.org/10.1007/978-3-031-36757-1_2
- [11] BUCHALCEVOVA, A.: Towards Higher Software Quality in Very Small Entities: ISO/IEC 29110 Software Basic Profile Mapping to Testing Standards, *International Journal of Information Technologies and Systems Approach*, Vol. 14, No. 1, pp. 79-96, 2021.
<https://doi.org/10.4018/IJITSA.2021010105>
- [12] TROJANOWSKA, J., DOSTATNI, E.: Application of the Theory of Constraints for Project Management, *Management and Production Engineering Review*, Vol. 8, No. 3, pp. 87-95, 2017.
<https://doi.org/10.1515/MPER-2017-0031>
- [13] DE JESUS PACHECO, D.A., ANTUNES JUNIOR, J.A.V., DE MATOS, C.A.: The constraints of theory: What is the impact of the Theory of Constraints on Operations Strategy?, *International Journal of Production Economics*, Vol. 235, No. May, 107955, 2021. <https://doi.org/10.1016/j.ijpe.2020.107955>
- [14] ERRAOUI, Y., CHARKAOUI, A.: An empirical comparison of DRP and demand-driven DRP, *Acta logistica*, Vol. 9, No. 2, pp. 195-205, 2022.
<https://doi.org/10.22306/al.v9i2.294>
- [15] PEGORARO, F., DA SILVA, S., GOMES, S.T.M., BORGES, J.C.M., DE SOUSA, S.F., DE MELO, M.P., RANK, R.C.I.C., POLETTO, K.Q.: Application of the five steps of the theory of constraints' continuous improvement in a lime industry, *Revista de gestao e secretariado-gesec*, Vol. 14, No. 2, pp. 2576-2592, 2023.
<https://doi.org/10.7769/gesec.v14i2.1731>
- [16] AKMAN, G., TAPSAHANOGLU, S.: Determining the optimal product mix in multiple constraints manufacturing environment: an application in the textile industry, *Industria Textila*, Vol. 73, No. 5, pp. 564-573, 2022.
<https://doi.org/10.35530/IT.073.05.202125>
- [17] ERHAN, E., TÜRKMEN, M.: Integrating the Theory of Constraints and Six Sigma: Process Improvement Implementation, *ISTANBUL Business Research*, Vol. 51, No. 1, pp. 123-147, 2022.
<https://doi.org/10.26650/ibr.2022.51.938481>
- [18] KNOP, K.: Elimination of constraints in the production process of power equipment components and the analysis of the resulting benefits, *Production Engineering Archives*, Vol. 24, No. 24, pp. 37-42, 2019. <https://doi.org/10.30657/pea.2019.24.09>
- [19] SAAD, S.M., BHOVAR, C., BAHADORI, R., ZHANG, H.: Industry 4.0 Application in Lean Manufacturing- A Systematic Review, *18th International Conference on Manufacturing Research (ICMR) / 35th National Conference on Manufacturing Research (NCMR)*, Vol. 15, pp. 341-346, 2021. <https://doi.org/10.3233/ATDE210059>
- [20] PSAROMMATIS, F., PROUVOST, S., MAY, G., KIRITSIS, D.: Product Quality Improvement Policies in Industry 4.0: Characteristics, Enabling Factors, Barriers, and Evolution Toward Zero Defect Manufacturing, *Frontiers in Computer Science*, Vol. 2, No. 26, pp. 1-15, 2020.
<https://doi.org/10.3389/fcomp.2020.00026>
- [21] LINDERSON, S., BIRKIE, S.E., BELLGRAN, M.: The issue of corporate mandatory standards in production improvement programmes, *Journal of Industrial Engineering and Management*, Vol. 17, No. 2, pp. 385-402, 2024.
<https://doi.org/10.3926/jiem.7182>
- [22] LABERGE, M., LEFRANCOIS, M., CHADOIN, M., PROBST, I., RIEL, J., CASSE, CH., MESSING, K.: Gender and Work in Ergonomics: recent trends, *Ergonomics*, Vol. 65, No. 11, pp. 1451-1455, 2022.
<https://doi.org/10.1080/00140139.2022.2129806>
- [23] HASANAIN, B.: The Role of Ergonomic and Human Factors in Sustainable Manufacturing: A Review, *Machine*, Vol. 12, No. 3, 159, pp. 1-27, 2024. <https://doi.org/10.3390/machines12030159>
- [24] KIM, S.: Role-Playing Game for Training a Design Process of Startup Company Compensation Plan, *International Journal of Game-Based Learning (IJGBL)*, Vol. 9, No. 2, pp. 40-54, 2019.
<https://doi.org/10.4018/IJGBL.2019040103>
- [25] BOUWENS, J., KOK, T., VERRIEST, A.: The Prevalence and Validity of EBITDA as a Performance Measure, *Comptabilité-Contrôle-Audit*, Vol. 25, No. 1, pp. 55-105, 2019.
<https://doi.org/10.3917/cca.251.0055>
- [26] ROZENBAUM, O.: EBITDA and Managers' Investment and Leverage Choices, *Contemporary Accounting Research*, Vol. 36, No. 1, pp. 513-546, 2017. <https://doi.org/10.1111/1911-3846.12387>
- [27] DUSPARA, L.: *The influence of tradition and number of employees on the competitiveness and profitability of enterprises in the metal processing industry*, 9th International scientific symposium region, entrepreneurship, development, pp. 155-167, 2020.
- [28] POWELL, D.J., ALFNES, E., HOLMEMO, M.D.Q., REKE, E.: *The Learning Way to EBITDA Improvement*, 7th European Lean Educator Conference (ELEC), Vol. 610, Springer, Cham, pp. 21-31, 2021.
https://doi.org/10.1007/978-3-030-92934-3_3

Optimising process flow in manufacturing: a study on standardisation and equipment capacityJana Samakova, Dagmar Babcanova, Norbert Czibula

- [29] DE QUEIROZ, W.N., DA CUNHA, M.F., DOS SANTOS, T.R.: EBITDA versus operating cash flow at companies listed at B3, *Journal Revista Contabilidade e Controladoria-RC C*, Vol. 13, No. 3, pp. 131-149, 2021.

<https://doi.org/10.5380/rcc.v13i3.80256>

- [30] RUBIN, A., EARL. B.: *Research methods for social work*, 7th ed., Linda Schreiber: Brooks/Cole, Cengage Learning, 2009.

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Enhancing supply chain performance through digitalization: insights from a qualitative study in an emerging market

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Keywords: supply chain performance, digitalization, artificial intelligence, logistics optimization, flow management.

Abstract: This study aims to explore the key determinants of supply chain performance in the era of digitalization, with a particular focus on the Moroccan context. Despite increasing interest in supply chain optimization, limited empirical research exists on how digital transformation influences supply chain efficiency in emerging economies. This gap highlights the need for a deeper understanding of the relationship between technological advancements and logistics performance in regions such as Morocco. A qualitative approach was adopted to investigate this issue, based on semi-structured interviews with 30 supply chain professionals. The data collected were transcribed and analyzed using IRAMUTEQ software, which allowed for a textometric analysis including cluster identification, factorial correspondence analysis (FCA), and similarity analysis. The results reveal that digitalization, real-time monitoring, data analytics, and artificial intelligence significantly enhance supply chain agility, visibility, and operational efficiency. Other critical determinants identified include logistics optimization, inventory management, and customer satisfaction. The findings also underline the importance of supply chain coordination, risk management, and sustainability strategies in fostering resilience and long-term competitiveness. This study provides both theoretical and practical implications by offering new insights into the interplay between digital technologies and supply chain performance in a developing country context. It emphasizes the need for businesses to invest in digital tools and strengthen collaboration across supply chain partners to remain competitive in a rapidly evolving environment.

1 Introduction

The supply chain has emerged as a critical driver of competitive advantage for businesses [1]. Supply chain management focuses on optimizing the overall value generated by a firm through the efficient utilization and allocation of resources across its operations. A supply chain encompasses a series of value-adding activities that link an organization's suppliers with its customers [2].

Globally, the supply chain sector has undergone significant transformation, driven by advancements in technology, globalization, and evolving consumer demands [3,4]. According to recent statistics, the global supply chain management market is projected to reach unprecedented growth, fueled by increasing investments in automation, digitalization, and sustainability initiatives [5]. Companies worldwide are adopting innovative strategies to enhance efficiency, reduce costs, and meet the growing demand for agility and resilience in supply chain operations [6,7]. These developments underscore the strategic importance of supply chains in the modern business environment and their critical role in driving economic growth and global trade [8].

Traditional determinants of supply chain performance focus on strategies like agility and leanness [9]. An agile supply chain, which adapts quickly to market changes, is a key factor in enhancing performance, particularly in retail. Lean strategies, aimed at reducing waste and optimizing

resources, also play a significant role, while hybrid strategies have a more limited impact [10]. Supply Chain Performance (SCP) reflects the ability to meet customer demands through timely delivery, product availability, and efficient resource management. It involves processes that cross organizational and functional boundaries, including procurement, manufacturing, distribution, and R&D. Despite numerous studies on organizational-level performance, inter-organizational SCP remains underexplored [11].

In the digital era, SCP is enhanced by digital transformation, which integrates digital technologies into business processes to optimize operations and value delivery [12]. Key determinants include digital procurement capabilities and data analytics capabilities, which significantly impact SCP by improving market insights, supplier relationships, and operational flexibility [13]. External analytics capabilities, focusing on market and supplier understanding, are particularly effective in boosting procurement capabilities, while internal analytics contribute more modestly. Digital integration also enhances supply chain agility and flexibility, enabling firms to adapt quickly to disruptions [14,15].

In the Moroccan context, the adoption of digital technologies in supply chain management remains a growing but relatively underexplored area. Morocco, as an emerging economy, has been investing significantly in

digital transformation initiatives across various sectors, including logistics and supply chains. However, challenges such as infrastructure limitations, the digital skills deficit, and varying levels of technology adoption among businesses influence the overall performance of supply chains. Understanding the determinants of supply chain performance in Morocco, particularly in light of its digitalization efforts, is crucial for identifying opportunities and addressing barriers to competitiveness in the global market.

Despite the growing body of literature on SCP and digitalization, there remains a significant lack of in-depth exploratory studies that investigate the specific determinants of SCP within the Moroccan context [16]. While existing research often focuses on global or generalized models [17], very few studies address how digital transformation concretely affects supply chain dynamics in emerging economies like Morocco, where challenges such as infrastructure gaps, technological disparities, and evolving market structures prevail [18]. This underscores a critical research gap, not just in terms of geographical focus, but also in the absence of contextualized analysis that captures the nuances of how Moroccan firms adopt and integrate digital tools in their supply chains. Therefore, this study aims to fill that gap by offering a grounded, qualitative investigation into the interplay between digitalization and SCP determinants, with the objective of generating insights that are both theoretically relevant and practically applicable to the Moroccan business environment undergoing digital transition.

The primary objective of this study is to explore the key determinants of SCP in the Moroccan context. To achieve this, a qualitative approach was adopted, utilizing semi-structured interviews with experts in supply chain management operating in Morocco. A lexicographic analysis was conducted using the IRAMUTEQ software to identify and classify clusters related to SCP determinants. This was followed by in-depth analyses, including Correspondence Factor Analysis (CFA) and similarity analysis, to examine the relationships between these determinants. The findings aim to provide both theoretical and practical implications, offering insights into improving SCP in the context of Morocco's evolving digital landscape. Its innovative contribution lies in combining expert insights with textometric analysis to map key SCP determinants, offering a contextualized understanding and paving the way for future quantitative and policy-oriented research.

The paper begins with a review of the literature on supply chain performance and digitalization, followed by a description of the qualitative methodology used. It then presents and discusses the results, highlighting key implications, and concludes with a summary of insights and recommendations for future research.

2 Methodology

2.1 Approach and method

The qualitative approach is particularly valuable for gaining an in-depth understanding of complex phenomena, providing rich, detailed insights that cannot be captured through quantitative methods alone [19,20]. It allows researchers to explore perspectives, uncover underlying factors, and interpret behaviors and interactions within specific contexts. In exploratory research, the qualitative approach is essential for investigating new or under-researched topics. It enables the identification of key variables, relationships, and patterns, offering a foundation for future theoretical development or hypothesis testing. When exploring determinants, the qualitative method facilitates the identification and understanding of nuanced factors that influence outcomes. Through semi-structured interviews and thematic analysis, this method captures diverse viewpoints and provides a comprehensive understanding of the underlying dynamics.

In the context of supply chain management, a qualitative approach is crucial for examining multifaceted challenges and strategies. It allows for a detailed analysis of processes, interactions, and decision-making within supply chains, providing insights into factors that drive or hinder performance. In Morocco, where supply chain management is evolving and digitalization is gaining traction, the qualitative approach is particularly relevant. It enables researchers to explore determinants of supply chain performance in a localized setting, considering unique cultural, economic, and technological factors. This approach sheds light on the specific challenges and opportunities faced by Moroccan businesses, offering actionable insights for improving supply chain efficiency and competitiveness.

2.2 Data collection and sample

The data for this study were collected through semi-structured interviews conducted with 30 experts in the field of supply chain management. These interviews were guided by a structured framework encompassing four main axes (Table 1).

Table 1 Descriptive statistics of the general corpus

Main axes	Description
Logistics performance	Exploring the key factors and metrics used to evaluate the effectiveness and efficiency of logistics operations.
Supply chain management	Investigating practices and strategies in procurement and supply chain coordination.
Determinants of logistics performance	Identifying and understanding the critical factors influencing logistics performance.
Role of digitalization and new technologies	Examining the impact of digital transformation and emerging technologies on improving supply chain performance.

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This approach ensured that the interviews covered all relevant aspects of the research topic, enabling a exploration of the determinants of supply chain performance in the Moroccan context.

The selection of interviewees was based on two main criteria: their specialization in supply chain and logistics, and their professional experience in the field. These criteria were chosen to ensure that the insights gathered would reflect informed and practical perspectives on supply chain performance in the Moroccan context. All participants have either managerial or operational roles in logistics and hold at least a Master's degree, which supports the relevance and credibility of the qualitative data collected (Table 2). The diversity in age and years of experience also contributes to a broader understanding of how digitalization is perceived and implemented across different levels within the supply chain profession.

Table 2 Characteristics of Interviewees

Characteristics		Frequency (n)	Percentage (%)
Gender	Female	20	83%
	Male	10	17%
Age	25-35 years	8	30%
	36-45 years	15	60%
	46-55 years	7	10%
Educational Qualification	Master's degree	25	83%
	PhD	5	17%
Professional Experience	5-9 years	12	16%
	10-15 years	13	25%
	More than 15 years	5	59%
Current Position	Logistics Director	4	17%
	Logistics Manager	16	33%
	Logistics Assistant/Agent	10	50%

2.3 Data analysis

After the data collection phase, all interviews were transcribed verbatim to preserve the richness and authenticity of expert opinions. The transcriptions were then compiled into a comprehensive textual corpus, forming the basis of the qualitative analysis. The corpus was processed using IRAMUTEQ, a powerful open-source tool widely used for lexicometric and statistical textual analysis [21,22].

The analytical process began with data cleaning and preparation, ensuring consistency in language and structure across the corpus. The corpus was then segmented into smaller units of context (text segments), which IRAMUTEQ processed to extract active forms (frequently used words) and lemmatized terms, allowing for the detection of linguistic patterns [22,23].

Using descending hierarchical classification (DHC), IRAMUTEQ grouped these text segments into thematic clusters based on co-occurrence and lexical proximity.

These clusters represent distinct themes emerging from the data, corresponding to the various determinants of supply chain performance as discussed by the interviewees. Each class was analyzed in detail to interpret the underlying meanings and patterns [23,24].

Additionally, the study applied CFA to visualize the relationships between terms and clusters, as well as a similarity analysis to explore co-occurrences and semantic connections between key concepts [25]. These complementary analyses allowed the identification of central themes, such as digitalization, logistics efficiency, customer satisfaction, agility, and risk management, and the interactions between them.

This multidimensional approach enabled a deep, structured, and theory-grounded interpretation of qualitative data, enhancing the validity of the findings. The use of IRAMUTEQ also ensured methodological rigor, reproducibility, and transparency, making it a suitable tool for exploring complex, context-specific dynamics such as those observed in the Moroccan supply chain sector undergoing digital transformation [18,26].

3 Results and discussion

This section presents the results of the textometric analysis conducted on the collected data, followed by a discussion of the key findings. The analysis, performed using IRAMUTEQ, allowed for the classification of qualitative data into structured themes, providing valuable insights into the determinants of supply chain performance.

3.1 Descriptive textual statistics

The descriptive statistics of the general corpus, presented in Table 3, summarize key metrics such as the number of texts, text segments, active forms, and classified segments, giving an overview of the dataset used in the study.

Table 3 Descriptive textual statistics of the general corpus

Statistic	Value
Number of texts	6
Number of text segments	192
Number of forms	1088
Number of occurrences	6942
Number of lemmas	1067
Number of active forms	1055
Number of additional forms	12
Number of active forms with frequency ≥ 3	491
Average forms per segment	36.16
Number of classes	6
Classified segments (%)	140 out of 192 (72.92%)

These statistics provide an initial overview of the dataset's structure and the effectiveness of the classification process. The classification rate of 72.92% indicates a strong lexical structuring, allowing for a

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detailed interpretation of the key themes emerging from the interviews. The following sections will analyze these themes in depth, examining the relationships between the identified determinants and their impact on supply chain performance in the Moroccan context.

To further analyze the determinants of supply chain performance, a frequency analysis of active words was conducted. Table 4 presents the 30 most frequently occurring terms in the dataset, highlighting key themes related to logistics efficiency, digitalization, inventory management, and performance optimization. These terms provide insights into the primary concerns and focus areas of supply chain experts in the Moroccan context.

Table 4 The most 30 frequent actives words

Active word	Freq.	Active word	Freq.
Logistics	159	Efficiency	37
Supply chain	154	Digitalization	36
Stock	79	Risks	35
Time	71	Disruptions	33
Costs	68	Customer	33
Customer satisfaction	59	System	32
Demand	53	Artificial intelligence	32
Market	49	Planning	32
Inventory	47	Responsiveness	32
Delivery reducing	47	Performance	30
Route	40	Flow management	30
Procurement	39	Optimization	29
Inventory management	38	Cost	29
Management	38	Challenge	29
Logistics performance	37	Logistic strategies	29

The high frequency of terms such as "logistics" (159), "supply chain" (154), "stock" (79), and "time" (71) underscores the central role of inventory and time management in optimizing supply chain efficiency. Additionally, the presence of "digitalization" (36) and "artificial intelligence" (32) indicates a growing interest in the adoption of technology to enhance logistics performance. The frequent occurrence of "costs" (68), "customer satisfaction" (59), and "performance" (30) highlights the emphasis on balancing operational efficiency with financial optimization and service quality. Moreover, words such as "risks" (35) and "disruptions" (33) suggest that supply chain resilience and risk management are critical concerns. Overall, these results confirm that efficiency, digital transformation, risk management, and customer-centric strategies are key determinants of supply chain performance in the Moroccan context. The following sections will delve deeper into these findings, exploring their implications for logistics strategies and decision-making in an increasingly digitalized environment.

3.2 Detailed results

The hierarchical clustering dendrogram presented in Figure 1 illustrates the classification of textual data into six distinct classes, each representing a thematic cluster related to supply chain performance and digitalization. This clustering was generated through lexicographic analysis using IRAMUTEQ, allowing for the identification of key themes and their interconnections.

Disruptions and Resilience (Class 1 - Red, 17.1%). This cluster highlights the impact of global disruptions on supply chains and the importance of resilience strategies. Businesses must remain flexible and adaptive to economic fluctuations, logistical challenges, and external shocks. Ensuring supply chain continuity requires robust systems capable of quickly responding to unforeseen events.

Real-Time Monitoring and Digitalization (Class 2 - Grey, 17.9%). The increasing reliance on real-time tracking, predictive analytics, and IoT-driven automation is a defining feature of modern supply chains. Digitalization enhances visibility, improves decision-making, and reduces inefficiencies, making supply chain processes more efficient and responsive to dynamic market conditions.

Logistics Optimization and Sustainability (Class 3 - Green, 19.3%). This cluster focuses on cost control, delivery efficiency, and sustainability in logistics. Companies seek to optimize their supply chains by reducing waste, enhancing performance metrics, and integrating sustainable practices that balance profitability with environmental responsibility.

Customer Loyalty and Service Quality (Class 4 - Cyan, 13.6%). Supply chain disruptions directly affect customer satisfaction and brand reputation. Issues such as stockouts, delayed deliveries, and poor service quality can damage customer loyalty, emphasizing the need for reliable supply chain management to maintain competitiveness and trust.

Agility and Competitive Advantage (Class 5 - Blue, 15%). The ability to adapt quickly and leverage big data for decision-making is a crucial determinant of supply chain success. Agility allows businesses to remain competitive by responding swiftly to changing market demands and optimizing operational performance through intelligence-driven strategies.

Coordination and Traffic Challenges (Class 6 - Pink, 17.1%). Effective coordination between supply chain partners is essential to minimize delays, congestion, and inefficiencies. Poor communication and outdated planning systems can lead to traffic bottlenecks and operational failures, underscoring the need for streamlined logistics and better utilization of resources.

The CFA (Figure 2) provides a structured visualization of the key determinants influencing supply chain performance in the Moroccan context. The findings reveal four major thematic clusters: disruptions and agility, logistics performance and customer satisfaction, digitalization and real-time monitoring, and operational efficiency.

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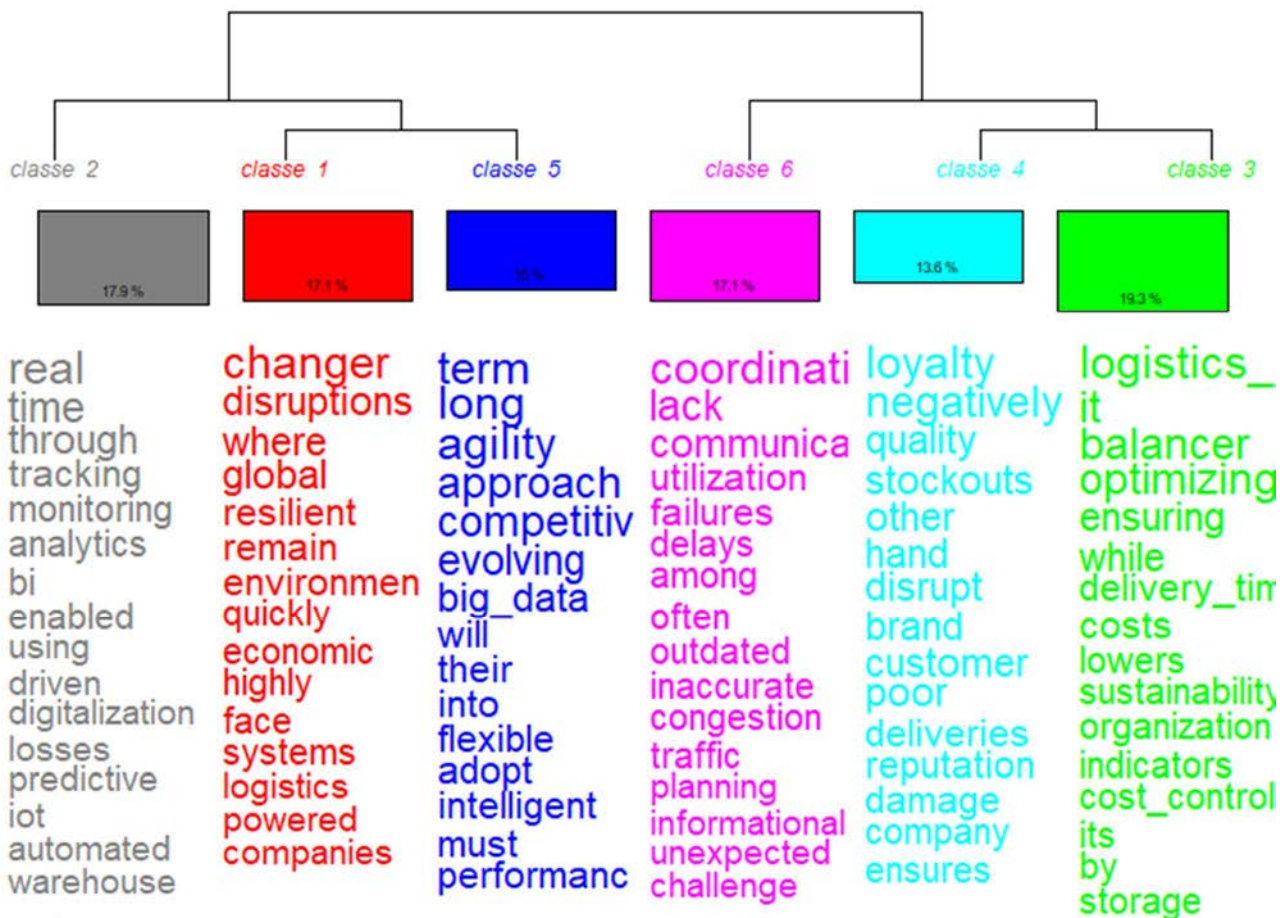


Figure 1 Hierarchical clustering dendrogram

The first cluster, positioned in the top-left quadrant, highlights the impact of global disruptions and economic uncertainties on supply chains. The presence of terms such as "disruptions," "agility," and "competitiveness" suggests that businesses need to adopt flexible and adaptive strategies to remain resilient. However, the frequent occurrence of "lack," "coordination," and "failures" underscores the challenges companies face in managing supply chain integration and communication, which can hinder overall efficiency. The second cluster, in the top-right quadrant, focuses on logistics performance and customer satisfaction. Terms such as "logistics performance," "optimization," and "storage" emphasize the importance of inventory management and cost control in ensuring supply chain efficiency. Additionally, the presence of "customer," "loyalty," and "reputation" confirms that poor logistics management, including stockouts, delays, or delivery failures, can severely impact brand trust and consumer retention. The third cluster, found in the bottom-left quadrant, highlights the role of digitalization, real-time monitoring, and predictive analytics in improving supply chain performance. The use of terms like "real-time," "tracking," "analytics," "IoT,"

and "automation" indicates that companies are increasingly leveraging advanced technologies to enhance visibility, optimize decision-making, and reduce inefficiencies. This reinforces the idea that supply chain digitalization is a crucial factor in modernizing logistics and improving responsiveness. The fourth cluster, in the bottom-right quadrant, emphasizes operational efficiency and cost optimization. Keywords such as "ensuring," "optimal," "reducing," and "precise" suggest that businesses are actively working to streamline supply chain processes, enhance performance, and mitigate financial risks. These findings highlight the growing importance of efficient resource allocation and continuous process improvements to sustain competitive advantage. Overall, the FCA analysis confirms that digitalization, agility, and optimization are key drivers of supply chain performance, while lack of coordination, disruptions, and logistical inefficiencies remain major challenges. To enhance supply chain efficiency, Moroccan firms must invest in digital transformation, improve supply chain resilience, and strengthen coordination mechanisms to ensure competitiveness in an evolving market landscape.

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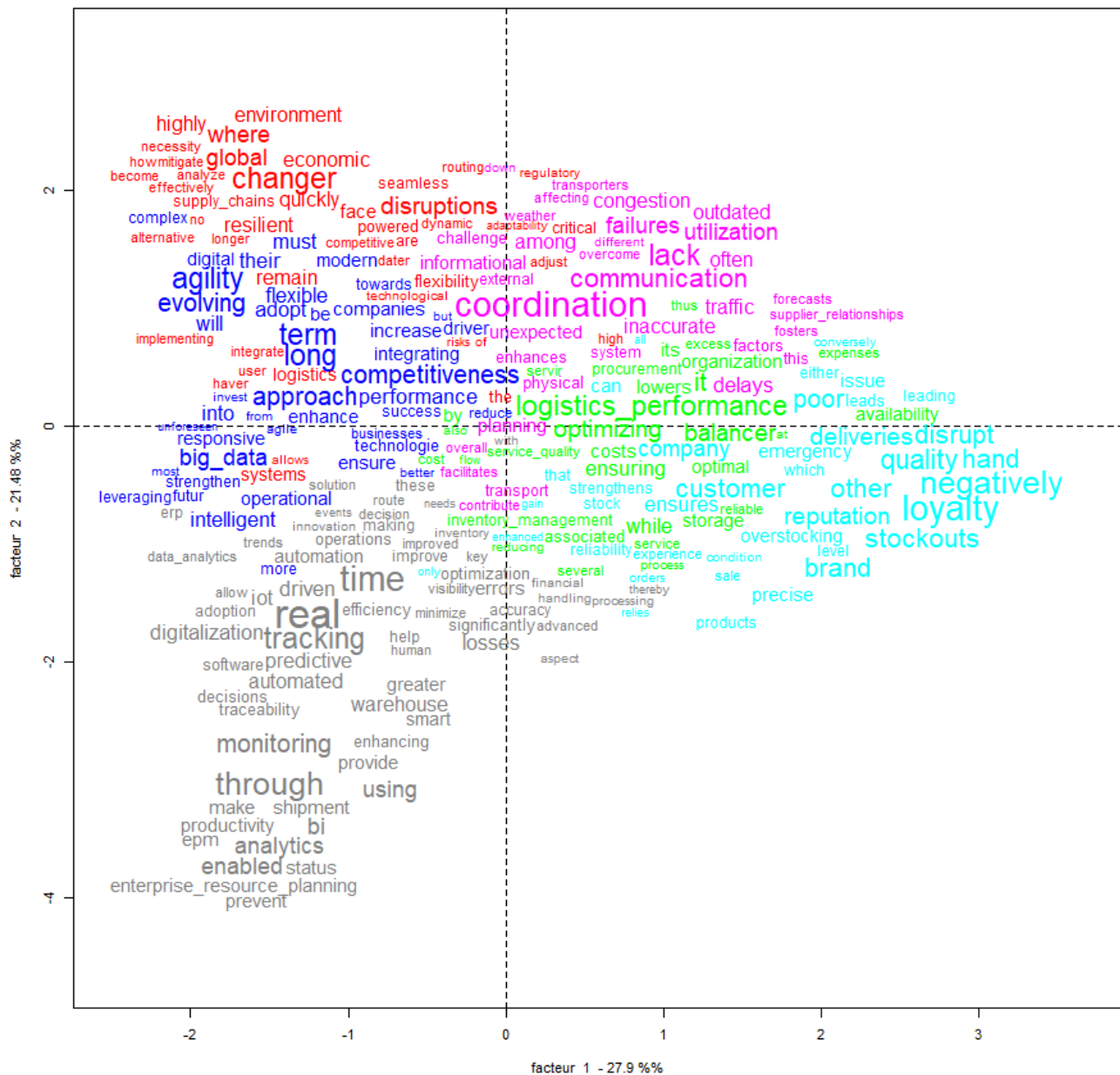


Figure 2 Correspondence Factor Analysis (CFA)

The similarity analysis (Table 5) presented in Figure 3 visually maps the relationships between key concepts related to supply chain performance. This graphical representation highlights how different determinants are interconnected, helping to identify the most influential factors and their interactions.

The similarity analysis reinforces the idea that supply chain performance is multidimensional, requiring a balance between logistics efficiency, digital integration, customer satisfaction, and inventory management. The strong connection between logistics and digitalization suggests that Moroccan firms should prioritize digital tools and AI-driven strategies to enhance performance. Additionally, inventory management and procurement

strategies must be optimized to meet customer expectations, ultimately driving supply chain success in an increasingly competitive market.

To further analyze the factors influencing supply chain performance in the digital era, Table 6 presents a summary of the key determinants within the Moroccan context. These determinants include technological advancements such as digitalization, real-time monitoring, data analytics, and AI integration, as well as strategic approaches like logistics optimization, supply chain coordination, and risk management. The table highlights how these elements contribute to improving supply chain efficiency, responsiveness, and resilience, ultimately enhancing competitiveness in a rapidly evolving market environment.

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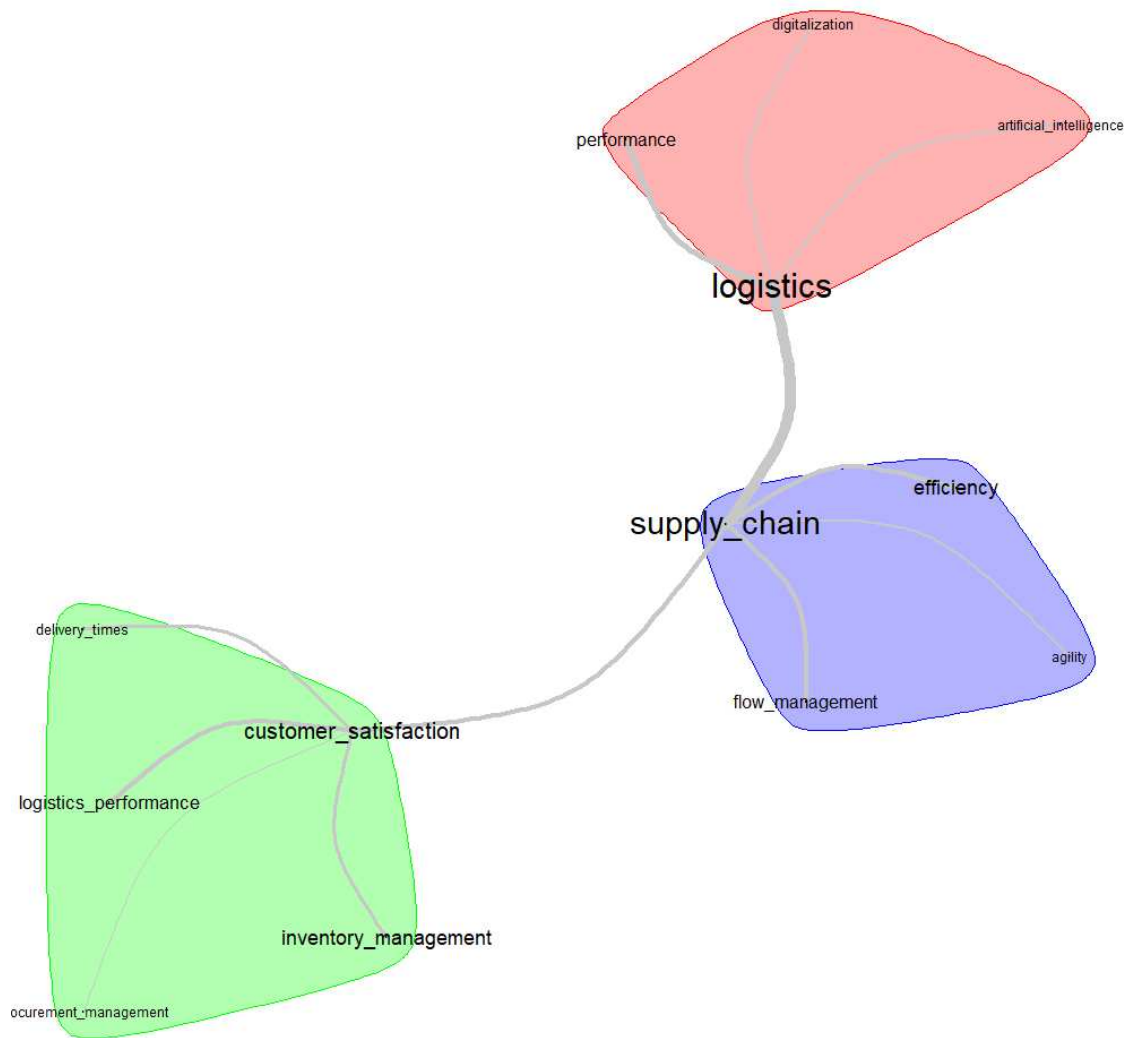


Figure 3 Similarity analysis

Table 5 Clusters of similarity analysis

Cluster	Key Themes
Supply chain (Central Node)	Supply Chain Performance
Logistics and digitalization (Red Cluster)	Digitalization, artificial intelligence, performance
Efficiency and flow management (Blue Cluster)	Efficiency, Agility, Flow Management
Customer satisfaction and inventory management (Green Cluster)	Customer satisfaction, delivery times, logistics performance, procurement & inventory management

The key determinants outlined in Table 6 underscore the transformational role of digitalization and advanced analytics in modern supply chain management. Real-time monitoring and AI-driven decision-making enhance

operational efficiency by providing greater visibility and predictive capabilities, allowing firms to mitigate risks and respond proactively to disruptions. Additionally, logistics optimization, sustainability initiatives, and customer-centric approaches are critical for maintaining high service quality while balancing costs and environmental impact. Furthermore, effective supply chain coordination and risk management strategies are essential for ensuring operational continuity and resilience in the face of economic uncertainties and global disruptions. For Moroccan firms, investing in smart logistics solutions, agile business models, and collaborative supply chain networks will be crucial to maintaining a competitive and sustainable supply chain ecosystem in the digital age.

The findings of this study align with existing literature that emphasizes the multidimensional nature of SCP. Similar to prior research conducted in global and emerging contexts [27,28], this study confirms that digitalization, agility, and logistics efficiency are consistently recognized as key enablers of high-performing supply chains.

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However, this research offers novel insight by contextualizing these determinants within the Moroccan ecosystem, where the digital transition is still emerging and unevenly adopted across sectors.

Table 6 Key determinants of supply chain performance in the era of digitalization in the Moroccan context

Key Determinants	Description	Impact on Supply Chain Performance
Digitalization & real-time monitoring	Integration of IoT, predictive analytics, and automated tracking systems.	Enhances visibility, reduces inefficiencies, and improves responsiveness to demand fluctuations.
Agility & flexibility	Ability to quickly adapt to market changes and disruptions.	Improves resilience, minimizes risks, and maintains business continuity.
Data analytics & integration	Use of big data, AI, and machine learning for decision-making.	Enhances forecasting, optimizes inventory, and supports proactive risk management.
Logistics optimization	Cost reduction strategies, route planning, and delivery efficiency.	Improves operational efficiency, reduces waste, and ensures timely deliveries.
Sustainability & green supply chain	Adoption of eco-friendly practices and sustainable logistics.	Enhances corporate responsibility, meets regulatory standards, and reduces environmental impact.
Customer-centric approach	Focus on service quality, delivery reliability, and brand reputation.	Strengthens customer loyalty, improves satisfaction, and reduces negative brand perceptions.
Supply chain coordination & integration	Collaboration between suppliers, distributors, and retailers.	Reduces bottlenecks, enhances communication, and ensures smoother workflow management.
Risk management & resilience	Strategies to mitigate disruptions and economic uncertainties.	Ensures supply chain continuity, minimizes financial losses, and enhances preparedness for crises.

The identification of digitalization and real-time monitoring as central determinants resonates with studies such as those by [29] and [30], who found that the integration of technologies like IoT and predictive

analytics significantly improves visibility, coordination, and adaptability in supply chains. What distinguishes the current findings is their grounding in qualitative narratives from Moroccan professionals, reflecting real-world challenges such as technological readiness, infrastructure gaps, and cultural resistance to change, factors often underrepresented in international studies.

The frequent mention of customer satisfaction, risk management, and inventory control might appear as general concepts, yet their co-occurrence with terms like "artificial intelligence," "real-time tracking," and "digital tools" in the similarity and FCA analyses indicates a direct and active linkage to digitalization efforts. This confirms that these themes are not discussed in isolation, but rather as components of digitally enabled performance strategies, reinforcing the view that digital transformation is an operational lever rather than a distant vision. Moreover, the emphasis on agility and flexibility as strategic capabilities in managing disruptions supports the work of [31] and more recently [28], who highlight the need for resilient supply chain design in the face of global volatility. In the Moroccan context, these finding gains specificity when linked to issues of traffic congestion, outdated planning systems, and coordination inefficiencies, which are barriers that could be alleviated through digital supply chain platforms and AI-based planning tools.

Finally, the identification of coordination and communication gaps mirrors the conclusions of [32], who noted that emerging economies often struggle with inter-organizational performance measurement. This study adds to that discussion by showing that digitalization is perceived by Moroccan experts not only as a technical upgrade but as a structural solution to systemic inefficiencies. In conclusion, while some of the identified determinants are indeed common in the literature, their interconnection with digitalization efforts, when grounded in the Moroccan context, offers a practical and theoretically informed contribution. This study bridges the gap between general supply chain knowledge and its application in a digitally evolving emerging market, pointing toward the need for hybrid strategies combining human expertise and digital tools to drive sustainable performance improvements.

4 Conclusion

This study aimed to explore the key determinants of supply chain performance in the era of digitalization, focusing on the Moroccan context through a qualitative approach. By conducting semi-structured interviews with industry experts and applying textometric analysis, the research sought to identify the main factors influencing supply chain efficiency, agility, and resilience in a rapidly evolving digital landscape.

The findings highlight several critical determinants that shape supply chain performance. Digitalization, real-time monitoring, and AI-driven decision-making emerged as pivotal enablers of efficiency and responsiveness, allowing

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firms to enhance visibility and optimize logistics operations. Agility and flexibility were identified as essential for adapting to market fluctuations and mitigating disruptions. Additionally, logistics optimization, inventory management, and customer satisfaction were found to be crucial for ensuring service reliability and sustaining competitive advantage. Moreover, the study underscores the importance of supply chain coordination and risk management in fostering resilience, particularly in the face of economic and logistical uncertainties. The results suggest that Moroccan businesses must further integrate advanced technologies and sustainable practices to strengthen their supply chain strategies and improve overall performance.

The findings also provide valuable guidance for practitioners aiming to enhance supply chain performance in the era of digitalization. One of the key managerial takeaways is the importance of integrating digital technologies, such as real-time monitoring, artificial intelligence, and predictive analytics, into supply chain processes. These tools enhance operational visibility, support data-driven decision-making, and help reduce inefficiencies, leading to improved responsiveness and agility in a competitive market.

Managers are also encouraged to strengthen coordination and collaboration across the supply chain—particularly among suppliers, distributors, and logistics partners, to minimize disruptions and enhance workflow continuity. Additionally, investing in risk management strategies is essential to anticipating and mitigating the impact of economic and logistical uncertainties. A customer-centric approach should be prioritized, focusing on delivery reliability and service quality to reinforce brand trust and customer loyalty. For Moroccan companies specifically, embracing sustainable logistics practices and optimizing cost structures is not only crucial for long-term competitiveness, but also for meeting increasing regulatory and environmental expectations.

From a theoretical perspective, this study contributes to the literature by offering an exploratory, context-specific understanding of the determinants of supply chain performance in an emerging economy undergoing digital transformation. It enriches current frameworks by showing how digitalization intersects with traditional performance drivers, such as logistics efficiency, coordination, and customer satisfaction, within the Moroccan context. Moreover, the use of textometric analysis combined with qualitative data presents a novel methodological contribution, supporting theory-building in complex, underexplored environments. The identification of determinant clusters, supported by FCA and similarity analysis, lays the groundwork for future quantitative validation, enabling the development of empirical models that can generalize these findings to similar contexts in other developing economies.

This study is limited to a purely qualitative approach, focusing on expert opinions to explore the key

determinants of supply chain performance in the digital era within the Moroccan context. While this method provides in-depth insights and a rich understanding of industry perspectives, it does not allow for statistical generalization. The findings, therefore, remain exploratory in nature and require further empirical validation.

As a future perspective, a quantitative study will be conducted to test and confirm the research hypotheses derived from this qualitative analysis. This will allow for a more generalizable assessment of the impact of digitalization on supply chain performance by incorporating a larger dataset and statistical modeling. Additionally, further research will investigate the benefits and challenges of AI integration in supply chain management, particularly in areas such as predictive analytics, automation, and decision-making optimization. These studies will contribute to a more comprehensive understanding of how digital transformation reshapes supply chain efficiency, resilience, and competitiveness in Morocco and beyond.

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References

- [1] JEROME, J.J.J., SONWANEY, V., BRYDE, D., GRAHAM, G.: Achieving competitive advantage through technology-driven proactive supply chain risk management: an empirical study, *Annals of Operations Research*, Vol. 332, No. 1, pp. 149-190, 2024. <https://doi.org/10.1007/s10479-023-05604-y>
- [2] SUKATI, I., HAMID, A.B., BAHARUN, R., YUSOFF, R.M.: The study of supply chain management strategy and practices on supply chain performance, *Procedia-Social and Behavioral Sciences*, Vol. 40, pp. 225-233, 2012. <https://doi.org/10.1016/j.sbspro.2012.03.185>
- [3] STEVENS, G.C.: Successful supply-chain management, *Management Decision*, Vol. 28, No. 8, 1990. <https://doi.org/10.1108/00251749010140790>
- [4] KATSALIAKI, K., GALETSI, P., KUMAR, S.: Supply chain disruptions and resilience: A major review and future research agenda, *Annals of Operations Research*, Vol. 319, pp. 965-1002, 2022. <https://doi.org/10.1007/s10479-020-03912-1>
- [5] IVANOV, D., DOLGUI, A., DAS, A., SOKOLOV, B.: Digital supply chain twins: Managing the ripple effect, resilience, and disruption risks by data-driven optimization, simulation, and visibility, In: Ivanov, D., Dolgui, A., Sokolov, B. (eds) *Handbook of Ripple Effects in the Supply Chain*. International Series in Operations Research & Management Science, Vol.

- 276, Springer, Cham. pp. 309-332, 2019. http://dx.doi.org/10.1007/978-3-030-14302-2_15
- [6] SIAWSH, N., PESZYNSKI, K., YOUNG, L., VO-TRAN, H.: Exploring the role of power on procurement and supply chain management systems in a humanitarian organization: a socio-technical systems view, *International Journal of Production Research*, Vol. 59, No. 12, pp. 3591-3616, 2021. <http://dx.doi.org/10.1080/00207543.2019.1634293>
- [7] GHOBAKHLOO, M., IRANMANESH, M., FOROUGH, B., TSENG, M.-L., NIKBIN, D., KHANFAR, A.A.A.: Industry 4.0 digital transformation and opportunities for supply chain resilience: a comprehensive review and a strategic roadmap, *Production planning & control*, Vol. 36, No. 1, pp. 61-91, 2025. <http://dx.doi.org/10.1080/09537287.2023.2252376>
- [8] AL-SWIDI, A.K., AL-HAKIMI, M.A., GELAIKAN, H.M., AL HAIFI, M.M., AHMED, A.A.: Harnessing digital technologies in circular supply chains: The role of technological opportunism capability and technological turbulence, *Sustainable Futures*, Vol. 9, 100492, pp. 1-12, 2025. <https://doi.org/10.1016/j.sftr.2025.100492>
- [9] GARCIA-BUENDIA, N., MOYANO-FUENTES, J., MAQUEIRA-MARÍN, J.M.: Lean supply chain management and performance relationships: what has been done and what is left to do, *CIRP Journal of Manufacturing Science and Technology*, Vol. 32, pp. 405-423, 2021. <https://doi.org/10.1016/j.cirpj.2021.01.016>
- [10] KHAN, S.A., CHAABANE, A., DWEIRI, F.: Supply chain performance measurement systems: a qualitative review and proposed conceptual framework, *International Journal of Industrial and Systems Engineering*, Vol. 34, No. 1, pp. 43-64, 2020. <https://doi.org/10.1504/IJISE.2020.104315>
- [11] SAAD, M., PATEL, B.: An investigation of supply chain performance measurement in the Indian automotive sector, *Benchmarking: An International Journal*, Vol. 13, No. 1/2, pp. 36-53, 2006. <https://doi.org/10.1108/14635770610644565>
- [12] SHAHADAT, M.M.H., CHOWDHURY, A.H.M.Y., NATHAN, R.J., FEKETE-FARKAS, M.: Digital technologies for firms' competitive advantage and improved supply chain performance, *Journal of Risk and Financial Management*, Vol. 16, No. 2, 94, pp. 1-17, 2023. <https://doi.org/10.3390/jrfm16020094>
- [13] HALLIKAS, J., IMMONEN, M., BRAX, S.: Digitalizing procurement: the impact of data analytics on supply chain performance, *Supply Chain Management: An International Journal*, Vol. 26, No. 5, pp. 629-646, 2021. <https://doi.org/10.1108/SCM-05-2020-0201>
- [14] RASOOL, F., GRECO, M., GRIMALDI, M.: Digital supply chain performance metrics: a literature review, *Measuring Business Excellence*, Vol. 26, No. 1, pp. 23-38, 2022. <https://doi.org/10.1108/MBE-11-2020-0147>
- [15] TAZHIBEKOVA, K., SHAMETOVA, A., MAHARRAMOV, R., MAKAR, S.: The role of information and digital tools in supply chain management during the Covid crisis, *Acta logistica*, Vol. 10, No. 1, pp. 25-34, 2023. <https://doi.org/10.22306/al.v10i1.344>
- [16] MHARZI, R., BEN KACEM, A., ELOUADI, A.: Catastrophe-related disruptions' preparedness and emergency management in Morocco: a proactive risks and resilience digital twin-based analysis, *Journal of Modelling in Management*, Vol. 20, No. 3, pp. 825-845, 2025. <https://doi.org/10.1108/JM2-02-2024-0050>
- [17] SASSI, A., OULLADA, O., ELKAZINI, R.: *Model for Assessing the Impact of Internet of Things on Supply Chain 4.0: Moroccan Case*, In: Mejdoub, Y., Elamri, A. (eds) *Proceeding of the International Conference on Connected Objects and Artificial Intelligence (COCIA2024)*, COCIA 2024, Lecture Notes in Networks and Systems, Vol. 1123, Springer, Cham., pp. 252-258, 2024. http://dx.doi.org/10.1007/978-3-031-70411-6_39
- [18] LAZRAK, Y., TISSAFI, A.E.I.: *Cocreating Sustainability in the Circular Supply Chain: A Qualitative Exploration among Moroccan SMEs*, In: 2024 IEEE 15th International Colloquium on Logistics and Supply Chain Management (LOGISTIQUEA), Sousse, Tunisia, pp. 1-6, 2024. <https://doi.org/10.1109/logistiqua61063.2024.10571473>
- [19] TENNY, S., BRANNAN, J.M., BRANNAN, G.D., *Qualitative study*, In: StatPearls. StatPearls Publishing, Treasure Island (FL), PMID: 29262162, 2025. <http://europepmc.org/abstract/med/29262162>
- [20] DICICCO-BLOOM, B., CRABTREE, B.F.: The qualitative research interview, *Medical education*, Vol. 40, No. 4, pp. 314-321, 2006. <https://doi.org/10.1111/j.1365-2929.2006.02418.x>
- [21] BELAHOUAOUI, R., ATTAK, E.H.: Digital taxation, artificial intelligence and Tax Administration 3.0: improving tax compliance behavior—a systematic literature review using textometry (2016–2023), *Accounting Research Journal*, Vol. 37, No. 2, pp. 172-191, 2024. <https://doi.org/10.1108/ARJ-12-2023-0372>
- [22] CHAVES, M.M.N., DOS SANTOS, A.P.R., DOS SANTOSA, N.P., LAROCCA, L.M.: *Use of the software IRAMUTEQ in qualitative research: an experience report*, In: Costa, A., Reis, L., Neri de Sousa, F., Moreira, A., Lamas, D. (eds) *Computer Supported Qualitative Research. Studies in Systems, Decision and Control*, Vol. 71, Springer, Cham., pp. 39-48, 2017. http://dx.doi.org/10.1007/978-3-319-43271-7_4

Enhancing supply chain performance through digitalization: insights from a qualitative study in an emerging market

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- [23] DE SOUZA, M.A.R., WALL, M.L., DE MORAIS CHAVES THULER, A.C., LOWEN, I.M.V., PERES, A.M.: The use of IRAMUTEQ software for data analysis in qualitative research, *Revista da Escola de Enfermagem da USP*, Vol. 52, pp. 1-7, 2018.
<https://doi.org/10.1590/s1980-220x2017015003353>
- [24] RAMOS, M.G., DO ROSÁRIO LIMA, V.M., AMARAL-ROSA, M.P.: *IRAMUTEQ Software and discursive textual analysis: interpretive possibilities*, In: Costa, A., Reis, L., Moreira, A. (eds) *Computer Supported Qualitative Research, WCQR 2018, Advances in Intelligent Systems and Computing*, Vol. 861, Springer, Cham., pp. 58-72, 2018.
http://dx.doi.org/10.1007/978-3-030-01406-3_6
- [25] LAVISSIÈRE, A., SOHIER, R., LAVISSIÈRE, M.C.: Transportation systems in the Arctic: A systematic literature review using textometry, *Transportation Research Part A: Policy and Practice*, Vol. 141, pp. 130-146, 2020.
<https://doi.org/10.1016/j.tra.2020.09.003>
- [26] OUBRAHIM, I., SEFIANI, N.: An integrated multi-criteria decision-making approach for sustainable supply chain performance evaluation from a manufacturing perspective, *International Journal of Productivity and Performance Management*, Vol. 74, No. 1, pp. 304-339, 2025.
<https://doi.org/10.1108/IJPPM-09-2023-0464>
- [27] BÜYÜKÖZKAN, G., GÖÇER, F.: Digital Supply Chain: Literature review and a proposed framework for future research, *Computers in Industry*, Vol. 97, pp. 157-177, 2018.
<https://doi.org/10.1016/j.compind.2018.02.010>
- [28] IVANOV, D., DOLGUI, A.: A digital supply chain twin for managing the disruption risks and resilience in the era of Industry 4.0, *Production Planning & Control*, Vol. 32, No. 9, pp. 775-788, 2021.
<https://doi.org/10.1080/09537287.2020.1768450>
- [29] NING, L., YAO, D.: The impact of digital transformation on supply chain capabilities and supply chain competitive performance, *Sustainability*, Vol. 15, No. 13, 10107, pp. 1-22, 2023. <https://doi.org/10.3390/su151310107>
- [30] GHOBAKHLOO, M.: Industry 4.0, digitization, and opportunities for sustainability, *Journal of Cleaner Production*, Vol. 252, 119869, 2020.
<https://doi.org/10.1016/j.jclepro.2019.119869>
- [31] CHRISTOPHER, M., PECK, H.: Building the resilient supply chain, *The International Journal of Logistics Management*, Vol. 15, No. 2, pp. 1-14, 2004. <https://doi.org/10.1108/09574090410700275>
- [32] SAAD, M., PATEL, B.: An investigation of supply chain performance measurement in the Indian automotive sector, *Benchmarking: An International Journal*, Vol. 13, No. 1/2, pp. 36-53, 2006.
<https://doi.org/10.1108/14635770610644565>

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Optimizing weaving industry clusters: strategic logistics and growth solutions for competitive regional development

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Keywords: weaving industry clusters, strategic logistics management.

Abstract: This research explores the clustering potential of the weaving industry in South Central Timor District, a sector deeply embedded in cultural heritage with significant economic potential. A qualitative descriptive approach, complemented by spatial analysis using the Average Nearest Neighbor method in ArcGIS 10.5, was employed to identify clustering patterns and assess the feasibility of cluster formation. Of the 1,013 weaving SMEs analyzed, 78 agglomeration centers were identified, encompassing 795 SMEs, with a spatial ratio of 0.060856 and a Z-score of 57.295888, indicating a strong potential for industrial clustering. The paper examines both the opportunities and challenges associated with clustering, particularly in terms of infrastructure development and the need for enhanced collaboration among key stakeholders. It presents a cluster-based development strategy focused on sustainability, cooperation, and market expansion to improve the competitiveness of the weaving industry at local and global levels. The study highlights the critical need for strengthening institutional support, enhancing access to financial resources, and implementing capacity-building programs to improve the entrepreneurial and technical capabilities of artisans. Additionally, fostering partnerships between government bodies, private enterprises, and academic institutions is essential to encourage innovation and knowledge sharing. By adopting an inclusive and well-coordinated cluster development model, the weaving industry in South Central Timor has the potential to achieve sustainable growth while preserving its cultural heritage.

1 Introduction

The weaving industry in South Central Timor Regency (TTS), East Nusa Tenggara (NTT), has long been a cornerstone of the region's cultural identity and traditional knowledge. This is in line with [1] that traditional weaving has long been an integral part of Indonesia's cultural heritage. This opinion is also reinforced by [2] that the art of traditional Indonesian weaving has been an inseparable part of the archipelago's cultural wealth for centuries and has become an inseparable part of the lives of the Indonesian people. Various literary sources, including books and journals, indicate that weaving has been present in Indonesia since prehistoric times. Evidence suggests that the tradition of textile weaving has persisted for thousands of years. Weaving skills, passed down through generations, along with distinctive patterns and techniques, have

become integral to the area's textile products. However, despite the sector's substantial potential, the weaving industry in TTS faces several obstacles that hinder its growth, especially in the area of market access, financing, and human resource development.

Given the rising global demand for high-quality woven products, both in domestic and international markets, clustering the weaving industry presents a promising strategy to address these challenges. Industrial clustering can foster synergies between key stakeholders, such as industry players, government bodies, educational institutions, and the private sector, thereby improving operational efficiency and overall competitiveness. By forming organized industrial clusters, weaving artisans can optimize the use of resources, improve market access, and integrate advanced technologies. This aligns with the argument [3] that industrial clusters play a pivotal role in

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promoting industrial development and competitiveness, especially when a region is endowed with abundant natural resources.

The opportunity for the weaving industry in TTS lies not only in the potential for an expanding global market but also in the rich cultural traditions that could serve as compelling selling points. However, the development of a robust weaving industry cluster faces significant challenges, including issues related to marketing, financing, and human resource development. Without focused efforts to address these barriers, the full potential of the weaving industry in TTS may remain underdeveloped.

This article seeks to offer a comprehensive analysis of the clustering potential of the weaving industry in South Central Timor, focusing on identifying key opportunities, challenges, and development strategies that can improve the competitiveness of the industry. The insights derived from this study aim to outline concrete steps that can help realize the region's weaving industry potential on a larger, more sustainable scale.

2 Materials and methods

This study was carried out in early 2024 in several sub-districts of South Central Timor District, specifically South Mollo, West Amanuban, Batu Putih, and Kokbaun. The research population included weaving industry participants and relevant stakeholders. A targeted sampling approach

was used to select respondents who were closely associated aligned with the objectives of the study.

Data gathering comprised either primary or secondary sources. Primary data were collected through interviews, direct observations, and focus group discussions, while secondary data were sourced from official reports and statistical data. The data were analysed using a descriptive qualitative approach, which enabled a comprehensive understanding of the local conditions, opportunities, and the challenges faced by the weaving industry.

To analyse the clustering of SMEs, the Avenza Map application was used to map their locations, and the Average Nearest Neighbour method in ArcGIS 10.5 was applied to assess the spatial distribution and proximity of these SMEs. This spatial analysis technique is expected to provide valuable insights into the clustering potential and support the development of strategies aimed at strengthening the weaving industry in the region.

3 Results

The industrial clustering of weaving SMEs was identified by mapping the distribution of 1,013 SMEs across the South Mollo, West Amanuban, Batu Putih, and Kokbaun sub-districts of South Central Timor District. The proximity of these SMEs was analyzed using the Average Nearest Neighbour technique to assess spatial relationships and identify clustering patterns. The locations of the weaving SMEs, based on the collected data, are shown in Figure 1.

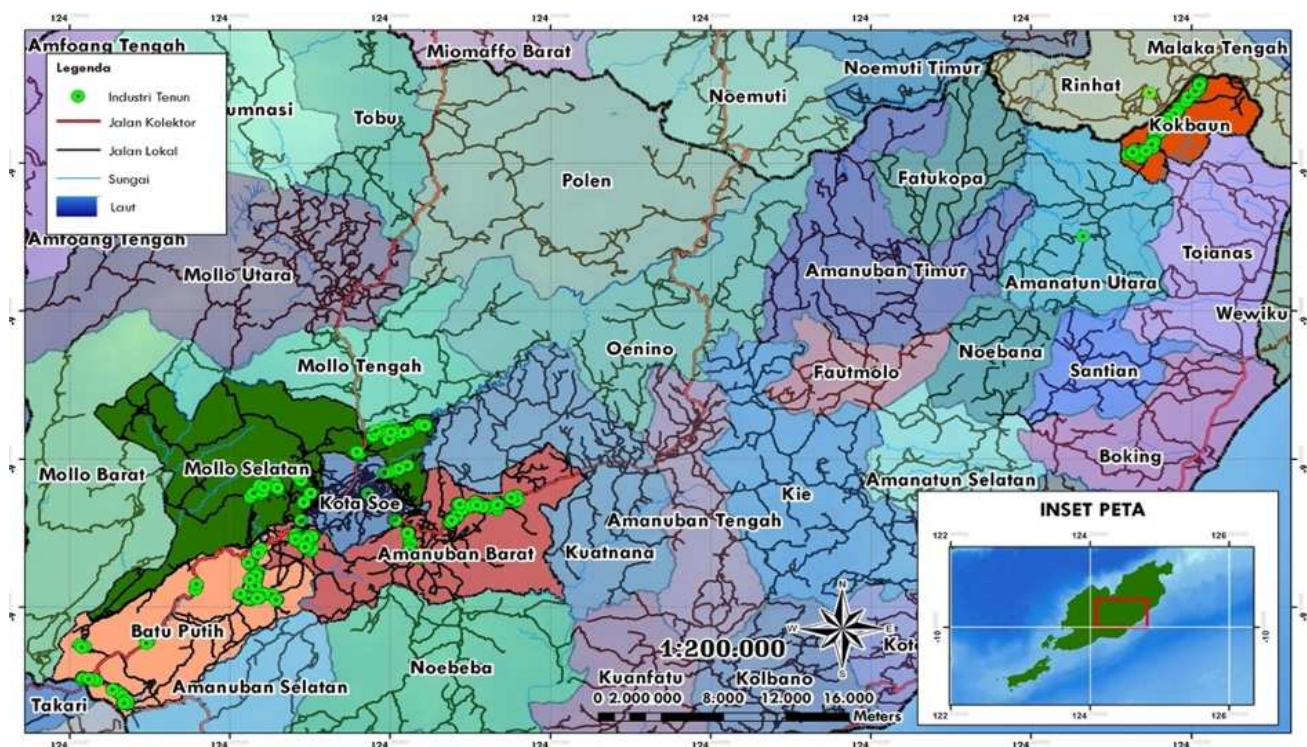


Figure 1 Map distribution of the weaving industry in South Central Timor, Indonesia

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The Average Nearest Neighbor analysis conducted using ArcGIS 10.5 reveals that the spatial distribution of weaving SMEs across the four sub-districts has a ratio of

0.060856. With a Z-score of -57.295888 and a significance level of 0.000, the results indicate a statistically significant clustering pattern in the distribution of these SMEs.

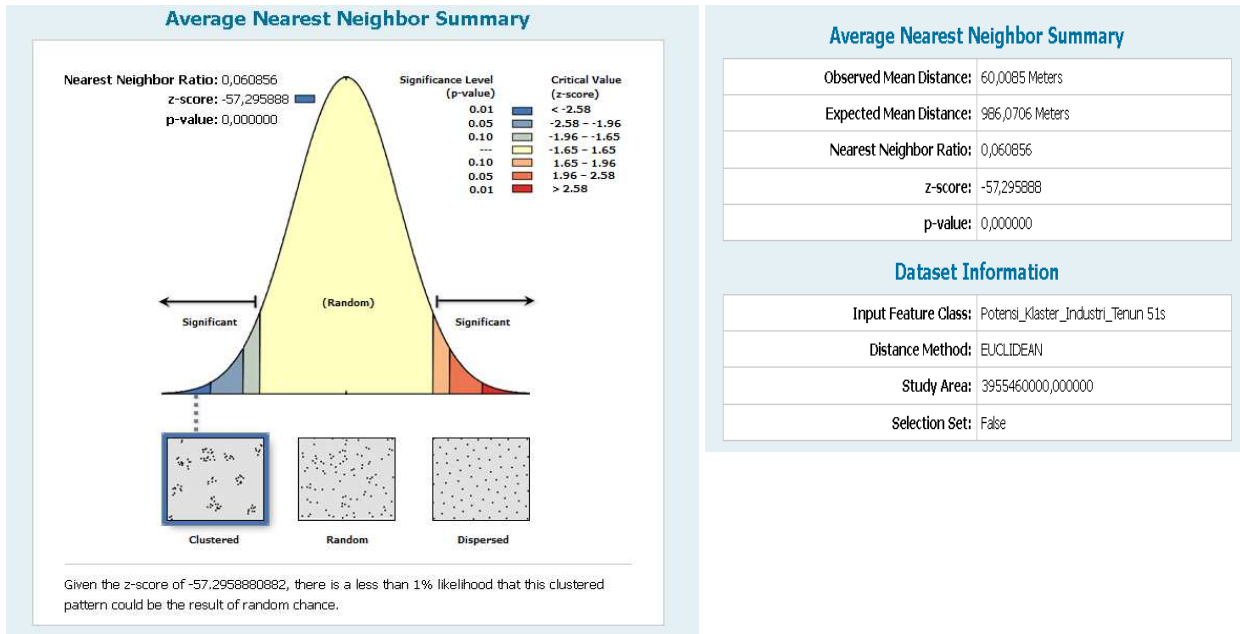


Figure 2 Results of average nearest neighbour analysis of weaving SMEs

The distribution analysis of industrial points reveals an average distance of 60.0085 meters between the nearest points. Among the 1,013 weaving SME locations examined, 795 points exhibit the shortest distances, as determined by the Average Nearest Neighbour analysis.

This represents 78.55% of the total industrial points, indicating a strong clustering tendency. The results highlight a significant disparity between the clustered distribution and a randomly distributed arrangement of industrial points.

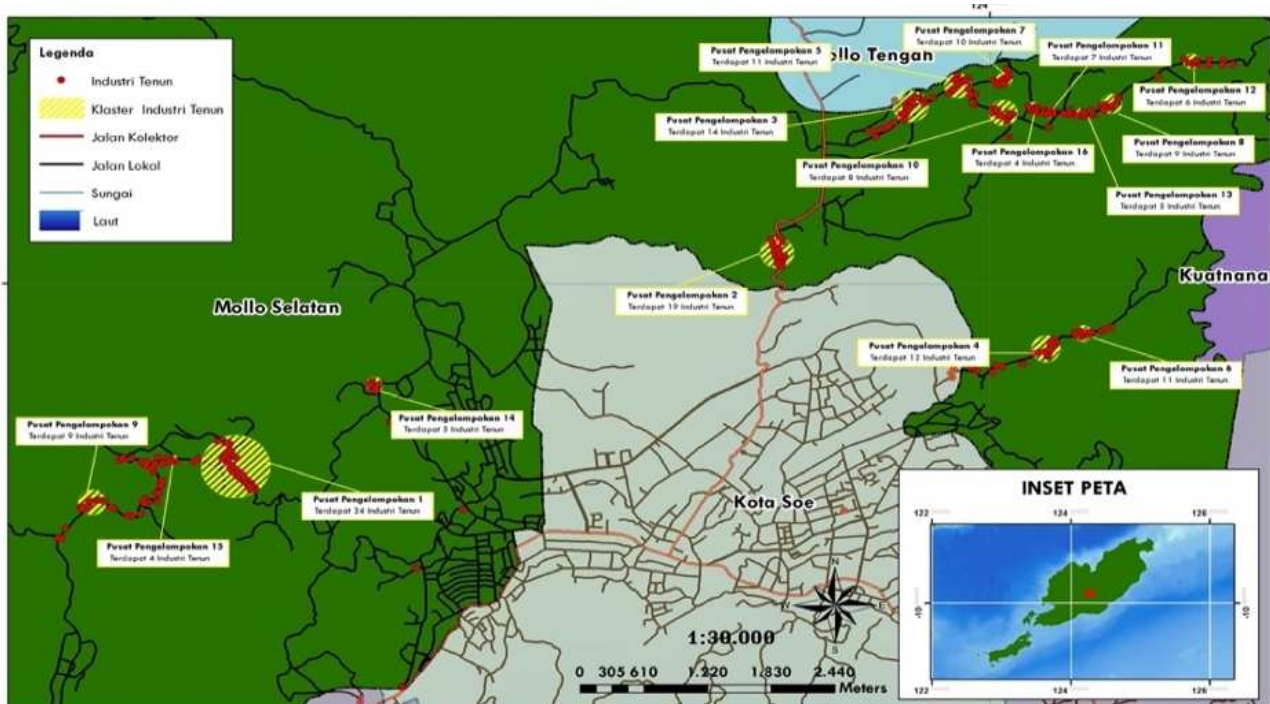


Figure 3 Clustering of weaving SMEs in South Mollo Sub-district

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Figure 3 presents the clustering centres of weaving SMEs in the South Mollo sub-district, where 16 centres have formed, accounting for a total of 168 clustered

SMEs. Similarly, Figure 4 shows the clustering centres in the West Amanuban sub-district, with 31 centres that aggregate 277 SMEs.

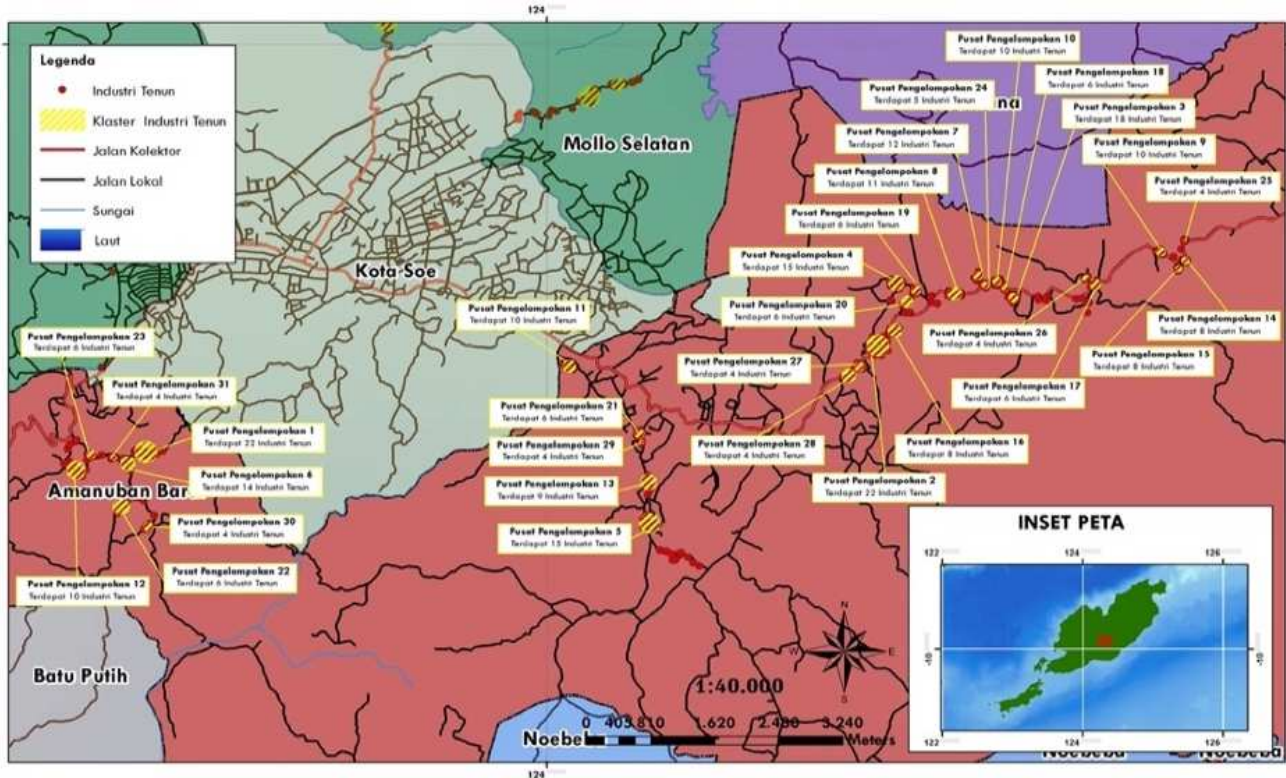


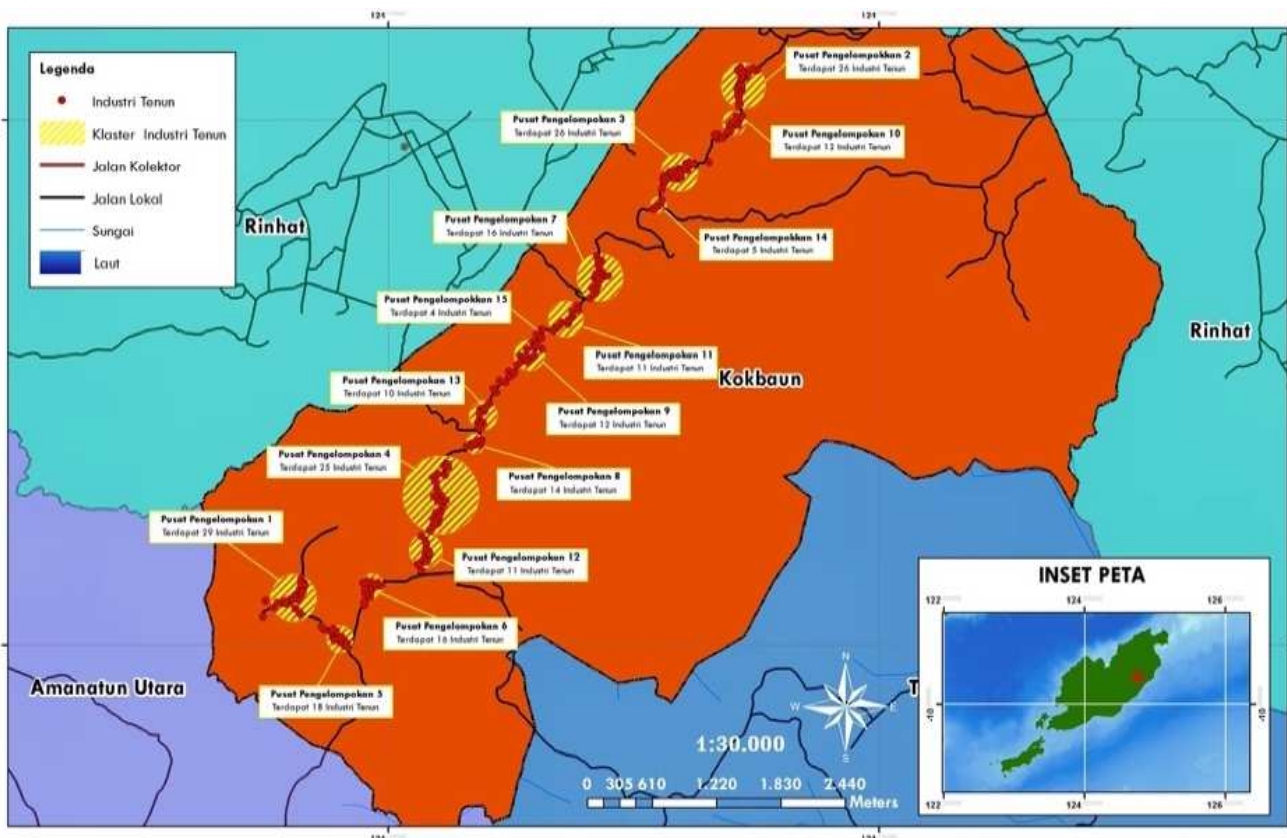
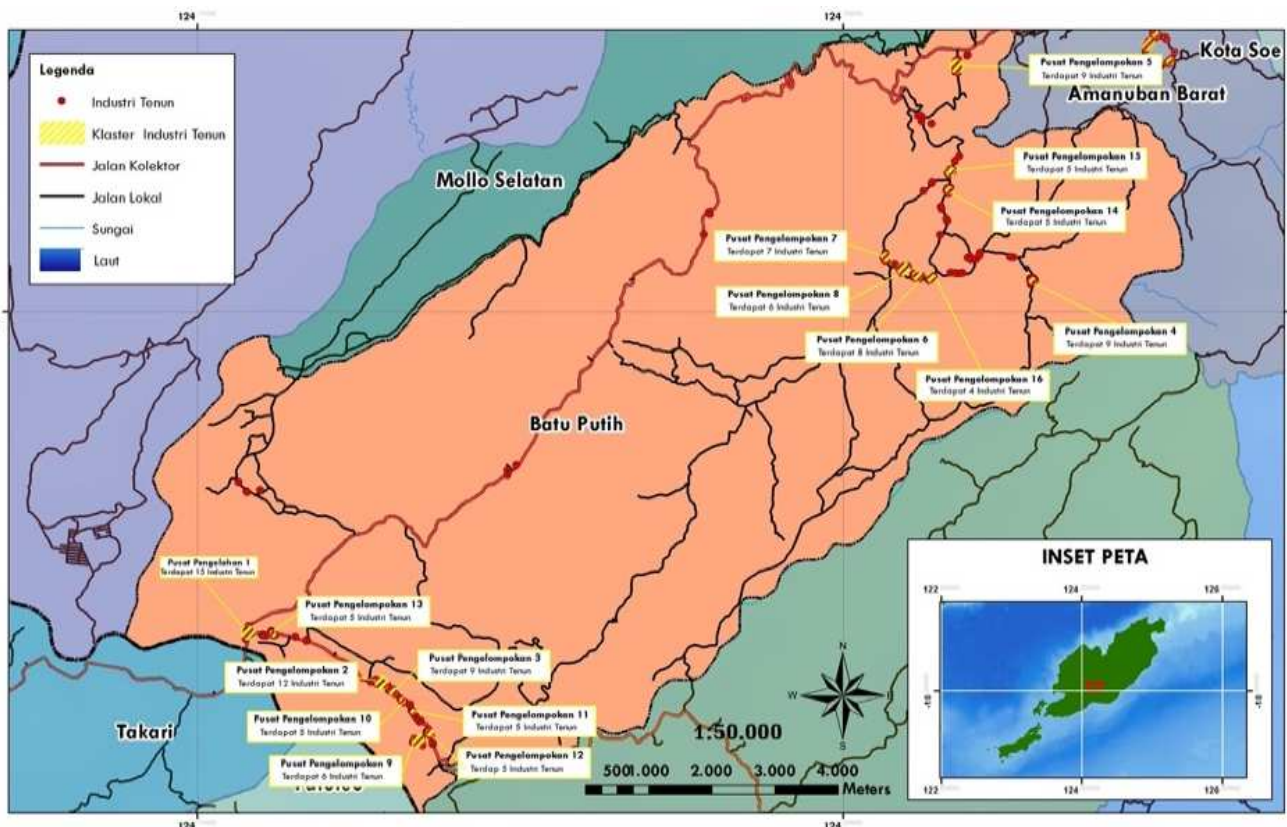
Figure 4 Clustering of weaving SMEs in West Amanuban Sub-district

Figures 5 and 6 illustrate the clustering centers of weaving SMEs in the Batu Putih and Kokbaun sub-districts. In the Batu Putih area, 16 clustering centers have

been identified, which include 115 agglomerated SMEs. Meanwhile, the Kokbaun area features 15 clustering centers, encompassing a total of 235 agglomerate SMEs.

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The nearest neighbor analysis revealed 78 agglomeration centers for weaving SMEs in the region. The evaluation of the agglomeration potential of these SMEs was carried out using the principles of industrial clustering, as outlined below:

1. Agglomeration Size:

- South Mollo sub-district: 16 clustering centers,
- West Amanuban sub-district: 31 clustering centers,
- Batu Putih sub-district: 16 clustering centers,
- Kokbaun sub-district: 15 clustering centers.

2. Involved Actors:

- Vertical Relationships: Yarn traders (local market), weaving processors/industries, retailers, and end consumers.
- Horizontal Relationships: Weaving industry, Office of Industry and Trade of East Nusa Tenggara Province, Office of Trade, Industry, Cooperatives and MSMEs of South Central Timor District, Regional National Craft Council (DEKRANASDA) East Nusa Tenggara Province, Regional National Craft Council (DEKRANASDA) South Central Timor District, and Bank Rakyat Indonesia.

3. Outcomes of Inter-Actor Relationships:

- Vertical Relationships: The production and distribution flow, starting from raw materials (yarn) to the finished product (woven fabric), which ultimately reaches the final consumer.
- Horizontal Relationships: Collaborative efforts among institutions and stakeholders to enhance the weaving industry, focusing on production, marketing, and regulatory aspects.

4. Market Reach:

Woven fabric products are used for daily wear, sold for everyday needs, and are the preferred choice for traditional ceremonies, such as weddings and cultural events. Additionally, these products serve as valuable souvenirs.

The involvement of both vertical and horizontal actors indicates a promising potential for all identified industrial agglomerations. This is further supported by the active engagement of various stakeholders in the industrial ecosystem and government interest. The positive response from provincial and district institutions underscores their commitment to fostering industrial clustering. Moreover, government initiatives, such as the provision of weaving houses, demonstrate tangible efforts to improve production quality and operational efficiency.

4 Discussion

The weaving industry in South Central Timor District (TTS), East Nusa Tenggara (NTT), represents a significant

pillar of the local economy, functioning as both a crucial source of income for many artisans and a vital component of the region's cultural heritage. The region's distinctive ikat weaving is highly esteemed, especially in the international market, owing to its unique dyeing techniques and intricate designs, which reflect the diverse cultural traditions of the area. However, despite its cultural value, the industry encounters various structural and economic obstacles that impede its full development. Challenges such as limited market access, insufficient financial support, and a dependence on traditional production methods hinder the sector's growth potential. Therefore, establishing a well-organized industrial cluster is crucial for improving production efficiency, expanding market access, and ensuring the long-term sustainability of the industry, all while safeguarding its cultural authenticity. Strategic collaboration among artisans, governmental bodies, and private sector stakeholders presents an opportunity to fully harness the potential of the weaving industry.

4.1 Opportunities in weaving industry cluster development

The principal opportunity for advancing the TTS weaving industry lies in the growing global demand for traditional woven products, which are increasingly regarded not only as artistic items but also as functional and fashion-oriented goods. In recent years, a significant increase has been observed in global demand for products that hold cultural significance and are environmentally sustainable. This trend offers TTS weavers a significant opportunity to position their products in international markets. Additionally, advancements in digital marketing and e-commerce platforms have expanded the ability for TTS weaving products to reach a broader audience, both locally and globally.

Enhancing relationships between artisans and various stakeholders—such as retailers, designers, and financial institutions—can further bolster the capacity of the weaving industry. Establishing industrial clusters would facilitate the sharing of resources and information, enabling artisans to introduce their products to broader markets more efficiently. Strengthening connections between producers and consumers, improving supply chain logistics, and refining distribution mechanisms can enhance production efficiency and market responsiveness.

Furthermore, partnerships with academic institutions and research centers would provide artisans with the tools to innovate through the adoption of new techniques and technologies, thus improving product quality. The formation of cooperative networks among artisans can increase bargaining power when negotiating raw material purchases or engaging with buyers. Moreover, integrating digital platforms and e-commerce strategies will enable artisans to compete effectively in both domestic and international markets. Support from both the government and the private sector through policies, financial support

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and infrastructure development will be essential for reinforcing these networks, ensuring the industry's sustainable development [4-6].

4.2 Challenges faced

Despite the significant opportunities, several challenges continue to obstruct the progress of the weaving industry in TTS. One of the most pressing issues is limited market access. Many artisans continue to depend on local markets, and their ability to reach broader national and international markets remains underdeveloped. This is due in large part to the absence of comprehensive marketing networks and insufficient awareness of global market trends. Research indicates that a lack of market networks and understanding of global trends often results in fluctuating or declining revenues for businesses, as they face challenges in attracting new customers or maintaining existing ones. Without a robust marketing strategy, businesses fail to maintain competitiveness, particularly in international markets. To mitigate this issue, artisans must develop comprehensive marketing plans that include market research, product customization, and competitive pricing strategies. Employing data-driven marketing techniques can further optimize campaigns and improve customer engagement, thus ensuring continued business growth [7-10].

Another key challenge is limited access to financing. Many artisans in TTS are unable to secure adequate financial resources, which restricts their ability to expand production capacity and modernize their equipment. The lack of financial support limits artisans' capacity for design innovation and technological improvements, reducing their competitiveness. Additionally, without sufficient capital, artisans are unable to access high-quality raw materials or expand their market reach, thus stifling growth. Financial constraints also prevent artisans from engaging in training programs or adopting new production technologies, limiting their ability to meet the demands of large-scale orders. Without external support from financial institutions or government programs, many artisans remain confined to traditional, small-scale operations and are unable to adapt to the evolving demands of the broader market [11-13].

The quality of human resources also represents a significant barrier to industry growth. While traditional weaving techniques have been passed down through generations, artisans often lack additional training in areas such as business management, marketing, and modern production methods. This absence of skill development hampers both product quality and production efficiency, undermining the industry's competitiveness. Additionally, many artisans are not familiar with modern production technologies, which further limits productivity and cost-effectiveness. The lack of digital literacy also exacerbates the situation, as artisans are unable to leverage e-commerce platforms to expand their market reach. To overcome these challenges, it is crucial to provide comprehensive training programs that address both technical skills and business

acumen, allowing artisans to thrive in an increasingly digital and competitive marketplace [14-16].

4.3 Weaving industry cluster development strategy

To address these challenges, several strategic approaches can be implemented to develop the weaving industry cluster in South Central Timor (TTS):

- **Improvement of Market Access through Digitalization:** Developing a robust digital marketing infrastructure is vital to enhancing market access. The creation of online platforms that allow artisans to sell directly to consumers can bypass traditional market limitations and increase market reach. Additionally, providing digital marketing training will help artisans understand how to effectively target broader audiences. Incorporating secure online payment systems and reliable logistics services will also enhance customer trust and streamline transactions. Collaborations with e-commerce platforms and influencers will help increase product visibility and brand recognition. Additionally, data analytics can assist artisans in understanding consumer preferences and refining their marketing strategies. Government and private sector support in the form of financial incentives or grants for digital transformation will be essential in helping artisans transition successfully to digital markets [17-19].
- **Expansion of Financing Access:** The establishment of an inclusive financing system is essential for the expansion of the weaving industry. Partnerships with banks, microfinance institutions, and non-bank lenders can provide artisans with the necessary capital to invest in modern equipment and expand production capacity. Financial literacy programs are also crucial to helping artisans manage their funds efficiently and make informed business decisions. Cooperative financing models within artisan communities could offer a sustainable financial support system, while integrating digital financial services, such as mobile banking and crowdfunding platforms, could simplify loan application processes. Government initiatives, such as low-interest loans or grants, could further incentivize artisans to innovate and expand their operations [20-22].
- **Comprehensive Skills Development Programs:** Providing training programs that cover not only traditional weaving techniques but also business management, design, and marketing is essential for improving both product quality and operational efficiency. Collaboration with academic institutions and designers will allow artisans to access new knowledge and innovative techniques. In addition, digital skills training will enable artisans to leverage online platforms for promotion and sales. Participation in trade fairs, workshops, and exhibitions can help

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artisans stay abreast of market trends and consumer preferences. Establishing apprenticeship programs with experienced artisans or professionals in the field can further enhance artisans' expertise. Government and private sector initiatives that support continuous education and professional development will ensure the long-term sustainability of the weaving industry [23-27].

- **Adoption of Modern Production Technologies:** The introduction of modern production technologies, such as automated looms and eco-friendly dyeing techniques, can significantly improve both production quality and efficiency. Innovation in design that incorporates traditional elements while responding to contemporary market trends can broaden the appeal of TTS woven products. Collaboration with research institutions can help introduce new materials and techniques that improve the durability and sustainability of woven products. Additionally, the use of digital design tools can streamline the production process while maintaining the authenticity of handcrafted textiles. Adopting environmentally friendly production practices, such as using natural dyes, will also appeal to environmentally conscious consumers, providing access to premium markets [28-30].
- **Fostering Collaboration Among Stakeholders:** Strong cooperation between artisans, government agencies, the private sector, and academic institutions is crucial to developing a thriving and sustainable weaving industry ecosystem. Industry associations or cooperatives can provide a platform for artisans to access funding, advocate for supportive policies, and facilitate knowledge-sharing. Regular forums, workshops, and networking events can strengthen stakeholder relationships and open new avenues for market expansion. Government support in the form of infrastructure development, tax incentives, and export facilitation will be instrumental in stimulating industry growth. Collaboration with universities and research institutions can also drive innovation and research, leading to more efficient production methods and innovative product designs [31-35].

5 Conclusion

The weaving industry in South Central Timor has great potential to grow, both economically and culturally. Through strategic industrial cluster organization, existing challenges, such as market access, financing, and the quality of human resources, can be overcome. By capitalizing on existing opportunities and implementing appropriate development strategies, the weaving industry in TTS can become a more competitive and sustainable sector.

Opportunities for clustering the weaving industry in TTS lie in the region's rich cultural heritage, strong

community networks, and growing market demand for traditional textiles. By leveraging these strengths, artisans can collaborate more effectively, share resources, and enhance product innovation to meet contemporary consumer preferences. The integration of digital marketing, e-commerce platforms, and environmentally friendly production techniques will further strengthen the industry's resilience and global competitiveness.

However, several challenges must be tackled to guarantee success of industrial clustering. Limited financial access, outdated production methods, and insufficient business and marketing skills remain significant obstacles for many artisans. Resolving these issues necessitates coordinated efforts from the government and the private sector, and educational institutions to provide financial support, infrastructure development, and capacity-building programs. Policies that encourage investment in the weaving industry, promote sustainable production practices, and facilitate access to broader markets will be essential in overcoming these barriers.

To develop a thriving weaving industry cluster, a comprehensive strategy must be implemented. This includes fostering collaboration among artisans and stakeholders, strengthening supply chains, and providing continuous training in modern business practices. Additionally, the establishment of industry associations or cooperatives can help advocate for artisans' rights and enhance their bargaining power. With a well-structured approach, the weaving industry in South Central Timor can transform into a dynamic and sustainable economic sector that preserves cultural heritage while driving regional economic growth.

References

- [1] HIDAYANI, N.: Cultural Heritage Preservation: The Art of Traditional Weaving is Applied not Only in Clothing, *Jurnal Impresi Indonesia*, Vol. 3, No. 2, pp. 128-138, 2024. <http://dx.doi.org/10.58344/jii.v3i2.4636>
- [2] SITANGGANG, H., FATONAH, F., NURHAYATI, N., PARDEDE, Y., DEFRIANTI, D.: Peranan Adat Melayu dalam Membangun Identitas Budaya, *Prosiding Seminar Nasional Humaniora*, Vol. 3, pp. 16-25, 2023.
- [3] KAKERISSA, A.L., HAHURY, H.D., LOUHENAPESSY, F.H.: Potential of Smoked Fish Industrial Cluster in the Islands Areas, *Acta logistica*, Vol. 9, No. 4, pp. 457-466, 2022. <https://doi.org/10.22306/al.v9i4.347>
- [4] OSEI, M.B., PAPADOPOULOS, T., ACQUAYE, A., STAMATI, T.: Improving sustainable supply chain performance through organisational culture: A competing values framework approach, *Journal of Purchasing and Supply Management*, Vol. 29, No. 2, 2023. <https://doi.org/10.1016/j.pursup.2023.100821>

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Nil Edwin Maitimu, Ariviana Lientje Kakerissa, Alfredo Tutuhatunewa, Richard Alexander de Fretes, Roxell Evangelo Manuhutu

- [5] ZHANG, H., JIANG, W., MU, J., CHENG, X.: Optimizing Supply Chain Financial Strategies Based on Data Elements in the China's Retail Industry: Towards Sustainable Development, *Sustainability*, Vol. 17, No. 5, 2207, pp. 1-19, 2025. <https://doi.org/10.3390/su17052207>
- [6] LAKSITO, H., RATMONO, D.: Increasing the competitiveness of creative industries based on information technology and good corporate governance in central Java, *International Journal of Data and Network Science*, Vol. 5, pp. 83-90, 2021. <https://doi.org/10.5267/j.ijdns.2021.3.002>
- [7] RAZAVI HAJIAGHA, S.H., ALAEI, S., AMOOZAD MAHDIRAJI, H., YAFTIYAN, F.: International collaboration formation in entrepreneurial food industry: evidence of an emerging economy, *British Food Journal*, Vol. 124, No. 7, pp. 2012-2038, 2022. <https://doi.org/10.1108/BFJ-08-2021-0884>
- [8] MARTÍN, O.M., CHETTY, S., BAI, W.: Foreign market entry knowledge and international performance: The mediating role of international market selection and network capability, *Journal of World Business*, Vol. 57, No. 2, pp. 1-14, 2022. <https://doi.org/10.1016/j.jwb.2021.101266>
- [9] HASANAT, M.W., HOQUE, A., HASSAN, M., MOU, B.I., ABDUL HAMID, A.B.: The Lack of Digital Marketing Skills: Developing a Digital Marketer Model for the Retail Industries, *Xi'an Jianzhu Keji Daxue Xuebao/Journal of Xi'an University of Architecture & Technology*, Vol. 12, No. 3, pp. 2673-2680, 2020.
- [10] RIZVANOVIĆ, B., ZUTSHI, A., GRILO, A., NODEHI, T.: Linking the potentials of extended digital marketing impact and start-up growth: Developing a macro-dynamic framework of start-up growth drivers supported by digital marketing, *Technological Forecasting and Social Change*, Vol. 186, No. Part A, pp. 1-24, 2023. <https://doi.org/10.1016/j.techfore.2022.122128>
- [11] ASAMPANA, I., AKANFERI, A.A., MATEY, A.H., TANYE, H.A.: Adoption of mobile commerce services among artisans in developing countries, *Interdisciplinary Journal of Information, Knowledge, and Management*, Vol. 17, pp. 101-123, 2022. <https://doi.org/10.28945/4921>
- [12] SAHU, S.C., DAS, A.: Traditional plant-based artifacts of Odisha, *Indian Journal of Traditional Knowledge*, Vol. 23, No. 1, pp. 56-66, 2024. <https://doi.org/10.56042/ijtk.v23i1.8146>
- [13] THE WORLD BANK: *Unfair Advantage : Distortive Subsidies and Their Effects on Global Trade (English)*. Equitable Growth, Finance and Institutions Insight Washington, D.C. : World Bank Group, 2023, <http://documents.worldbank.org/curated/en/099062623130526530> [20 Feb 2025], 2023.
- [14] KHAN, M.I., YASMEEN, T., KHAN, M., HADI, N. U., ASIF, M., FAROOQ, M., AL-GHAMDI, S.G.: Integrating industry 4.0 for enhanced sustainability: Pathways and prospects, *Sustainable Production and Consumption*, Vol. 54, pp. 149-189, 2025. <https://doi.org/10.1016/j.spc.2024.12.012>
- [15] SHAJI, G.A.: The Fourth Industrial Revolution: A Primer on Industry 4.0 and its Transformative Impact, *Partners Universal Innovative Research Publication (PUIRP)*, Vol. 2, pp. 16-40, 2024. <https://doi.org/10.5281/zenodo.10671872>
- [16] ALHAMMADI, A., ALSYOUF, I., SEMERARO, C., OBAIDEEN, K.: The role of industry 4.0 in advancing sustainability development: A focus review in the United Arab Emirates, *Cleaner Engineering and Technology*, Vol. 18, pp. 1-20, 2024. <https://doi.org/10.1016/j.clet.2023.100708>
- [17] ADIYONO, N.G., SYAH, T.Y.R., ANINDITA, R.: Digital Marketing Strategies To Increase Online Business Sales Through Social Media, *Journal of Humanities, Social Science, Public Administration and Management (HUSOCPUMENT)*, Vol. 1, No. 2, pp. 31-37, 2021. <https://doi.org/10.51715/husocpument.v1i2.58>
- [18] SPIGARELLI, F., COMPAGNUCCI, L., LEPORE, D.: Blockchain unlocking collaborative opportunities for environmental sustainability through innovation intermediaries, *The Journal of Technology Transfer*, Vol. 50, pp. 516-551, 2025. <https://doi.org/10.1007/s10961-024-10106-5>
- [19] DWIVEDI, Y.K., HUGHES, L., BAABDULLAH, A.M., RIBEIRO-NAVARRETE, S., GIANNAKIS, M., AL-DEBEI, M.M., DENNEHY, D., METRI, B., BUHALIS, D., CHEUNG, C.M.K., CONBOY, K., DOYLE, R., DUBEY, R., DUTOT, V., FELIX, R., GOYAL, D.P., GUSTAFSSON, A., HINSCH, C., JEBABLI, I., JANSSEN, M., KIM, Y., KIM, J., KOOS, S., KREPS, D., KSHETRI, N., KUMAR, V., OOI, K., PAPAGIANNIDIS, S., PAPPAS, I.O., POLYVIOU, A., PARK, S., PANDEY, N., QUEIROZ, N.M., RAMAN, R., RAUSCHNABEL, P.A., SHIRISH, A., SIGALA, M., SPANAKI, K., TAN, G.W., TIWARI, M.K., VIGLIA, G., WAMBA, S.F.: Metaverse beyond the hype: Multidisciplinary perspectives on emerging challenges, opportunities, and agenda for research, practice and policy, *International Journal of Information Management*, Vol. 66, pp. 1-55, 2022. <https://doi.org/10.1016/j.ijinfomgt.2022.102542>
- [20] SURYA, B., MENNE, F., SABHAN, H., SURIANI, S., ABUBAKAR, H., IDRIS, M.: Economic Growth, Increasing Productivity of SMEs, and Open Innovation, *Journal of Open Innovation: Technology, Market, and Complexity*, Vol. 7, No. 1, 20, pp. 1-37, 2021. <https://doi.org/10.3390/joitmc7010020>
- [21] ILO: *Financing Small Businesses in Indonesia: Challenges and Opportunities*/International Labour Office – Jakarta: ILO, 2019, [Online], Available: <https://www.ilo.org/sites/default/files/wcmsp5/group>

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- s/public/@asia/@ro-bangkok/@ilo-jakarta/documents/publication/wcms_695134.pdf [20 Feb 2025], 2019.
- [22] GONCALVES, M., HAIDAR, N., CELIK, E.: Drivers and motivations of Lebanese women entrepreneurs: insights from the demand-constraint-choice framework, *Cogent Business & Management*, Vol. 11, No. 1, pp. 1-33, 2024, <https://doi.org/10.1080/23311975.2024.2371068>
- [23] SIEG, P., POSADZIŃSKA, I., JÓŹWIĄK, M.: Academic Entrepreneurship As A Source Of Innovation For Sustainable Development, *Technological Forecasting and Social Change*, Vol. 194, 122695, pp. 1-13, 2023, <https://doi.org/10.1016/j.techfore.2023.122695>
- [24] HASANAH, U., SUKOCO, B.M., SUPRIHARYANTI, E., WU, W.: Fifty years of artisan entrepreneurship: a systematic literature review, *Journal of Innovation and Entrepreneurship*, Vol. 12, No. 46, pp. 1-25, 2023, <https://doi.org/10.1186/s13731-023-00308-w>
- [25] COFRÈ, S.D., JARA, M.Á.: Navigating design and innovation hegemonies in Chilean crafts, *Third World Quarterly*, Vol. 2024, pp. 1-22, 2024, <https://doi.org/10.1080/01436597.2024.2425330>
- [26] MARQUES, C., SANTOS, G., RATTEN, V., BARROS, A.: Innovation as a booster of rural artisan entrepreneurship: a case study of black pottery, *International Journal of Entrepreneurial Behavior & Research*, Vol. 25, No. 4, pp. 753-772, 2018, <https://doi.org/10.1108/IJEBr-02-2018-0104>
- [27] MULLER, E., PERES, R.: The effect of social networks structure on innovation performance: A review and directions for research, *International Journal of Research in Marketing*, Vol. 36, No. 1, pp. 3-19, 2019, <https://doi.org/10.1016/j.ijresmar.2018.05.003>
- [28] ALBU, A.V., CACIORA, T., BERDENOV, Z., ILIES, D.C., STURZU, B., SOPOTA, D., HERMAN, G.V., ILIES, A., KECSE, G., GHERGHELEŞ, C.G.: Digitalization of garment in the context of circular economy, *Industria Textila*, Vol. 72, No. 1, pp. 102-107, 202. <https://doi.org/10.35530/IT.072.01.1824>
- [29] CIRERA, X., FRÍAS, J., HILL, J., LI, Y.: *A Practitioner's Guide to Innovation Policy: Instruments to Build Firm Capabilities and Accelerate Technological Catch-Up in Developing Countries*, The World Bank, Washington, DC, 2020, [Online], Available: <https://documents1.worldbank.org/curated/en/158861581492462334/pdf/A-Practitioner-s-Guide-to-Innovation-Policy-Instruments-to-Build-Firm-Capabilities-and-Accelerate-Technological-Catch-Up-in-Developing-Countries.pdf> [20 Feb 2025], 2020.
- [30] VERBOEKET V., KRIKKE H, SALMI M. Implementing Additive Manufacturing in Orthopedic Shoe Supply Chains—Cost and Lead Time Comparison, *Logistics*, Vol. 8, No. 2, 49, pp. 1-23, 2024. <https://doi.org/10.3390/logistics8020049>
- [31] AUDRETSCH, D.B., BELITSKI, M., CAIAZZA, R., PHAN, P.: Collaboration strategies and SME innovation performance, *Journal of Business Research*, Vol. 164, 114018, pp. 1-15, 2023, <https://doi.org/10.1016/j.jbusres.2023.114018>
- [32] KESIDOU, E., LOVE, J.H., OZUSAGLAM, S., WONG, C.Y.: Changing the Geographic Scope of Collaboration: Implications for Product Innovation Novelty and Commercialization, *Journal of Product Innovation Management*, Vol. 40, No. 6, pp. 859-881, 2023. <https://doi.org/10.1111/jpim.12695>
- [33] TUTUHATUNewa, A., SURACHMAN, SANTOSO, P.B., SANTOSO, I.: Influence of Information Sharing, Partnership, and Collaboration in Supply Chain Performance; Study on Apples Agroindustry, *Advances in Systems Science and Applications*, Vol. 19 No. 3, pp. 80-92, 2019, <https://doi.org/10.25728/assa.2019.19.3.689>
- [34] ZHANG, H.: Does combining different types of innovation always improve SME performance? An analysis of innovation complementarity, *Journal of Innovation & Knowledge*, Vol. 7, No. 3, pp. 1-11, 2022. <https://doi.org/10.1016/j.jik.2022.100192>
- [35] MARIANI, L., TRIVELLATO, B., MARTINI, M., MARAFIOTI, M.: Achieving Sustainable Development Goals Through Collaborative Innovation: Evidence from Four European Initiatives, *Journal of Business Ethics*, Vol. 180, pp. 1075-1095, 2022. <https://doi.org/10.1007/s10551-022-05193-z>

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Factors influencing the development of competitive capabilities of border trade entrepreneurs

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Abstract: This study investigates the factors influencing export competitiveness in border trade by focusing on Thai entrepreneurs engaged in trade with Cambodia. This study employs structural equation Modeling (SEM) to examine the relationships between consumer culture and lifestyle, foreign environmental factors, and export competitiveness. The data were collected from 200 establishments across various industries, primarily in the food, beverage, and tobacco sectors. The results indicate that the foreign environment factor significantly influences export competitiveness ($\beta = 0.613$, $p < 0.001$), while consumer culture and lifestyle play a crucial role in shaping foreign environment perceptions ($\beta = 0.77$, $p < 0.001$). However, consumer culture and lifestyle do not directly affect export competitiveness, highlighting that entrepreneurs prioritize market expansion without altering product offerings to accommodate local preferences. This study confirms that Thai products are well-received in Cambodia because of their established reputation and consumer trust. Additionally, border trade presents opportunities for Thai businesses to capitalize on infrastructure development and economic growth in neighboring countries. These findings support the theory of planned behavior by emphasizing the importance of market analysis, motivational factors, and operational preparedness in trade decision-making. From a practical standpoint, this study offers key policy recommendations, including entrepreneurial knowledge development, cross-border collaboration through special economic zones (SEZs), customs system enhancement, and the adoption of electronic platforms to streamline trade processes. These measures aim to improve trade efficiency and economic cooperation between Thailand and Cambodia.

1 Introduction

Border and transit trades are forms of international trade involving the movement of goods over land through border provinces via three main types of border crossings: permanent, temporary, and relaxed. Thailand shares its borders with four neighboring countries. In the first seven months of 2024, Thailand recorded a border trade surplus, with the highest value of trade occurring between Thailand and Malaysia, followed by Lao PDR, Myanmar, and Cambodia, respectively [1]. Cambodia is an interesting neighboring country that warrants further study as the value of border trade between Thailand and Cambodia continues to increase steadily. Cambodia also serves as a connection point for cross-border transportation, enabling the distribution of goods by land to Vietnam, a country experiencing consistent economic growth and relying more on imports than exports [2]. Cambodia has garnered international attention for trade and investment. The Asian Development Bank assessed Cambodia's economic situation and found that its economy is expected to expand steadily. The Gross Domestic Product (GDP) grew by 5.3 percent in 2024 and is projected to grow by up to 6.3 percent in 2025 [3]. Trade and investment from many countries have provided the Cambodian population with jobs and steadily increased the average income per capita each year. As Cambodia's economy grows, the country

increasingly relies on importing consumer goods. This reliance stems from Cambodia's demand for goods and services, exceeding the capacity of its domestic production sector. Furthermore, the quality of domestically produced goods and services remains below international standards. Cambodia imports large quantities of goods from China, Thailand, and Vietnam. Thai products, especially daily consumer goods, are particularly popular in Cambodia because of the similar lifestyles and cultures of the two nations.

However, the Thailand-Cambodia border trade still faces several limitations, resulting in most consumer goods sold in the Cambodian market being products from only large operators. This is due to several factors. First, SMEs lack promotion and support to access policies and the various benefits provided by government agencies. For international businesses to succeed, entrepreneurs require support through appropriate government policies [4-5]. Second, limitations in land transport networks, including both rail and road transport, result in delays in the transport of goods and damage during transit. Therefore, efficiently managing logistics is crucial for enhancing the potential of international trade and investment [5-6]. Third, regarding entrepreneurial capabilities, conducting business internationally requires entrepreneurs to study consumer differences, develop products aligned with consumer needs

in foreign markets [7-8], identify opportunities to expand markets, and manage risks arising from changes in consumer behavior or government policies [9].

Despite growing literature on regional trade and SME challenges, there remains a lack of empirical research focusing specifically on the competitive capabilities of border trade entrepreneurs operating between Thailand and Cambodia. While several studies discuss macroeconomic factors and trade statistics, few provide a detailed analysis of the on-ground capabilities, knowledge gaps, or digital readiness of entrepreneurs in these border areas. Furthermore, existing research tends to overlook the impact of cross-border knowledge-sharing mechanisms, and innovation diffusion at the micro-enterprise level. The evolving economic relationship between the two countries also demands updated models to analyze how border entrepreneurs adapt to changes in infrastructure, transport policies, and consumer preferences.

This study aims to identify the key factors affecting the development of competitiveness among Thailand-Cambodia border trade entrepreneurs, including providing in-depth data on entrepreneurs' opinions regarding the current border and cross-border trade situations. The findings serve as guidelines for government agencies in policy development to promote entrepreneurs and enhance international infrastructure for entering the border trade business in the next phase.

2 Literature review

2.1 Thailand's border trade

Thailand has a geographical advantage as the center of the ASEAN region, enabling connections to neighboring countries with adjacent borders. It also serves as a trade gateway for China and India, representing nearly half of the world's population. This strategic position presents Thailand with significant trade opportunities. In addition, establishing the Greater Mekong Sub-Region Cooperation Group, comprising Thailand, Myanmar, Lao PDR, Vietnam, Cambodia, and China, contributes to developing trade, investment, transportation, and other areas under a unified agreement. A key focus is to facilitate the movement of goods and people across international borders through initiatives such as: 1) single-stop inspection and comprehensive product inspections; 2) integrating related systems of member countries, such as customs, immigration, product safety, and standards inspection systems, to streamline procedures; 3) exchanging traffic rights to allow vehicles from member countries to enter and deliver goods within their borders; 4) facilitate cross-border transportation of goods (transit) by conducting inspections only when necessary in accordance with the single-stop inspection principle and refrain from collecting taxes on goods in transit; and 5) facilitating individuals' cross-border movement. However, the current implementation of cross-border transport agreements remains slow due to legal constraints within member states and other limitations [10]. For example,

Thai law prohibits foreign customs officers from working at Thai customs checkpoints. Additionally, customs checkpoint opening and closing times vary between countries; local officers often lack the necessary knowledge and understanding of procedures; related documents are not standardized in a universal language; and transportation channels differ across countries. For the Thai-Cambodian border trade route, which uses road transport in the eastern region of Thailand to connect to Phnom Penh, the highway connecting the cities of Thailand and Cambodia has different numbers of traffic lanes and a limited number of cargo release checkpoints. This leads to congestion on the route and at the cargo release checkpoints (Thailand-Cambodia land checkpoints). Additionally, the quality of road surfaces in Cambodia contributes to damage of goods during transportation. These issues are among the factors that resulted in Cambodia's logistics costs in 2022 reaching 26 percent of the GDP [11]. While Thailand's logistics costs are 13 percent of the GDP [12], they are significantly lower than that of Cambodia. However, Thailand and Cambodia are both committed to developing more efficient border trade routes. As part of this effort, they revived the railway service, which had been suspended for 49 years, by upgrading the Ban Klong Luek border station in Thailand and the Poipet station in Cambodia. Additionally, the efficiency of road surfaces has been improved to provide a better alternative for transporting goods, helping entrepreneurs reduce logistics costs. This allows businesses to offer competitive product prices in the Cambodian market.

2.2 Conceptual framework and hypotheses development

2.2.1 The role of the theory of planned behavior (TPB) in understanding export entrepreneurs

This study develops a framework using the theory of planned behavior (TPB) to study consumer attitudes, behaviors, and social norms that influence purchasing decisions for everyday consumer goods. The TPB is valuable for predicting and explaining intentions and behavioral expressions, contributing to a deeper understanding of human needs [13-14]. As a part of society, businesses must understand human behavior to meet consumers' daily needs. By doing so, businesses can survive, steadily grow, and achieve sustainable development. Social changes directly influence business operations. Culture, which is transmitted from one society to another both materially and mentally, plays a crucial role. Social and cultural factors significantly influence the success or failure of business operations, and exert both direct and indirect effects [15-17]. In addition, a study by Falahat, Soto-Acosta, and Ramayah [4] found that the organizational culture of entrepreneurs is positively associated with creating competitive advantages and improving business performance at the international level. Consequently, exporters must quickly adapt to changes in

international markets, including variations in lifestyle and culture, to build competitive capabilities and achieve a competitive edge in global markets. Finally, the business environment is another critical factor that influences the success or failure of business operations, with both direct and indirect effects.

According to Wheelen and Hunger [15] and Thompson and Strickland [16], the environment influencing business operations comprises the following factors. 1) Social and Cultural Factors: Business is inherently a part of society and social changes directly influence business operations. Culture, which is cultivated and transmitted materially and mentally from one society to another, plays a crucial role. 2) Technological Factors: Technological advancements are essential drivers of new processes and innovations, enabling effective decision-making and problem solving. 3) Economic Factors: Economic conditions directly affect consumers' purchasing power and consumption behavior, thereby influencing business performance. 4) Political and Legal Factors: Changes in political and legal environments affect strategic decision-making, guiding businesses to plan effectively and achieve their objectives. 5) International Factors: Advancements in global communication and transportation allow entrepreneurs to expand beyond their domestic markets, facilitating investments and connections across multiple countries. This aligns with the findings of Ipek and Tanyeri [18], who emphasized that the social and cultural environment in foreign markets is a critical factor that exporters cannot overlook, as it significantly impacts the costs of operating international businesses. Therefore, entrepreneurs must leverage their resources and capabilities to create added value in their products and services, while adhering to social norms. Establishing export strategies based on these principles enables businesses to succeed in foreign markets [19].

Based on the literature review above, the following hypotheses are proposed:

Hypothesis 1 (H1): Consumer culture and lifestyle factors influence foreign environmental factors.

Hypothesis 2 (H2): Consumer culture and lifestyle factors influence export competitiveness factors.

2.2.2 Factors determining the competitiveness of exporters

International trade is a key factor in driving a country's economic growth and development. As the global market environment continues to evolve, exporters must adapt to rapid changes to gain a competitive advantage over their competitors [22]. Government promotion, through the creation of an environment conducive to business, operates in four key areas: 1) economic performance, including economic conditions, international trade, foreign investment, employment, and inflation; 2) government efficiency, including fiscal status, taxes, business laws, and economic and social governance frameworks; 3) business efficiency, including production efficiency, the labor

market, finance, management, and attitudes; and 4) infrastructure, including physical, scientific, technological, educational, health, and environmental aspects. These efforts help exporters plan their strategies more effectively, leading to sustainable competitiveness in foreign markets [23]. According to Forte and Carvalho [20], factors that can be measured in economic/financial terms, such as sales volume, sales growth, and return on investment, along with those that cannot be measured in economic/financial terms, such as competitive pressure, creating awareness and image abroad, and customer satisfaction, influence export performance from both economic and strategic management perspectives. Operating in a globalized environment has pressured entrepreneurs to look beyond the domestic market and seek new opportunities. While trade competition is no longer confined by borders, exports offer organizations a pathway for sustainable growth, especially when the domestic economy is sluggish or declining, or when domestic market demand is limited. Furthermore, the ease of moving goods and services across borders is an environmental factor that significantly impacts export performance. Policy options that the government can use to stimulate exports and enhance Thailand's international trade competitiveness are critical [21-22].

In addition, the research findings of Hanifzadeh, Talebi, and Sajadi [17] identified three key characteristics of the business environment that have the highest impact on business growth: 1) Personal factors: educational attainment, experience related to setting up and managing a business, skills relevant to business growth, risk-taking propensity, amount of human and social capital, and motivation related to business growth. 2) Environmental factors: Environmental benefits including proximity to the environment, environmental dynamism, supportive policies in the business environment, and relevance of the environment to business expertise. 3) Business characteristics: Professional business practices in an environment with highly competitive advantages including brand strength, technology level, and human and social capital.

In this era of globalization, entrepreneurs must develop strategies focused on differentiation by adding value to products and services that surpass those of their competitors. This approach enhances entrepreneurs' competitive abilities and enables creation of sustainable competitive advantages. According to Obadia [23], the benefits derived from operations drive exporters to remain determined and succeed in their international businesses. The first dimension of these benefits is the exporter's economic performance [24]. According to Chu et al. [25], strong relationships, economic promotion policies, and the partner country's environment are crucial to the competitiveness of products in the export market. Moreover, developing countries have adopted various strategies to stimulate the domestic economy and attract investors, such as creating tax incentives and subsidies.

This has led large foreign companies to enter small markets by investing more than they export and using unfair pricing strategies to reduce competition. Promoting a country's economic policies through exports remains a key factor in helping domestic industries grow sustainably. Exports encourage entrepreneurs to focus on developing human resource skills, utilizing technology, and efficiently using production factors. This, in turn, helps spread the operational risks [26].

Based on the above literature review, the following hypothesis can be stated:

Hypothesis 3 (H3): Foreign environmental factors influence export competitiveness factors.

Additionally, a model is developed based on the literature review to explain the relationships between the variables, as shown in Figure 1.

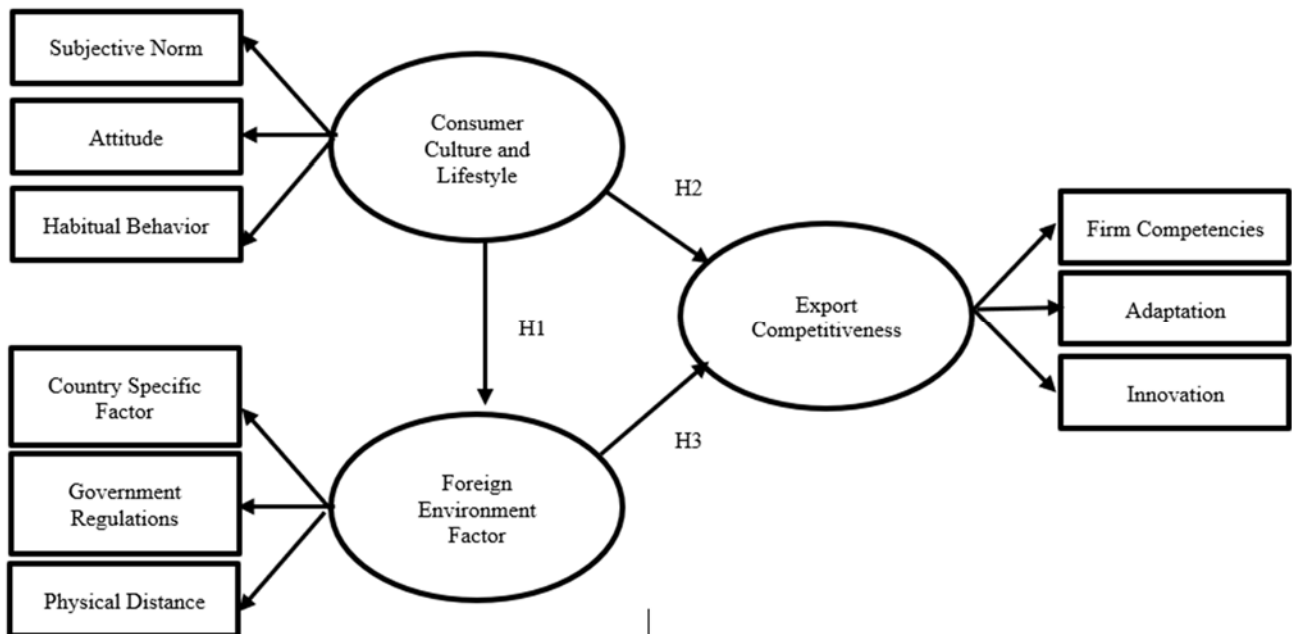


Figure 1 Conceptual framework

3 Methodology

3.1 Participants and procedure

This study employs a quantitative methodology to identify the key factors that influence the competitiveness of border trade entrepreneurs, with data collected using a structured questionnaire administered to experienced exporters and distributors of consumer goods. The questionnaire comprised five sections: 1) general establishment information (closed-ended questions), 2) cultural and consumer lifestyle factors, 3) foreign environmental factors (closed-ended questions), 4) exporter competitiveness factors (closed-ended questions utilizing a 5-point Likert scale for interval-scale measurement), and 5) open-ended questions for additional suggestions from business operators to enhance border trade potential.

The research instruments were rigorously validated for quality, with content validity confirmed by three experts yielding an Index of Item Objective Congruence (IOC) between 0.67 and 1.00, exceeding the standard criterion of 0.50 to 1.00 [27]. Reliability testing produced Cronbach's alpha coefficients ranging from 0.743 to 0.917, surpassing the acceptable threshold of 0.70 [28].

3.2 Data analysis

This study utilized quantitative data collection from primary sources, employing questionnaires as research tools to gather data from areas bordering Thailand and its neighboring countries. A purposive sampling method was chosen to maximize the likelihood of accessing a sample group capable of providing relevant information that aligned with the research objectives while minimizing potential response bias. Considering the criteria for determining the sample size for structural equation modeling (SEM) analysis outlined by Kline [29], the sample size for a moderately complex model should not be less than 200. Accordingly, this study set the minimum sample size at 200 participants, using information provided by the executives or managers of the establishments.

The data were analyzed using both descriptive and inferential statistical methods. Descriptive statistics—such as percentages, means, and standard deviations—were used to summarize the demographic and general characteristics of the respondents. For inferential analysis, SEM was employed due to its suitability for examining complex relationships among both observed and latent variables. This method is particularly effective for

investigating the multidimensional nature of entrepreneurial competitiveness. Moreover, SEM allows for simultaneous testing of direct and indirect effects, offering a comprehensive view of how various factors interrelate to influence the competitive capabilities of border trade entrepreneurs. This analytical approach aligns closely with the study's aim of identifying key structural relationships and generating insights to inform future policy development.

4 Results

4.1 Firm demography and sample characteristics

The analysis of general data from 200 establishments revealed that the majority were limited companies,

accounting for 78 establishments (39%), followed by public limited companies with 65 establishments (32.5%) and limited partnerships/general partnerships with 57 establishments (28.5%). Most establishments had five to 10 years of business experience, representing 78 establishments (39%), and most operated in the food, beverage, and tobacco industries, totaling 133 establishments (66.5%). Regarding the questionnaire respondents, the analysis showed that most were male (51.5%) and had five to 10 years of experience in imports and exports, accounting for 76 establishments (38%) (Table 1).

Table 1 Firm demography and sample characteristics

Firm Demography	Frequently (LSPs)	Percent (%)
Firm Registration		
Public Limited Company	65	32.5
Limited company	78	39
Limited Partnership/ Ordinary Partnership	57	28.5
Total	200	100
Firm Experience		
Less than 5 years	59	29.5
5–10 years	78	39
11–15 years	26	13
More than 15 years	37	18.5
Total	200	100
Types of Industries		
Metal products, machinery, and transport equipment	56	28
Food, beverages, and tobacco	133	66.5
Textiles and leather	5	2.5
Other	6	3
Total	200	100
Sample Characteristics		
Gender		
Male	103	51.5
Female	97	48.5
Total	200	100
Work Experience		
Less than 5 years	12	6
5–10 years	76	38
11–15 years	64	32
More than 15 years	48	24
Total	200	100

Table 2 presents the results of the data analysis using descriptive statistics from the mean, standard deviation, and relationships between the variables. It demonstrates that the culture and lifestyle of consumers and the foreign

environment are important for the competitiveness of exporters. The variables used in this study have statistically significant relationships.

Table 2 Mean, standard deviation, and correlation matrix

	Mean	SD	Consumer culture and lifestyle	Foreign environment factor	Export competitiveness
Consumer culture and lifestyle	4.199	0.405	1		
Foreign environment factor	3.995	0.513	0.537**	1	
Export competitiveness	4.049	0.542	0.485**	0.529**	1
Average variance extracted ($\sqrt{\text{AVE}}$)			0.543	0.607	0.617
Composite reliability (CR)			0.991	0.995	0.996

Note: ** significant at the 0.01 level

4.2 Measurement model

Using confirmatory factor analysis, the structural validity test results indicated that the factors of consumer culture and lifestyle, exporter economic efficiency, foreign environment, and exporter competitiveness have factor loadings ranging from 0.400 to 0.829, all exceeding the threshold of 0.4, as suggested by Guadagnoli and Velicer [30], with statistical significance set at $p < 0.001$.

Additionally, the convergent validity test results showed a composite reliability (CR) value greater than 0.7, consistent with the criterion set by Hair, Black, Babin, and Anderson [31]. The discriminant validity test results revealed an average variance extracted (AVE) value greater than 0.5, meeting the standard proposed by Barclay, Higgins, and Thompson [32] as shown in Table 3.

Table 3 Measurement model

Variable	Construct	Items	Factor loading	CR	AVE
Consumer culture and lifestyle	Subjective norm	3	0.400; 0.471; 0.716	0.991	0.543
	Attitude	3	0.592; 0.462; 0.602		
	Habitual behavior	4	0.580; 0.536; 0.451; 0.550		
CMIN/df = 1.744; CFI = 0.927; TLI = 0.900; RMR = 0.031; RMSEA = 0.061					
Foreign environment factor	Country specific factor	5	0.778; 0.548; 0.661; 0.676; 0.512	0.995	0.607
	Government regulations	5	0.531; 0.509; 0.592; 0.600; 0.640		
	Physical distance	4	0.707; 0.498; 0.635; 0.530		
CMIN/df = 1.744; CFI = 0.934; TLI = 0.909; RMR = 0.038; RMSEA = 0.062					
Export competitiveness	Firm competencies	5	0.690; 0.607; 0.412; 0.668; 0.621	0.996	0.617
	Adaptation	5	0.661; 0.829; 0.674; 0.561; 0.604		
	Innovation	5	0.638; 0.501; 0.561; 0.484; 0.627		
CMIN/df = 1.828; CFI = 0.930; TLI = 0.911; RMR = 0.042; RMSEA = 0.065					

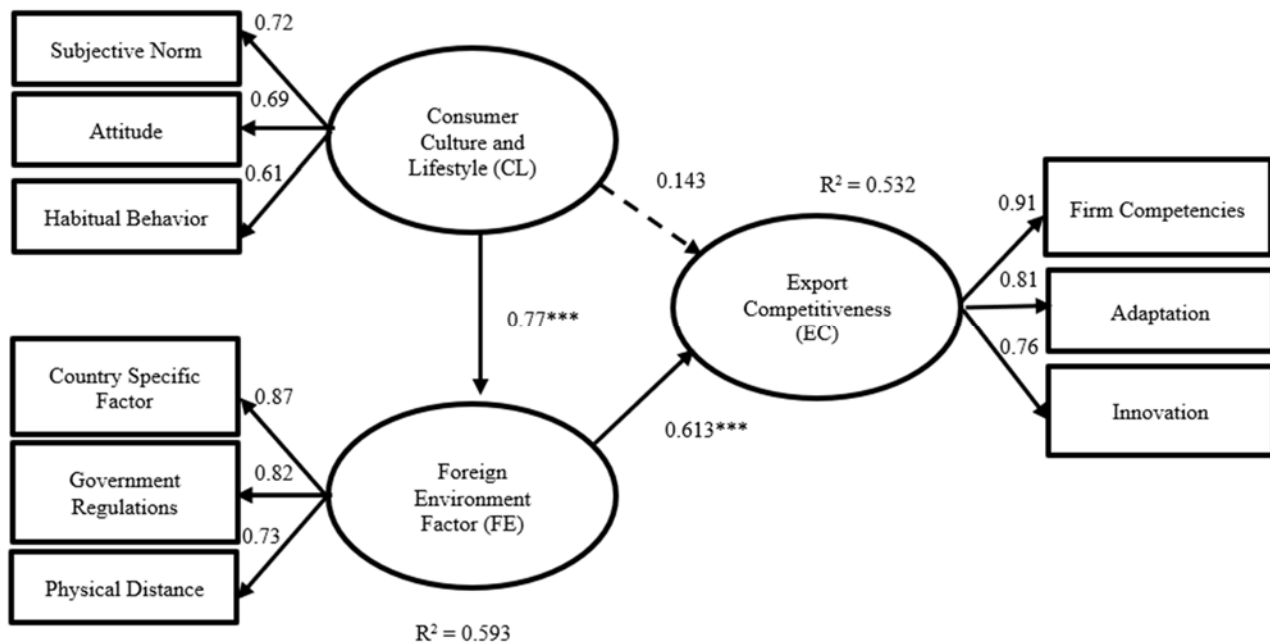
4.3 Structural model and hypotheses testing

The SEM analysis results can be explained as follows:

The test of variance of the independent variables in relation to the dependent variable showed that the foreign environment factor accounted for 59% of the variance ($R^2 = 0.593$), whereas the export competitiveness factor accounted for 53% ($R^2 = 0.532$).

The results of the structural equation analysis indicated that the model was consistent with the empirical data, with

GFI and AGFI values greater than 0.8 [33], SRMR values less than 0.05 [36], and RMSEA values less than 0.08 [34], as shown in Figure 2. The path coefficient values, shown in Table 4, reveal that consumer culture and lifestyle factors have a significant direct influence on the foreign environment factor ($\beta = 0.77$, $p < 0.001$) but do not significantly influence the export competitiveness factor. Conversely, the foreign environment factor directly influences the export competitiveness factor ($\beta = 0.613$, $p < 0.001$).



Chi-Square =28.163; df = 17; χ^2/df =1.657; RMSEA = 0.057; GFI = 0.970; AGFI = 0.922; SRMR = 0.011

Figure 2 Structural model

Table 4 Structural model and hypotheses testing

Hypotheses	Paths	Direct effect	Indirect effect	Relationship
Direct hypothesis				
H1	CL → FE	0.77***	-	supported
H2	CL → EC	0.143	-	not supported
H3	FE → EC	0.613***	-	supported
Mediation hypothesis				
H4	CL → FE → EC	-	0.844	supported

Note: *** significant at the 0.001 level

5 Discussion

The results of this study confirm both Hypothesis 1 (H1) and Hypothesis 3 (H3), highlighting the interconnected roles of consumer culture, foreign environmental factors, and export competitiveness in the context of Thailand–Cambodia border trade. Border trade offers a strategic pathway for entrepreneurs in neighboring countries to expand their market access and tap into new consumer segments. Thailand, as a central player in the Altasia production base (the alternative Asian supply chain), benefits from its abundant production resources, a skilled workforce, and adherence to high production standards—factors that enhance the global competitiveness and appeal of Thai consumer products [40].

Daily consumer goods, in particular, are highly popular in neighboring countries like Cambodia. This popularity is influenced by Cambodian consumers' trust in the quality and branding of Thai products, which is often shaped by direct experience from having lived and worked in Thailand [17][41–42]. These shared experiences and lifestyle similarities foster a strong sense of cultural familiarity and brand confidence, which in turn shape

foreign environmental conditions such as demand patterns, trade preferences, and import behaviors—thus supporting Hypothesis 1 (H1). Additionally, Cambodia's limited domestic production capacity—particularly in consumer goods—makes imported goods a practical necessity. The relatively low distribution and transport costs further ensure the affordability of these goods in Cambodian markets. As a response to growing consumer demand, both Thai and Cambodian governments have intensified cross-border cooperation in the retail and distribution sectors. This has resulted in enhanced logistics infrastructure, improved policy coordination, and greater efficiency in product flow—all of which improve the foreign environmental conditions that influence export success. These developments support Hypothesis 3 (H3), as they illustrate how favorable external factors—such as infrastructure development, public utility expansion, and policy support—enhance the export competitiveness of Thai entrepreneurs. For instance, the expansion of Thai construction material exports into Cambodia has been driven by the country's rapid infrastructure growth and consistent economic development [35–37]. This indicates that structural and institutional factors within the foreign

environment directly contribute to Thai businesses' ability to operate effectively and competitively in cross-border trade.

In contrast, the study's findings do not support Hypothesis 2 (H2). While literature such as Thompson and Strickland [38] emphasizes the need for businesses to adapt their operations to fit the socio-cultural dimensions of foreign markets, this study found that most Thai entrepreneurs do not significantly adjust their products for the Cambodian market. Instead, entrepreneurs prioritize market expansion based on perceived cultural and lifestyle similarities, choosing to retain existing product formats. Responses to open-ended questions indicate that entrepreneurs view product adaptation as unnecessary, cost-intensive, and risky—particularly because the goods being exported (primarily basic consumer products) already align with Cambodian tastes, cultural norms, and consumption habits. This finding suggests that in border trade contexts where cultural alignment is high, such as between Thailand and Cambodia, the perceived need for product adaptation may be minimal. Entrepreneurs often rely on the existing cultural compatibility to drive exports, reducing the urgency for market-specific customization. As a result, while consumer culture significantly shapes the external trade environment (supporting H1), it does not always lead to adaptive business behavior (contradicting H2).

In conclusion, the findings underscore the importance of consumer lifestyle and culture in shaping trade conditions and the strategic role of external environmental factors in enhancing export competitiveness. These insights are especially relevant for policymakers and businesses seeking to strengthen cross-border trade through infrastructure investment, policy coordination, and the leveraging of cultural proximity.

6 Conclusion

6.1 Theoretical contributions

This research utilized the TPB developed by Icek Ajzen in 1985 as a framework to predict relationships within a structural equation model and explain individual behavior. This theory offers valuable insights for decision-making in border trade, outlined as follows: Market Analysis: Entrepreneurs should evaluate factors such as market demand, potential risks, positive attitudes, and opportunities for their products or services before committing to border trade. Motivational Factors: Entrepreneurs should identify motivations for engaging in border trade, including government promotional policies, support from industry associations or trading partners, and the influence of successful competitors, which may encourage them to follow similar strategies. Operational Preparedness: Entrepreneurs should gain a comprehensive understanding of access to financial resources, foreign market regulations, and logistics capabilities. Organizations with stronger knowledge, control, and

readiness in these areas are better positioned to achieve success in cross-border trade.

To investigate these complex and interrelated factors, the study employs Structural Equation Modeling (SEM), a particularly suitable analytical approach. SEM allows for the simultaneous analysis of multiple dependent relationships and the inclusion of latent variables, which is critical for capturing abstract constructs such as consumer culture, foreign environmental influences, and export competitiveness. Unlike traditional regression techniques, SEM accommodates both direct and indirect effects, making it ideal for testing the mediated relationships proposed in the conceptual framework. As a theory-driven, confirmatory method, SEM is well-aligned with the study's hypotheses (e.g., H1 and H3), enabling empirical validation of theoretical assumptions. Moreover, SEM controls for measurement error and provides robust model fit indices (such as CFI, RMSEA, and TLI), thereby enhancing the reliability, precision, and policy relevance of the research findings.

6.2 Practical implications

The findings of this study offer statistically significant insights that support Hypothesis 1 (H1) and Hypothesis 3 (H3), revealing clear relationships among consumer culture, foreign environmental factors, and export competitiveness. The structural equation modeling (SEM) results confirm that consumer lifestyle and cultural familiarity—particularly the trust of Cambodian consumers in Thai products—have a strong positive effect on shaping the foreign environmental conditions in the Cambodian market. In turn, these environmental factors, including trade policies, infrastructure, and logistics systems, significantly influence the export competitiveness of Thai entrepreneurs operating along the border. These statistical findings suggest that the theoretical model used in this study is not only empirically valid but also practically relevant.

In addition, the results of this study provide actionable insights for practitioners and policymakers in both Thailand and Cambodia, especially in the context of enhancing the competitive capabilities of border trade entrepreneurs. The statistically supported relationships between consumer culture, foreign environmental factors, and export competitiveness highlight the need for targeted strategies that address both individual entrepreneurial readiness and systemic trade conditions. Based on these findings, several key recommendations are proposed:

Entrepreneurial Knowledge Development: Governments should prioritize educational initiatives that equip entrepreneurs with a clear understanding of regional economic cooperation frameworks, particularly ASEAN trade agreements. By improving their knowledge of how to access and apply these policies, entrepreneurs will be better positioned to identify trade opportunities, mitigate risks, and engage more effectively in cross-border commerce.

Cross-Border Collaboration: The research supports the establishment of Special Economic Zones (SEZs) along the Thai-Cambodian border. These zones can act as growth engines for SMEs by providing shared infrastructure, simplifying cross-border employment policies, and streamlining customs and trade facilitation. Enhanced coordination between both countries will improve operational efficiency and reduce barriers to entry for new entrepreneurs.

Customs System Enhancement: The SEM analysis underscores logistical and procedural inefficiencies as major constraints to export competitiveness. To address this, both governments should invest in customs modernization by adopting integrated digital systems, enabling real-time data exchange, and implementing risk-based inspection frameworks. These measures will reduce processing times and enhance the predictability and reliability of cross-border trade.

Adoption of Electronic Platforms: Embracing digital transformation is critical for reducing administrative burdens. The integration of electronic platforms—for licensing, customs documentation, and logistics coordination—will not only streamline operations but also improve transparency and governance, creating a more inclusive and business-friendly environment for SMEs involved in international trade.

In summary, these targeted policy interventions—rooted in the empirical findings of this study—highlight the importance of aligning entrepreneurship support with broader structural reforms to unlock the full potential of border trade between Thailand and Cambodia.

6.3 Limitations and future research

This research has several limitations: 1) Scope of Data Collection: The data was gathered solely from Thai entrepreneurs engaged in border trade with Cambodia. Future research could broaden its scope to include entrepreneurs from other countries involved in border trade. This provides insights from a wider range of perspectives and captures the diverse experiences of entrepreneurs in different contexts. 2) Focus on Thai Entrepreneurs: The study exclusively focuses on Thai entrepreneurs' opinions. Future studies could extend this study to include the perspectives of both importers and exporters. This approach offers more comprehensive insights and helps develop sustainable strategies to enhance the potential of border trade.

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References

[1] Department of Foreign Trade: Department of Foreign Trade News, [Online], Available: <https://www.dft.go.t>

- h/th-th/NewsList/News-DFT/Description-News-DFT/ArticleId/28472/28472 [17 Sep 2024], 2024.
- [2] Asian Development Bank: Cambodia diversifying beyond garments and tourism country diagnostic study, [Online], Available: <https://www.adb.org/sites/default/files/publication/149852/cambodia-diversifying-country-diagnostic-study.pdf> [17 Sep 2024], 2024.
- [3] Asian Development Bank: ADB's work in Cambodia, [Online], Available: <https://www.adb.org/where-we-work/cambodia/overview> [17 Sep 2024], 2024.
- [4] FALAHAT, M., SOTO-ACOSTA, P., RAMAYAH, T.: Analysing the importance of international knowledge, orientation, networking and commitment as entrepreneurial culture and market orientation in gaining competitive advantage and international performance, *International Marketing Review*, Vol. 39, No. 3, pp. 463-481, 2021.
<https://doi.org/10.1108/imr-02-2021-0053>
- [5] NJINYAH, S.Z.: The effectiveness of government policies for export promotion on the export performance of SMEs Cocoa exporters in Cameroon, *International Marketing Review*, Vol. 35, No. 1, pp. 164-185, 2018.
<https://doi.org/10.1108/imr-05-2016-0103>
- [6] FAROQUE, A.R., KUIVALAINEN, O., AHMED, J.U., RAHMAN, M., ROY, H., ALI, M.Y., MOSTAFIZ, M.I.: Performance implications of export assistance: the mediating role of export entrepreneurship, *International Marketing Review*, Vol. 38, No. 6, pp. 1370-1399, 2021.
<https://doi.org/10.1108/imr-07-2020-0141>
- [7] SOUSA, C.M.P., RUZO-SANMARTÍN, E., VARELA-NEIRA, C., TAN, Q.: How to successfully adapt distribution strategy in exporting? The moderating effects of commitment and responsiveness, *International Marketing Review*, Vol. 41, No. 6, pp. 1218-1241, 2024.
<https://doi.org/10.1108/IMR-06-2023-0123>
- [8] ARUN, K., YILDIRIM OZMUTLU, S.: The effect of environmental competitiveness, customer and competitor orientation on export performance, *Journal of Business & Industrial Marketing*, Vol. 39, No. 2, pp. 142-160, 2024.
<https://doi.org/10.1108/JBIM-01-2022-0019>
- [9] LUKASON, O., VISSAK, T.: Internationalization and failure risk patterns, *Review of International Business and Strategy*, Vol. 29, No. 1, pp. 25-43, 2019.
<https://doi.org/10.1108/ribs-06-2018-0054>
- [10] International Institute for Trade and Development: Cross-border transportation between Thailand and neighboring countries, [Online], Available: https://www.itd.or.th/en/itd-data-center/67_17 [17 Sep 2024], 2023.
- [11] Phnom Penh Post: Cambodia updates national accounts base year for enhanced economic accuracy, [Online], Available: <https://www.phnompenhpost.com/business/cambodia-updates-national-accounts->

- base-year-for-enhanced-economic-accuracy [17 Sep 2024], 2024.
- [12] Office of the National Economic and Social Development Council: Thailand's Logistics Report 2023, [Online], Available: <https://www.nesdc.go.th/download/logistics/report/LogisticsReportTH.pdf> [17 Sep 2024], 2023.
- [13] AJZEN, I.: The theory of planned behavior, *Organizational Behavior and Human Decision Processes*, Vol. 50, No. 2, pp. 179-211, 1991. [https://doi.org/10.1016/0749-5978\(91\)90020-T](https://doi.org/10.1016/0749-5978(91)90020-T)
- [14] VANICHKITPISAN, P., TEMIYASATHIT, C.: *Factors influencing attitude toward behavior in using mass transit system in Bangkok: a case study in car users*, 2017 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM), Singapore, 2017, pp. 412-416, 2017. <https://doi.org/10.1109/IEEM.2017.8289923>
- [15] HUNGER, J.D., WHEELEN, T.L.: *Strategic Management*, California, Prentice Hall, 2000.
- [16] THOMPSON, A.A., STRICKLAND, A.J.: *Strategic Management: Concepts and Cases*, New York, NY, USA: McGraw-Hill, 2003.
- [17] HANIFZADEH, F., TALEBI, K., SAJADI, S.M.: The analysis of effect of aspiration to growth of managers for SMEs growth case study, *Journal of Entrepreneurship in Emerging Economies*, Vol. 10, No. 2, pp. 277-301, 2018. <https://doi.org/10.1108/jeee-10-2016-0045>
- [18] İPEK, İ., TANYERI, M.: Home country institutional drivers and performance outcomes of export market orientation: the moderating role of firm resources, *International Journal of Emerging Markets*, Vol. 16, No. 4, pp. 806-836, 2020. <https://doi.org/10.1108/ijoem-10-2019-0803>
- [19] BRUTON, G., KHAVUL, S., SIEGEL, D., WRIGHT, M.: New financial alternatives in seeding entrepreneurship: microfinance, crowdfunding, and peer-to-peer innovations, *Entrepreneurship Theory and Practice*, Vol. 39, No. 1, pp. 9-26, 2015. <https://doi.org/10.1111/etap.12143>
- [20] FORTE, R.P., CARVALHO, S.: Do domestic market characteristics influence firms' export intensity?, *EuroMed Journal of Business*, Vol. 19, No. 2, pp. 398-423, 2022. <https://doi.org/10.1108/emjb-09-2021-0129>
- [21] MAHAKITSIRI, D., SUWANPRASERT, W.: Who are pure exporters?, *The World Economy*, Vol. 46, No. 6, pp. 1759-1781, 2023. <https://doi.org/10.1111/twec.13351>
- [22] GEBRE, W.M., BIRBIRSA, Z.A. ABEGAZ, M.B.: The export performance of textile and apparel industry of Ethiopia: a comparative study with global emerging exporters, *Research Journal of Textile and Apparel*, Vol. ahead-of-print, No. ahead-of-print, pp. 1-16, 2024. <https://doi.org/10.1108/RJTA-11-2023-0123>
- [23] OBADIA, C.: Benefits-based drivers of exporters' attitudinal commitment toward their foreign distributors, *International Marketing Review*, Vol. 27, No. 6, pp. 606-629, 2010. <https://doi.org/10.1108/02651331011088254>
- [24] NES, E.B., SOLBERG, C.A., SILKOSET, R.: The impact of national culture and communication on exporter-distributor relations and on export performance, *International Business Review*, Vol. 16, No. 4, pp. 405-424, 2007. <https://doi.org/10.1016/j.ibusrev.2007.01.008>
- [25] CHU, H.L., DO, N.T., NGUYEN, L., LE, L., HO, Q.A., DANG, K., TA, M.A.: The economic impacts of the European Union's Carbon Border Adjustment Mechanism on developing countries: the case of Vietnam, *Fulbright Review of Economics and Policy*, Vol. 4, No. 1, pp. 1-17, 2024. <https://doi.org/10.1108/frep-03-2024-0011>
- [26] HAINI, H., WEI LOON, P., RAIMI, L.: Does export structure enhance the growth gains from foreign investment? Evidence from the ECOWAS region, *International Journal of Development Issues*, Vol. 23, No. 2, pp. 190-211, 2023. <https://doi.org/10.1108/ijdi-12-2022-0282>
- [27] ROVINELLI, R.J., HAMBLETON, R.K.: On the use of content specialists in the assessment of criterion-referenced test item validity, *Tijdschrift Voor Onderwijs Research*, Vol. 2, pp. 49-60, 1977.
- [28] TAVAKOL, M., DENNICK, R.: Making sense of Cronbach's alpha, *International Journal of Medical Education*, Vol. 2, pp. 53-55, 2011. <https://doi.org/10.5116/ijme.4dfb.8dfd>
- [29] KLINE, R.B.: *Principles and Practice of Structural Equation Modeling*. New York, NY, USA: Guilford Press, 2011.
- [30] GUADAGNOLI, E., VELICER, W.F.: Relation of sample size to the stability of component patterns, *Psychol. Bull.*, Vol. 103, No. 2, pp. 265-275, 1988. <https://doi.org/10.1037/0033-2909.103.2.265>
- [31] HAIR, J.F., BLACK, W.C., BABIN, B.J., ANDERSON R.E.: *Multivariate Data Analysis*, 7th ed., New York, NY, USA, Pearson, 2010.
- [32] BARCLAY, D., HIGGINS, C., THOMPSON, R.: The partial least squares (PLS) approach to causal modeling: Personal computer adoption and use as an illustration, *Technology Studies*, Vol. 2, pp. 285-309, 1995.
- [33] BYRNE, B.M.: *Structural Equation Modeling with AMOS: Basic Concepts, Applications, and Programming*, Mahwah, NJ, USA, Lawrence Erlbaum Associates, 2001.
- [34] HU, L.T., BENTLER, P.M.: *Evaluating model fit*, In: *Structural Equation Modeling: Concepts, Issues, and Application*, R.H. Hoyle, Ed. Thousand Oaks, CA, USA: Sage, 1995, pp. 77-99, 1995.
- [35] CHU, H.L., DO, N.T., NGUYEN, L., LE, L., HO, Q.A., DANG, K., TA, M.A.: The economic impacts

of the European Union's Carbon Border Adjustment Mechanism on developing countries: the case of Vietnam, *Fulbright Review of Economics and Policy*, Vol. 4, No. 1, pp. 1-17, 2024.

<https://doi.org/10.1108/frep-03-2024-0011>

- [36] FAROQUE, A.R., KUIVALAINEN, O., AHMED, J. U., RAHMAN, M., ROY, H., ALI, M.Y., MOSTAFIZ, M.I.: Performance implications of export assistance: the mediating role of export entrepreneurship, *International Marketing Review*, Vol. 38, No. 6, pp. 1370-1399, 2021.

<https://doi.org/10.1108/imr-07-2020-0141>

- [37] NJINYAH, S.Z.: The effectiveness of government policies for export promotion on the export performance of SMEs Cocoa exporters in Cameroon, *International Marketing Review*, Vol. 35, No. 1, pp. 164-185, 2018.

<https://doi.org/10.1108/imr-05-2016-0103>

- [38] THOMPSON, A.A., STRICKLAND, A.J.: *Strategic Management: Concepts and Cases*, New York, NY, USA, McGraw-Hill, 2003.

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Managing risks in the transport of dangerous goods: the role of international regulations

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Keywords: transport, dangerous goods, risk, regulations regarding transport of dangerous goods, risk reduction.

Abstract: The use of applicable international conventions and agreements related to various types of transport helps to ensure safe and efficient movement of passengers and goods, as well as confirmation of transport by providing appropriate, standardized documentation. International conventions and agreements allow for better coordination of flow of people and goods between countries, introduce safety standards but also help to minimize environmental risks. In the context of increasing challenges related to environmental protection and different levels of experience reflected by solutions in this field implemented in different countries, international regulations, applicable in these countries play a key role in shaping responsible and safe flow of goods. It concerns first of all flow of dangerous goods, which, in general can be described as any material posing a threat to human health and life. The objective of the paper is to describe the impact of the use of international conventions and agreements on reducing the risk when transporting different types of dangerous goods. This article primarily focuses on the regulations regarding the treatment of dangerous goods in road, rail and sea transport because these regulations are among the most frequently used. For the practical organization and supervision of the flow of dangerous goods, the groups of risk factors discussed in the article, the comparison of dangerous goods classifications across road, rail, and sea transport conventions, as well as the examples of universal risk-reducing solutions based on regulatory requirements, prove particularly useful.

1 Introduction

The use of applicable international conventions and agreements related to various types of transport helps to ensure safe and efficient transport of passengers and goods, as well as confirmation of such activity by providing appropriate, standardized documentation [1]. International conventions and agreements allow for better coordination when transporting people and goods between countries, introduce safety standards but also help to minimize environmental risks. In the context of increasing challenges related to environmental protection and different levels of experience reflected by solutions in this field implemented in different countries, international regulations, applicable in these countries play a key role in shaping responsible and safe flow of goods. It concerns first of all transport of dangerous goods named also as hazardous cargo, hazardous materials or hazmat [2,3]. In general such type of cargo can be described as any material posing a threat to people and environment due to their toxic ingredients [4,5]. Dangerous goods can cause also damages in property as well as disturbances in the transport system [3]. Such goods are classified first of all based on their toxicity, ecotoxicity and physicochemical properties. It should be emphasized, that despite the risk associated with the transport of dangerous goods, nowadays it is not justified to prohibit such transport [6]. Enhancing safety of transport requires treatment of each type of hazardous goods in a specific manner, taking into account regulations

dedicated for considered kind of transport. Enforcing those rules ensures a higher level of safety for people and natural environment.

The number of road accidents related to transport of dangerous goods is limited. Even though the chance of occurrence of an accident seems to be minimal, the consequences can be much more devastating than of a similar accident not involving hazardous materials. Contemporarily most transportation networks in Europe run through heavily populated areas. In such places an accident involving dangerous goods such as a spill of toxic materials, chemical fire or explosion can affect a large population [7].

Because of significant consequences of any accidents involving dangerous goods, it is critical to identify and analyze all of main possible risks associated with them. This process should lead to establishing appropriate ways of handling such goods or incidents involving them. The main purpose of the article is to present the impact of international conventions on reducing the risk of treating dangerous goods in road, rail, and maritime transport. Basic risk factors related to treatment of dangerous goods and examples of universal types of actions taken to reduce this risk are presented in the article. International conventions governing road, rail, and maritime transport are considered, as these modes are among the most commonly used for organizing, supervising and documenting the flow of dangerous goods. There are

several chapters distinguished in the article, related to presentation of methods used, assumptions of research, results of research and conclusions.

2 Literature review

When considering the essence of risk in this article it is assumed, that risk of an event is often described as a combination of three processes [8]:

- the probability of the occurrence of the event,
- the noxiousness or severity of the event,
- the efficacy of a recommended coping response.

It also seems reasonable to take into account the approach to description of risk, according to which it can be understood also as the relationship between frequency and the number of people suffering from a specified level of harm in a given population from the realization of specified hazards [9].

Using the aforementioned ways of approaching risk it should be stated that transport of dangerous goods is subject to a high level of risk not because of how often accidents might occur but because of the high severity [10] and possibly low efficacy of emergency response.

The key risk factors of dangerous goods transport can be grouped into five main categories [7,11,12]:

- human errors,
- technical,
- environmental,
- planning,
- security.

According to European Community's data regarding road transportation of dangerous goods almost half of the accidents are caused by human error or at least by error appearing, due to human factor being a major contributor. This would place it as the lead cause of accidents involving transport of dangerous materials. Most flows of hazardous goods are exposed to transportation networks crossing populated areas with heavy road traffic or with other crowded routes and places when transporting such cargo in different ways. The technical state of vehicles, containers and packaging meant to transport dangerous goods has significant influence on risk. The type of risk considered may increase significantly in intermodal transport conditions [13]. Appropriate maintenance and adherence to regulations can drastically limit the risk of spillage, fire or other incidents including hazardous materials. Environmental conditions can also strongly increase the risk associated with transport of dangerous goods. Adverse conditions or other unexpected events can not only damage the means of transport but also the transported cargo which may lead to a dangerous incident. Proper planning is essential in keeping the risk of transporting dangerous goods to a minimum, starting from proper documentation of materials transported and communicating with appropriate authorities to route and emergency response planning [14]. Thorough preparation decisively reduces risk during transport. Properly organized security measures play a crucial role in ensuring safety of cargo. Deterring potential threats and unauthorized access. It prevents sabotage, tempering or theft of dangerous materials or means of transport. Table 1 includes the list of general and specific risk factors of hazardous materials transport representing groups described so far.

Table 1 Dangerous goods transport risk factors

General group of risk factors	Specific risk factors
Human error/lack of training	insufficient education related to treatment of dangerous goods, lack of experience related to dangerous goods, old age, bad physical condition of personnel handling dangerous goods, stress and exhaustion, personnel not complying with the rules/regulations, accident due to the fault of another road user, excessive speed of vehicle with hazardous materials, miscommunication.
Technical/mechanical	breakdown of vehicle carrying hazardous materials, bad technical condition of infrastructure, insufficient vehicle maintenance, old vehicle age, bad technical condition of the vehicle, bad technical condition of the container or packaging, improper load securing prior to transport, improper maintenance of emergency equipment, improper technical qualification and calibration of equipment.
Environmental	high or low external temperature, bad road conditions, high traffic density, high humidity, high population density, exposure of cargo to excessive heat, exposure of cargo to sunlight for too long, occurrence of fires along the vehicle route, occurrence of flooding along the vehicle route, passage of a vehicle through a territory subject to war, terrorist attack on a vehicle carrying dangerous goods, external fire, external explosion, high winds.
Planning	inadequate safety equipment on the vehicle, incomplete dangerous goods transport documentation, emergency plan, safety and quality rating system, lack of emergency equipment, quantity of dangerous materials transported.
Security	theft of a means of transport with hazardous materials, improper vehicle placement, sabotage, fraud and the release of cargo to an unauthorized person.

Source: own research based on: [11,12,15,16].

Transport of dangerous goods introduces inherent risks, encompassing various factors. Appropriate planning and adherence to safety regulations are critical components in mitigating these risks.

Transport of dangerous goods is a specific type of transport, that requires the involvement of specialized material resources and application of strict procedures [11,17]. These procedures and resources are established by international regulations, known as transport guidelines. The provisions were created with the primary purpose of eliminating or reducing risks associated with the transport of hazardous materials by reducing the likelihood of an accident occurring and the extent of damage. The regulations should not result in transport bans. Such activity must meet many legal requirements and restrictions. Guidelines for international transport by road (ADR – *The Agreement concerning the International Carriage of Dangerous Goods by Road*), by rail (RID – *Agreement Concerning the International Carriage of Dangerous Goods by Rail*), by inland waterways (AND – by sea (IMDG – *The International Maritime Dangerous Goods Code*) and by air (DGR – *Dangerous Goods Regulations of IATA – International Air Transport Association*) all have common origins thus all of them have similar purpose and scope [18,19].

ADR is an international agreement under the auspices of the United Nations Economic Commission for Europe. According to it apart from some excessively dangerous goods, other dangerous goods may be carried internationally by road in compliance with packaging and labeling guidelines, as well as with regulations regarding the construction, equipment and operations of the vehicle carrying goods in question [20].

RID is a proposal of regulation with the aim to ensure safety, prevent accidents, damages to persons, property and the environment during transport of hazardous materials by rail. RID is a part of the COTIF convention concerning international carriage by rail [21].

Similarly to RID, IMDG is a part of SOLAS convention concerning safety of life at sea. IMDG was developed like ADR and RID to enhance and harmonize the safe carriage of dangerous goods in packaged form and to prevent pollution of the environment [22]. All the guidelines mentioned serve similar purpose in corresponding transport sectors. While ADR and RID are mainly European regulations, IMDG is used worldwide.

3 Methodology

When preparing this article two main methods were applied: desk research and literature study. Desk research was used for collection as well as analysis of existing data and information reflecting current situation and existing problems related to:

- accidents when transporting dangerous goods,
- status of applicable international agreements and conventions concerning the handling of dangerous goods in transport,

- range of countries, that take into account individual, international agreements and conventions,
- results of application of agreements and conventions in terms of reducing incidents related to the impact of the transport of goods on the natural environment and people,
- experience of carriers related to the application of applicable regulations arising from individual conventions.

Taking into consideration literature study as the second method used for preparation of this article it is important to highlight main issues studied:

- the approaches helpful to describe risk when transporting specific types of goods,
- types of main risk factors influencing transport of dangerous goods,
- results of research in the area of preparation, implementation of actions to reduce risk, and results of risk reduction when transporting hazardous goods.

The applied research approach enabled the presentation of solutions prepared in the area of reducing the risk of transporting dangerous goods in road transport based on the implemented regulations of international conventions related to the treatment of dangerous goods in such type of transport.

4 Results and discussion: examples of regulations in international agreements that influence risk reduction when transporting dangerous goods

ADR, RID and IMDG regulations define dangerous goods as substances and articles the carriage of which is prohibited by specific regulations or authorized only under the conditions prescribed therein [18,19]. Additionally, such types of goods can be described by potentially dangerous reactions involving them, such as [20]:

- combustion or evolution of considerable heat,
- evolution of flammable, asphyxiant, oxidizing or toxic gases,
- formation of corrosive substances,
- formation of unstable substances,
- dangerous rise in pressure (in case of storage in tanks).

Classification of dangerous goods is crucial in implementing procedures for safe national and international transport of those articles. For this reason, ADR, RID and IMDG implement classifications of their own. In Table 2 hazard classes described in ADR and RID as well as IMDG regulations are included.

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Table 2 Classification of dangerous goods in ADR, RID and IMDG Code

Class number	ADR/RID	IMDG Code
Class 1.	Explosive substances and articles	Explosives
Class 2.	Gases	Gases
Class 3.	Flammable liquids	Flammable liquids
Class 4.		Flammable solids; substances liable to spontaneous combustion; substances which, in contact with water, emit flammable gases
Class 4.1.	Flammable solids, self-reactive substances, polymerizing substances and solid desensitized explosives	
Class 4.2.	Substances liable to spontaneous combustion	
Class 4.3.	Substances which, in contact with water, emit flammable gases	
Class 5.		Oxidizing substances and organic peroxides
Class 5.1.	Oxidizing substances	
Class 5.2.	Organic peroxides	
Class 6.		Toxic and infectious substances
Class 6.1.	Toxic substances	
Class 6.2.	Infectious substances	
Class 7.	Radioactive material	Radioactive material
Class 8.	Corrosive substances	Corrosive substances
Class 9.	Miscellaneous dangerous substances and articles	Miscellaneous dangerous substances and articles

Source: own research based on: [20-22].

As presented in Table 2, ADR and RID both implement the same classification whereas the IMDG Code differs. While the difference is visible it's worth noting that the categorization includes the same substances but grouped in wider classes. Therefore, it is necessary to use different typology for individual classes according to ADR, RID and IMDG.

Additionally, to the class system, all three conventions implement "Packing groups" which are described as groups to which, for packing purposes, certain substances may be assigned in accordance with the degree of danger they present [20-22]:

- Packing group I: substances presenting high danger,
- Packing group II: substances presenting medium danger,
- Packing group III: substances presenting low danger.

Hazard classes and packing groups allow for procedures in place regarding certain groups of substances. This combined with the possibility of quicker identification of goods, decreases the chance for any incident and in case of one allow for rapid and proper emergency response. Methods like these effectively decrease the risks of hazardous goods transport.

All of the aforementioned conventions introduce many regulations to achieve their goals of increasing the safety

of transport. Through presenting and describing some of them the way those regulations influence risk levels in dangerous goods transport is shown.

Regulations introduced by ADR, RID and IMDG conventions are for example [20-22] marking and labeling vehicles and containers based on the hazard class of the goods transported, equipping vehicles with hazard markings identifying dangers posed by transported goods as well as what substance is transported, creating and sharing documentation containing all necessary information about transport, construction and maintenance of the vehicle corresponding to the type of goods transported, staff training regarding adequate ways of handling dangerous goods, maintaining a high level of security to avoid tempering with the goods.

One of practices easily noticed every day is marking and labeling vehicles and containers transporting or storing dangerous goods. Labels and placards inform about the kind of danger appropriate to the goods transported. Labels are placed on small packages like boxes, barrels or small tanks, whereas placards identify vehicles or large containers. Both of them are diamond shaped, usually brightly colored, include a pictogram and written description of the hazard class as well as it's number.

Additionally, vehicles carrying dangerous materials should be equipped with type of hazard marking identifying materials that are being transported. The top

number indicates the primary and secondary hazards posed by the carried substance. In the bottom the UN identification number is displayed which identifies the material transported. All of those marking technics allow for universal ways to identify the substance and any hazards posed by it.

Marking containers, tanks, and vehicles carrying dangerous goods raises awareness among those who come into direct contact with the transport, as well as people in its vicinity. Most importantly, such markings inform other users of roads, railways, and shipping routes about the hazards associated with the transported goods. Greater attention of people nearby makes them more cautious and decreases the risk of an accident occurring.

While vehicle and container markings help to inform people present on site, preparation of appropriate documentation is important to keep every party of the transport process informed. These documents should include information about the nature of the goods transported, emergency procedures, the materials, the shipper and any necessary certificates.

Besides appropriate markings, vehicles transporting dangerous goods are required to be in a proper technical state. Firstly, specific construction of vehicles ensures their suitability for carrying dangerous goods. That includes fitting appropriate containers such as tanks and adequate emergency equipment. Additionally, vehicles should be fitted with lighting and reflective surfaces to increase visibility in low light conditions, systems of securing transported materials and security measures to prevent unauthorized access. Finally, to ensure safety, regular inspections of equipment and maintenance allow for keeping safety levels of transport relatively high.

Awareness of the personnel handling and transporting goods is also very important. To achieve this the staff has to be trained in a couple of major areas of interest. General training allows for understanding of general risks associated with dangerous goods. It includes an overview of hazard classes, labeling etc. Additionally specific training allows for comprehension of classes of materials that might be handled more often. Emergency response, load securing and security awareness training increases the overall awareness of drivers and other workers, which reduces the risks of human error during handling dangerous materials.

To prevent any cases of tempering, sabotage or theft, it is important to put a security system in place. It should include elements like access restrictions to prevent unauthorized personnel from tempering vehicles or cargo, employees identification to ensure the staff is properly trained to handle dangerous goods, monitoring and tracking cargo, containers and vehicles in real time allows for additional security and quick emergency response. Additionally appropriate sealing and locking of vehicles as well as containers ensures safety of cargo and communication protocols allow for easy communication within the organization and with the authorities. Lastly, transport guidelines enable quick and adequate emergency

response in case of an accident involving dangerous goods. Both from the personnel on site as well as the authorities and emergency services [20-22].

5 Conclusions

ADR, RID and IMDG conventions have a long-standing history. These have been developed based on extensive experience gained from various types of accidents involving dangerous goods. Considered conventions include wide range of aspects and provide a comprehensive framework for regulation of conditions that must be met in organizing and carrying out transport of dangerous goods. However, while these conventions have evolved to address emerging risks and challenges, some areas could still be improved to better serve the overall purpose.

It is important to add that the article does not take into account in detail the regulations and risks related to dangerous goods in air transport. Such issues have to be considered separately. Air transport of dangerous goods is governed first of all by the International Air Transport Association (IATA) Dangerous Goods Regulations, but also by the International Civil Aviation Organization (ICAO) Technical Instructions. These regulations address the specific risks associated not only with types of loads, but also with the high speeds, altitude, and pressurized conditions of air travel. Therefore, the range and types of dangerous goods that can be transported by air are significantly limited compared to road, rail and sea transport.

Enhancing harmonization and consistency between ADR, RID and IMDG conventions as well as regulations for air transport, would make cross-border transport smoother and reduce complexity for stakeholders. Essentially making the whole process less complex without lowering safety standards.

It is important to continue the process of updating the conventions to address emerging risks posed by new technologies, evolving supply chain dynamics and changing environmental conditions. For example, new dangerous goods will either start being transported or be transported at a higher scale. Additionally, issues connected to cybersecurity must be addressed in the future.

Apart from introducing new regulations, enhancing the capacity for training initiatives and programs for all stakeholders would improve awareness and competencies. This requires providing more resources for education and information exchange. Exchanging experiences internationally among countries, regulatory bodies, industry stakeholders and emergency responders would strengthen the effectiveness of the conventions.

New technologies are not only a threat but also, if used and developed properly, can increase the security levels of dangerous goods transport. Implementing Industry 4.0 solutions, has the potential to decrease risk levels in transport.

Given the preliminary nature of this article, after presenting the individual conventions, the attention is

focused on exemplary practical aspects of the actions taken based on the regulations. This approach aims to address the practical features of such conventions. It intends to showcase the real-world applications and impact on safety that these regulations have.

References

- [1] INGVARSON, J.: Effects of standardization in risk management regulations for land-use planning related to process industries and transportation of dangerous goods, *Journal of Loss Prevention in the Process Industries*, Vol. 91, 105383, pp. 1-12, 2024. <https://doi.org/10.1016/j.jlp.2024.105383>
- [2] TORRETTA, V., RADA, E.C., SCHIAVON, M., VIOTTI, P.: Decision support systems for assessing risks involved in transporting hazardous materials: A review, *Safety Science*, Vol. 92, pp. 1-9, 2017. <http://dx.doi.org/10.1016/j.ssci.2016.09.008>
- [3] FLODÉN, J., WOXENIUS J.: A stakeholder analysis of actors and networks for land transport of dangerous goods, *Research in Transportation Business & Management*, Vol. 41, pp. 1-12, 2021. <https://doi.org/10.1016/j.rtbm.2021.100629>
- [4] VERMA, M., VERTER, V.: Railroad transportation of dangerous goods: Population exposure to airborne toxins, *Computers & Operations Research*, Vol. 34, No. 5, pp. 1287-1303, 2007. <https://doi.org/10.1016/j.cor.2005.06.013>
- [5] KANJ, H., KULAGLIC, A., HOSNY FOUAD ALY, W., AL-TARAWNEH, M.A.B., SAFI, K., KANJ, S., FLAUS, J.M.: Agent-based risk analysis model for road transportation of dangerous goods, *Results in Engineering*, Vol. 25, 103944, pp. 1-11, 2025. <https://doi.org/10.1016/j.rineng.2025.103944>
- [6] LUNDIN, J., ANTONSSON, L.: Road tunnel restrictions – Guidance and methods for categorizing road tunnels according to dangerous goods regulations (ADR), *Safety Science*, Vol. 116, pp. 170-182, 2019. <https://doi.org/10.1016/j.ssci.2019.03.004>
- [7] RUSSO, F., RINDONE C.: Transport of dangerous goods in urban area: planning for sustainable future, *Sustainable Futures*, Vol. 5, pp. 1-11, 2025. <https://doi.org/10.1016/j.sfr.2025.100649>
- [8] MADDUX, J. E., ROGERS, R. W.: Protection motivation and self-efficacy: A revised theory of fear appeals and attitude change. *Journal of Experimental Social Psychology*, Vol. 19, No. 5, pp. 469-479, 1983. [https://doi.org/10.1016/0022-1031\(83\)90023-9...](https://doi.org/10.1016/0022-1031(83)90023-9...)
- [9] VRIJLING, J.K., VAN HENGEL, W., HOUBEN, R.J.: A framework for risk evaluation, *Journal of Hazardous Materials*, Vol. 43, No. 3, pp. 245-261, 1995. [https://doi.org/10.1016/0304-3894\(95\)91197-V](https://doi.org/10.1016/0304-3894(95)91197-V)
- [10] CHAI, H., DONG, K., LIANG, Y., HAN, Z., HE, R.: Machine learning-based accidents analysis and risk early warning of hazardous materials transportation, *Journal of Loss Prevention in the Process Industries*, Vol. 95, No. June, 105594, 2025. <https://doi.org/10.1016/j.jlp.2025.105594>
- [11] FIKUS, J., PRZYBYLSKA, E.: Risk assessment for the transport of class 1 hazardous materials by road, *Organization and Management: Scientific Quarterly*, Vol. 4, No. 56, pp. 5-19, 2021. <https://doi.org/10.29119/1899-6116.2021.56.1>
- [12] OGGERO, A., DARBRA, R., MUNOZ, M., PLANAS, E., CASAL, J.: A survey of accidents occurring during the transport of hazardous substances by road and rail, *Journal of Hazardous Materials*, Vol. 133, No. 1-3, pp. 1-7, 2006. <https://doi.org/10.1016/j.jhazmat.2005.05.053>
- [13] BHAVSAR, N., HASSINI, E., VERMA, M.: Rail-Truck intermodal transportation for dangerous goods, *Transportation Research Procedia*, Vol. 82, pp. 2766-2778, 2025. <https://doi.org/10.1016/j.trpro.2024.12.218>
- [14] PEKARČÍKOVÁ, M., KLIMENT, M., KRONOVÁ, J., TREBUŇA, P., HOVANA, A.: Simulation-Based Optimization of Material Supply in Automotive Production Using RTLS Data, *Applied Sciences*, Vol. 15, No. 16, pp. 1-18, 9102, 2025. <https://doi.org/10.3390/app15169102>
- [15] GUO, J., MA, K., REN, H.: Topological analysis of risks in hazardous materials transportation systems using fitness landscape theory and association rules mining, *Reliability Engineering and System Safety*, Vol. 264, Part B, No. December, 111396, 2025. <https://doi.org/10.1016/j.res.2025.111396>
- [16] WANG, A., ZHU, G., LI, J.: Collaborative supervision of dangerous goods supply chain: A blockchain-based conceptual platform, *Computers & Industrial Engineering*, Vol. 200, No. February, 110818, 2025. <https://doi.org/10.1016/j.cie.2024.110818>
- [17] IZDEBSKI, M., JACYNA-GOŁDA, I., GOŁDA, P.: Minimisation of the probability of serious road accidents in the transport of dangerous goods, *Reliability Engineering and System Safety*, Vol. 217, 108093, pp. 1-14, 2022. <https://doi.org/10.1016/j.res.2021.108093>
- [18] CONCA, A., RIDELLA, C., SAPORI, E.: A risk assessment for road transportation of dangerous goods: a routing solution, *Transportation Research Procedia*, Vol. 14, pp. 2890-2899, 2016. <https://doi.org/10.1016/j.trpro.2016.05.407>
- [19] BUDNY, A., ROKICKI, T.: Road transport of dangerous goods in Poland, *Ekonomika i Organizacja Logistyki*, Vol. 6, No. 3, pp. 13-21, 2021. <https://doi.org/10.22630/EIOL.2021.6.3.18>
- [20] Agreement Concerning the International Carriage of Dangerous Goods by Road: Vol 1, United Nations, 2022.
- [21] Convention concerning International Carriage by Rail (COTIF) Appendix C – Regulations concerning the International Carriage of Dangerous Goods by Rail (RID), Intergovernmental Organisation for International Carriage by Rail, 2023.

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- [22] The International Maritime Dangerous Goods (IMDG) Code, [Online], Available: <https://www.imo.org/en/OurWork/Safety/Pages/DangerousGoods-default.aspx>, [3 Jan 2025], 2024.

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Enhancing cybersecurity readiness in express logistics: the role of cyber-attack features and project team skills

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Keywords: logistics cybersecurity, express delivery services, cybersecurity readiness, cyber-attack features, project team skills.

Abstract: The increasing frequency and complexity of cyberattacks pose a significant threat to the express logistics sector, where digital coordination and data integrity are essential for operational continuity. This study examines how specific cyber-attack features influence team-based cybersecurity readiness, focusing on the mediating role of project team skills. The research addresses a practical problem faced by logistics firms in Jordan, many lacking standardized cybersecurity protocols despite rising digital adoption. Using a quantitative, cross-sectional design, data were collected from 310 employees in express delivery service companies. Structural equation modeling (SEM) via SmartPLS was employed to test the proposed relationships. The results demonstrate that cyber-attack features significantly affect cybersecurity readiness, both directly and through the partial mediation of project team skills. Teams with stronger technical and collaborative capabilities were more effective in translating threat exposure into organizational preparedness. The model accounted for 69% of the variance in cybersecurity readiness. This study contributes a novel integration of technical threat dimensions and human-centered readiness within logistics operations. It offers actionable insights for logistics managers aiming to strengthen cyber resilience through targeted skill development and team-based interventions.

1 Introduction

The logistics sector has undergone a major shift by adopting digital tools like real-time tracking, smart devices, cloud services, and connected communication platforms to boost efficiency and responsiveness [1-3]. Within this changing environment, express delivery services rely heavily on these digital systems to handle fast and time-sensitive deliveries across wide and often complex areas [4,5]. While these technologies improve speed and visibility, they also create more opportunities for cyberattacks, increasing the risk of digital threats [6,7].

As logistics systems become more connected—linking with external delivery partners, online retailers, and global networks—the risks related to cybersecurity also grow in scale and complexity [8-10]. Many logistics companies, particularly in less developed regions, struggle with old systems, inconsistent security measures, and limited spending on protective tools. These gaps make them easy targets for attacks like ransomware, phishing, service disruptions, and data theft [11,12]. Cybercriminals take advantage of the sector's need for fast responses and heavy reliance on digital connections, knowing that even brief service interruptions can cause widespread problems across supply chains [5,6].

Because of this, cybersecurity preparedness has become a key concern, especially for express delivery services that depend on real-time operations and consistent performance [1-4]. Being prepared goes beyond having the right technology; it also means ensuring teams are trained

to recognize threats, respond effectively, and recover quickly [7,8]. Without proper readiness, companies risk financial losses, damage to their reputation, and legal consequences. Therefore, cybersecurity should be treated as an organizational priority, not just a technical task [9,11].

The express delivery sector in Jordan has seen rapid growth, fueled by rising online shopping, urban development, and national plans like Jordan Vision 2025, which support logistics improvements [13-15]. Mobile apps and smart delivery platforms have reshaped how services operate, particularly in cities such as Amman [14,16]. These systems played a vital role during the COVID-19 lockdowns by keeping deliveries running despite movement restrictions [14,17].

Today, delivery firms in Jordan depend on digital tools like GPS tracking, automated dispatching, and centralized data systems to handle operations and customer service [17-20]. However, many small and mid-sized companies face security challenges due to outdated technology, poor cybersecurity management, and a lack of readiness [18,20,21]. Often, they do not have dedicated security staff or formal response plans, leaving general IT workers to handle threats they may not be trained for [19,22]. These issues are made worse by inconsistent risk planning and minimal investment in staff training, especially for project teams that operate without clear cybersecurity guidelines [16,20].

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Cyberattacks come with specific patterns and traits—such as their type, how often they happen, how complex they are, and whether they're new or evolving—that affect how a company can respond and recover [23,24]. Knowing these features helps classify threats and understand their potential impact on operations [23,27]. For example, phishing targets human mistakes, ransomware blocks access to data, and denial-of-service attacks make services unavailable [28-30]. When attacks are frequent, complicated, or unexpected, traditional security tools often fail—especially in industries that rely on fast, continuous operations [31-36].

Team-based cybersecurity readiness refers to how well a company's staff—across IT, security, and risk roles—can prepare for, handle, and bounce back from cyber threats [38,39]. This readiness includes access to tools and soft skills like staying aware, making decisions under pressure, and working together in real time [38,42]. Without strong teamwork and clear communication, even advanced technology can fall short during an incident [43-47]. Therefore, it's important to assess readiness through technical systems, team behavior, and organizational culture [40,38].

The skills of project teams—including technical expertise, flexibility, coordination, and problem-solving—play a major role in responding to cyber threats effectively [43,51]. In fast-moving delivery environments, these teams are often the first to deal with an incident [41,52]. Quick, skilled responses are crucial to controlling threats and getting services back on track [48,53]. Technically capable teams can spot weak points and apply the right fixes, while clear communication helps ensure that all efforts are aligned during a crisis [44,47,54]. Adaptability is also key, as it allows teams to adjust quickly in unpredictable situations—a critical strength in high-risk operations [55,56].

Even though interest in cybersecurity is growing, most research still focuses on technical solutions and legal rules, with little attention to the teams' skills [57]. Some studies have looked at individual training or practice exercises, but few explore how the real-world skills of project teams affect security outcomes [58,59]. Often, teams are seen only as parts of the organization, which hides their specific contributions [40,57]. This lack of focus is especially noticeable in the Middle East, where detailed research on cybersecurity in logistics is still limited [19,60]. While the growth of logistics in Jordan has been studied, there's little data on how delivery teams handle cyber threats [14,20,22]. Without this knowledge, it's hard to design effective and tailored strategies [17,22].

To close this gap in understanding, the present study looks at how the skills of project teams influence the relationship between the nature of cyberattacks and overall cybersecurity readiness in Jordan's express delivery sector [61,62]. It adds to academic knowledge by connecting the traits of cyber threats with the abilities of teams, offering a more people-focused view of logistics cybersecurity. The study specifically examines how often attacks occur, how

complex or new they are, and how team skills shape the company's ability to respond.

The rest of this paper is organized as follows: Section 2 reviews the existing literature on cyber-attack characteristics, team skills, and cybersecurity preparedness. Section 3 outlines the research method, including how the survey was designed and the data were analyzed. Section 4 presents the study's findings. Section 5 discusses the broader theoretical and practical implications. Finally, Section 6 offers conclusions and suggests areas for future research.

2 Literature review

2.1 Cyber-attack features in logistics

Cyberattacks on logistics operations, especially in express delivery service companies (EDSCs), have become more common as the industry becomes increasingly dependent on digital systems and connected technologies. These attacks often take advantage of technical flaws and human mistakes, leading to serious problems such as financial losses, service interruptions, and damage to a company's reputation [63-65]. A major entry point for these attacks is software and IT infrastructure weaknesses, including poor application design, insecure settings, and gaps in Internet of Things (IoT) devices often used in logistics platforms [63-65]. In express delivery companies, these weaknesses frequently affect critical systems like tracking tools, logistics applications, and online data storage platforms, making them prime targets for hacking and service breakdowns [63-65].

Although experts recommend strategies like regular system updates, safe programming methods, and secure software development cycles [69-71], studies show that many logistics companies—particularly small and medium-sized enterprises (SMEs)—struggle to apply these measures consistently [66-68]. SMEs usually lack the funding or expertise to establish strong cybersecurity systems. In contrast to larger organizations that implement complete cybersecurity plans and perform regular testing, SMEs often depend on general IT support and basic security tools, which leaves many gaps open for exploitation [66-68]. This reflects a significant divide between what the literature recommends and what is realistically implemented in day-to-day logistics operations.

Human mistakes are another major source of cybersecurity issues and remain a persistent problem across various sectors [72-74]. In logistics, errors such as incorrect data handling, falling for phishing scams, and misusing systems can compromise security and privacy [72-74]. The high-pressure work environment and frequent staff turnover in express delivery services make it even harder to maintain consistent cybersecurity practices [75-77]. While training and awareness programs are widely encouraged [78-80], research suggests that these efforts often fail to have a long-term impact unless they are supported by regular monitoring and a strong organizational focus on cybersecurity behavior [78-80].

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Another common risk is poor authentication habits, like weak or repeated passwords. These practices can make it easier for attackers to gain unauthorized access to systems used for delivery tracking, customer interactions, and payment processing [81-83]. The problem becomes more serious in cloud-based platforms, where poor identity and access controls can expose larger parts of a company's digital infrastructure to attack [84-86]. Although tools like multi-factor authentication (MFA), password managers, and real-time access monitoring are strongly recommended [87-89], many logistics companies—especially those in developing regions like Jordan—struggle to apply these protections due to limited budgets or technical know-how [66-68].

Insider threats—whether intentional or accidental—also pose serious dangers within logistics companies [90-92]. Employees, contractors, or outside service providers with access to sensitive systems can either make errors that compromise security or intentionally misuse their access without being detected by typical security measures [90-92]. To counter these risks, companies need to use a combination of tools like activity monitoring, user behavior analysis, and strict access control policies [93-95]. Although research on detecting insider threats is growing, practical applications in the logistics sector are still rare and not well-documented [93-95].

The cybersecurity risks faced by Jordanian express delivery firms show why it's important to have comprehensive protection strategies that address technical systems, human factors, and access control weaknesses. Even though general guidelines are widely known [63-95], few studies examine how these recommendations are implemented in logistics environments. This lack of research is especially noticeable in the Middle East, where region-specific data is limited. As cyber threats continue to evolve, focused research—especially studies on how teams respond in real situations—is vital for creating effective cybersecurity strategies that improve protection and resilience in logistics [66-68,84-86].

2.2 Team-based cybersecurity readiness

Team-based cybersecurity readiness refers to how well technical and operational teams can work together to prevent and respond to cyber threats quickly and efficiently [43,51]. In express delivery companies, where services depend on fast digital systems and timely operations, having this kind of team coordination is especially important. As cyberattacks become more complex, teams from different departments must maintain a unified and prepared approach to protect the organization [41,55].

This type of readiness involves six connected areas forming a strong defense system. The first is prevention capability, which reflects how effectively a team can identify and reduce threats before they cause harm. This includes hardening systems, ensuring secure configurations, applying updates, and running regular security checks [41,45]. In logistics, these efforts should focus on systems like fleet tracking, order processing, and

customer service tools [52]. Teams that follow guidelines such as the NIST Cybersecurity Framework tend to be more resilient [43,51]. However, studies show that while many know these frameworks, small and mid-sized project teams often fail to apply them consistently [41,51].

The second aspect is threat detection readiness, which measures how well teams can monitor systems for unusual activity before a problem escalates. This includes using tools like intrusion detection systems (IDS), event monitoring platforms (SIEM), and analyzing system logs [44,47]. In fast-paced logistics settings, spotting issues early is essential to avoid major disruptions [48]. Regular training and practice scenarios improve this skill, but evidence shows that many logistics teams either don't fully use these tools or struggle with them due to limited skills or system complexity [44,47].

Incident response coordination is the third key area, focusing on how quickly and effectively a team can react during a cyber incident. This involves assigning roles, stopping threats, and analyzing what happened [39,50]. In express delivery services, where delays can affect large networks, well-prepared teams communicate clearly and follow detailed response plans [38,40]. Despite having such plans, many teams don't practice them regularly, which leads to slower and less effective responses when real incidents occur [39,50].

The fourth area, recovery and continuity readiness, relates to how well a team can restore systems and resume normal operations after an attack. This includes executing disaster recovery plans (DRPs), using business continuity procedures (BCPs), and checking data for accuracy [41]. In logistics, delays in restoring key systems can affect deliveries and customer services [39]. While many studies support using DRPs and BCPs, little research shows how well they work in real-world logistics situations, especially in regions like the Middle East [39,41].

Role alignment and task ownership, the fifth component, deals with clearly assigning responsibilities so that every team member knows their duties during a cyber incident. Studies show that when tasks match each person's skills, the team becomes more efficient and accountable [51,55]. Using role charts or skill maps helps with this, but such practices are not consistently applied in logistics project teams [38]. When roles are unclear, teams may duplicate efforts, skip steps, or make slow decisions during a crisis [51,55].

The final area, crisis communication effectiveness, focuses on how well a team shares important information during a cyberattack. Internally, this helps coordinate actions, while externally it helps maintain trust with customers and partners. Both are crucial in express delivery settings where timing is everything [40,45]. However, many logistics teams lack structured communication plans or pre-prepared messages, leading to confusion and mixed messaging when issues occur [38].

In summary, team-based cybersecurity readiness in the logistics sector depends on a combination of technical, organizational, and interpersonal skills. The six main

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areas—prevention, detection, response, recovery, clear role assignments, and effective communication—build a team's ability to manage cyber threats. Still, there is a clear need for more real-world research on how these elements work together in logistics, especially in fast-moving environments like Jordan's express delivery industry [41,51]. Future studies should explore how project teams can better integrate these areas to build more practical and effective cybersecurity systems.

2.3 Project team skills

Project teams rely on various skills, including technical ability, clear communication, adaptability, leadership, and effective problem-solving. These skills are especially important in fast-moving and complex environments such as logistics and cybersecurity, where teamwork across departments is essential [96,97]. In express delivery companies that depend heavily on digital tools and tight schedules, a team's capabilities directly affect how well cybersecurity measures are applied, improved, and sustained. When teams combine their skills effectively, they can solve problems quickly, work efficiently under pressure, and maintain high performance even in uncertain situations.

Technical knowledge is a key part of this skill set. Team members must understand topics like computer networks, software systems, data security, and managing cyber risks [98]. In logistics, this means ensuring that tools like routing systems, tracking platforms, and cloud-based databases are secure and work smoothly with operational needs [97]. However, since teams often include logistics professionals and IT experts, differences in technical understanding can make collaboration difficult. To address this, companies should support ongoing training, mentoring, and knowledge-sharing tools that help align everyone's expertise [96].

Strong communication and teamwork are also crucial. These abilities help build trust, promote transparency, and support coordination among team members, especially in logistics companies that operate across different locations and cultures [99,100]. To keep communication clear, teams benefit from using shared digital tools, clear communication protocols, and inclusive practices that support open dialogue [101, 102]. Good communication also ensures that logistics and cybersecurity knowledge are integrated effectively [102].

The ability to think critically and solve problems helps teams respond quickly when issues arise. Project-based learning environments have developed these abilities effectively, helping team members apply what they've learned to real situations [103]. These skills are essential in cybersecurity because threats can appear unexpectedly, requiring fast thinking and quick decisions [104,105]. Teams trained to assess situations under pressure are more capable of preventing problems from escalating.

Time management and sound decision-making are also important, especially in time-sensitive logistics projects. Tools like Gantt charts and time-blocking strategies help

teams stay on track and balance cybersecurity tasks with business goals [106,107]. While including diverse viewpoints in decisions can improve judgment, avoiding delays or groupthink is important. In cybersecurity, timely and informed decisions can significantly affect how effectively threats are handled.

Adaptability is another vital skill. Techniques from agile project management—like working in short cycles and holding daily check-ins—help teams adjust their plans as new issues arise [108,109]. In logistics, where conditions often change quickly, adapting is essential. Simulations and training based on different scenarios can help prepare teams to face new cyber threats.

Creative thinking is also becoming more important in cybersecurity work. Finding new solutions—like customized firewalls or unique team-based response plans—depends on a workplace culture that supports experimentation and learning from mistakes [110,111]. Brainstorming sessions, hackathons, and innovation workshops allow teams to test and improve new ideas [112]. Still, such practices are not common in logistics, so companies need to focus more on encouraging innovation in their cybersecurity efforts.

Leadership plays a key role in bringing all these skills together. Effective leaders offer clear direction, boost team morale, and make sure everyone is accountable during stressful or complex situations [113-115]. Good leaders also set a strong example, promote ethical behavior, and encourage a focus on security across all levels of a project. However, many team leaders lack specific training in cybersecurity, which limits their ability to guide teams effectively during a crisis. Conflict resolution is important for keeping the team united and focused alongside leadership. Disputes are likely in high-pressure settings, and handling them constructively requires emotional intelligence, defined roles, and open communication [116,117].

Ongoing learning and professional development help maintain team readiness over time. Opportunities such as certifications, online courses, workshops, and peer learning keep skills current and responsive to new threats [118,119]. When organizations support learning through dedicated time, mentorship programs, and formal training systems, teams are better equipped to keep their skills from becoming outdated [120].

In conclusion, project team skills form the backbone of organizational strength in logistics cybersecurity. Combining technical know-how, leadership, adaptability, and effective teamwork enables teams to respond quickly and work together during cybersecurity incidents. However, many logistics companies fail to fully invest in these skills or support structured training, revealing a gap between what is known to be important and what is practiced in the field.

2.4 Theoretical framework

To understand how cyber-attack characteristics influence team-based cybersecurity readiness—and how

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team skills play a role in that relationship—this study uses a blend of theories from cybersecurity, supply chain operations, and organizational behavior. This mixed approach is well-suited to Jordan's express delivery sector, where the rapid shift to digital operations has improved efficiency and increased vulnerability to cyber risks [1,7,11].

The first theory used is Cyber Supply Chain Risk Management (C-SCRM), which focuses on the risks that travel across connected digital supply chains. In express delivery companies, problems can arise from third-party systems, cloud tools, or last-mile technologies like RFID tracking or route optimization software [4,9]. C-SCRM helps explain how these external risks can affect internal systems, making it clear that teams must work together across all parts of the logistics chain to prevent and respond to threats [6,8]. While this framework is gaining attention, it is not yet widely applied in small or medium-sized delivery firms, indicating a need for more localized cybersecurity models.

The second theory, Digital Transformation Theory, examines how businesses adopt modern technologies like cloud systems, data platforms, and blockchain to improve services [1,5]. These tools offer faster, more transparent operations and introduce new security risks. Managing this balance requires teams that are both skilled and flexible. In Jordan, many logistics companies have adopted digital platforms quickly, especially since the pandemic, but their internal security measures have not always kept pace. This gap between technical tools and team readiness highlights the need to strengthen both areas together [11,14,19].

Resilience Engineering Theory adds another perspective by focusing not on avoiding failures but on how organizations respond when problems occur. In logistics, even brief delays or outages can impact entire delivery systems and damage customer trust [6,50]. This theory emphasizes adaptability, showing how teams can maintain service during disruptions by staying flexible and alert. It is a valuable lens for studying how teams in logistics respond to real-time cyber threats, though it has not been widely applied to this field yet [7,41].

Socio-Technical Systems (STS) Theory further broadens the view by examining how people, technology, and company structures interact to affect cybersecurity. In express delivery firms, especially in Jordan, many mid-sized companies rely on informal teamwork and shared practices more than advanced security tools [2,5]. STS Theory shows that even well-designed systems can fail if team roles are unclear or communication breaks down. It supports the growing recognition that human behavior and team coordination are as important as technical tools in keeping systems safe [1,14,19].

Lastly, the Capability-Based View (CBV) looks at how a company's internal strengths—such as team skills, learning capacity, and ability to combine technical and human resources—determine its overall performance [4,12]. CBV helps explain why two firms with similar IT tools may show different readiness levels. The key

difference lies in how well their teams apply knowledge, adapt to changes, and learn from experience [7,10]. However, CBV is still rarely used in logistics cybersecurity, even though it highlights the crucial role of project teams in building long-term resilience.

This study's framework combines five theories—C-SCRM, Digital Transformation, Resilience Engineering, STS, and CBV—to provide a well-rounded understanding of how cyber risks, team capabilities, and organizational systems interact. This combined approach offers a strong foundation for studying cybersecurity in Jordan's express delivery sector. Using this theoretical mix, the study develops testable ideas and builds a tailored model for understanding how teams can strengthen cybersecurity in fast-changing logistics environments [1,4,5].

2.5 Hypotheses development

With cyberattacks becoming more frequent, advanced, and damaging, the need for strong cybersecurity preparation has grown, particularly in fast-changing industries like logistics and express delivery. Research increasingly highlights that certain features of cyberattacks—such as how complex they are, how accurately they target systems, and how often they happen—play a major role in shaping how organizations plan for and handle such threats [121,122]. Attacks that are both frequent and damaging often push companies to improve their internal security measures, raise awareness among staff, and build coordinated readiness strategies across departments [45,123].

Different aspects of cyberattacks, such as how they break into systems, the scale of disruption they cause, or the use of new methods, influence how organizations shape their defense strategies [124,125]. The logistics sector is especially at risk because cyberattacks can interrupt key functions like package tracking, route management, and real-time communication. Companies that gain a clear understanding of the nature of these attacks tend to respond more effectively. Their strategies often include team-based simulations, rehearsals based on specific roles, and organized processes for managing incidents [126,127].

These threats also bring about internal changes in how organizations operate, raising risk awareness and encouraging the development of team-based cybersecurity practices [123,128]. Studies across industries such as information technology and finance show that organizations regularly facing complex cyber threats are usually better prepared than those with less exposure [122,124]. Despite this, there's limited research on how these patterns apply to the express logistics industry, especially in developing countries. To address this gap, the first hypothesis is proposed:

H1: Cyber-attack features positively affect Team-Based Cybersecurity Readiness.

Additionally, cyber threats put considerable pressure on internal teams, particularly those working on projects with tight deadlines and high technological demands. These

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attacks require teams to be quick-thinking, skilled in technology, and strong in collaboration. As attackers increasingly exploit weaknesses between people and systems, teams must become more adaptable, mentally resilient, and clear in communication to respond effectively [96,97].

Facing complex cyber threats often leads to better knowledge sharing, stronger links between departments, and clearer task assignments [98]. Well-functioning teams provide psychological safety, well-defined responsibilities, and shared accountability—all important for handling cybersecurity incidents [99-102]. In addition, the ability to think critically, stay flexible, and make decisions under pressure has become essential for effective cybersecurity teams [103-105]. These qualities are especially important in logistics, where short delays can result in immediate financial and reputational harm.

Because cyber risks are unpredictable, teams must continuously train, practice with realistic scenarios, and use flexible project management approaches to improve their skills [106-109]. While skill development has been widely discussed in academic work, little evidence is focused on logistics cybersecurity. Therefore, the second hypothesis is:

H2: Cyber-attack features positively influence Project Team Skills.

Although technical systems remain a key part of cybersecurity, recent studies suggest that the team's abilities—rather than just the technology—play the biggest role in maintaining readiness under pressure. Teams with specialized knowledge and the ability to understand how systems interact tend to perform better in fast-changing threat situations, especially when quick decisions are needed [96,97,130]. These teams can design secure systems, find and fix vulnerabilities, and respond in a coordinated way within strict time limits.

Soft skills also matter greatly. Communication, trust, and planning help teams share information quickly during a crisis and prevent delays in resolving issues [100,101]. How well teams coordinate within their group and with others affects how fast they detect, contain, and recover from attacks. Research also shows that solution-focused, time management, and adaptability contribute to better responses and less system downtime [103-105,131].

Adaptability is crucial in logistics, where operations move quickly and outside factors often change. Because of this, project teams in express delivery need a wide range of skills to handle digital threats effectively. Based on this:

H3: Project Team Skills positively influence Team-Based Cybersecurity Readiness.

Lastly, this study focuses on how team skills act as a bridge between external cyber threats and an organization's readiness. While threats come from outside, their impact depends on how internal teams react, adjust, and work together. Even advanced threats like shape-shifting malware or social engineering tactics can overcome strong

technical defenses; however, the outcome often depends on human factors like teamwork, communication, and flexibility [4,9,11,29].

Teams that build these abilities respond better during crises and learn and grow from these experiences, turning threats into opportunities to strengthen their resilience [5,7,38,40]. In the logistics industry, research indicates that an organization's readiness often depends more on employee skills than on how much money is spent on technology [6,12,45,51]. This point is especially relevant in Jordan, where technical resources may not be evenly available, making the role of team dynamics even more important [13,14,19,20].

Therefore, the study presents project team skills as a key factor in turning external threats into internal preparedness. Understanding this connection explains differences in readiness and helps identify where improvements can be made at the intersection of people and technology.

H4: Project Team Skills mediate the relationship between Cyber-Attack Features and Team-Based Cybersecurity Readiness.**2.6 Conceptual framework**

This study presents a conceptual framework (Figure 1) that explores how cyber-attacks influence an organization's ability to prepare for and manage cybersecurity threats. It emphasizes the role of project team skills in shaping effective responses. This model is especially relevant for express delivery service companies (EDSCs) in Jordan, where the shift to digital systems has significantly boosted operational capabilities and increased vulnerability to cyber threats [14,15].

Their digital exposure grows as these companies adopt tools like IoT-enabled tracking, cloud-based logistics platforms, and online customer services. This wider digital presence puts their key systems and sensitive data at risk from more advanced attacks [7,11]. In this context, cyber-attacks stem from weaknesses affecting technology and how people interact with systems. These issues include poor software design, incorrect network settings, weak user access controls, and insider threats that have not been properly addressed—problems that are common causes of breaches across many industries [69,73,77]. In logistics and transport, older IT systems and disconnected digital setups worsen things by limiting visibility into threats and reducing the ability to respond quickly [6,71].

In addition to technical issues, risks are linked to human behavior—such as using the same passwords repeatedly, delaying software updates, or falling victim to phishing and social engineering. These weaknesses weaken an organization's security posture [75,89]. Because threats come from many directions, logistics companies need well-organized responses that do more than react to attacks. Cyber readiness must be fast and dependable in a field where continuous service is essential to remain competitive.

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In this framework, team-based cybersecurity readiness means how well a group of employees, usually organized as a project team, can predict, identify, respond to, and recover from cyber incidents under pressure. Unlike older models that focused only on technology, today's understanding of readiness includes a range of elements—like preventive strategies, early warning systems, awareness of current threats, clear communication within teams, and planned recovery procedures [51,55]. These are especially important in the logistics sector, where attacks interrupt vital tasks such as tracking parcels, managing deliveries, and handling payments.

A key part of being ready is having clearly defined roles and the ability to coordinate under stress. Teams with a shared understanding of their responsibilities, take ownership of tasks, and communicate effectively are likelier to catch attacks early and limit their impact [53,102]. Specific challenges in logistics—such as hacked GPS data or stolen customer information—require teams to work quickly and in sync across departments to keep operations running smoothly and maintain customer trust.

At the heart of this framework is the role of project team skills. These include technical know-how—like using cybersecurity tools, managing systems, and analyzing threats—and soft skills, such as adaptability,

communication across departments, and making good decisions under pressure [38,96]. In express delivery services, teams often work in different locations, with different systems and responsibilities. Therefore, they must bring together different types of information quickly and create a shared response plan, often while facing time constraints and unclear situations [100,101].

Studies show that teams with strong critical thinking, good time management, and awareness of the situation can turn scattered data into useful information, making their responses quicker and reducing disruptions [104,110]. In many logistics companies, how well a team is prepared—not how advanced their technology—often decides how quickly and effectively they can respond to attacks. This highlights the importance of building team capabilities and positions team skills as a key factor in shifting from reacting to threats to being ready for them ahead of time.

To conclude, the conceptual framework combines three main elements—cyber-attack characteristics, project team skills, and team-based cybersecurity readiness—into one model designed specifically for the logistics industry. It shows how technical weaknesses and human strengths interact and highlights how well-prepared teams help turn outside threats into opportunities for building stronger internal defenses.

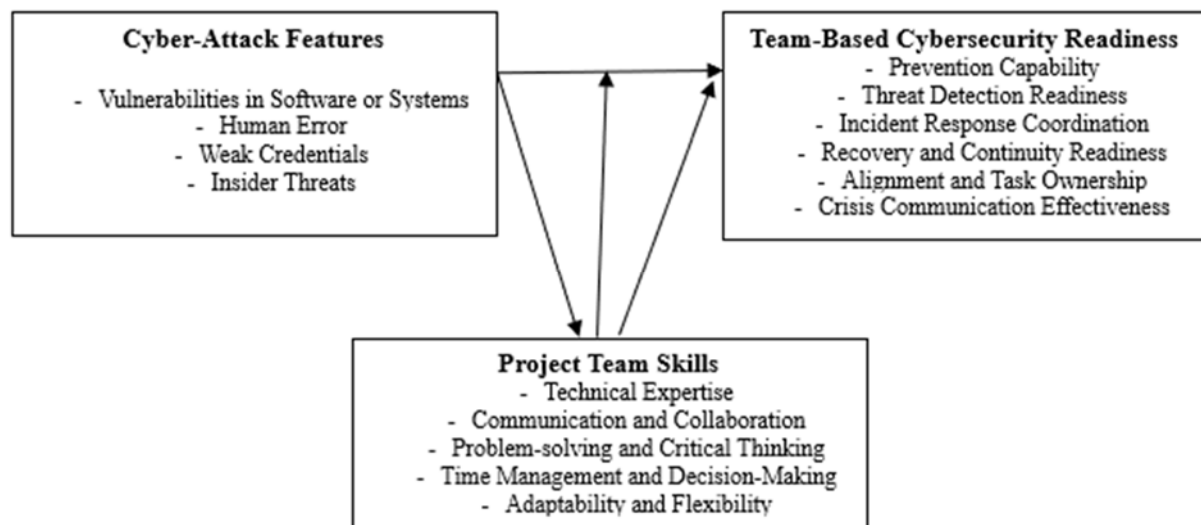


Figure 1 Conceptual model

3 Methodology

3.1 Research design

This study adopted a quantitative, cross-sectional survey design to investigate how cyber-attack characteristics influence team-based cybersecurity readiness, with project team skills acting as a mediating variable, specifically within the context of Jordanian express delivery service companies [132]. A structured questionnaire was utilized as the primary data collection tool, offering a standardized format for capturing responses efficiently from a broad sample over a limited period [133-134]. The quantitative approach was chosen due to its

suitability for testing theoretical models and quantifying abstract constructs using statistical methods [132]. The study's cross-sectional nature enabled data collection at a single point in time, aligning well with the operational realities of the logistics sector [134]. Similar methodologies have been effectively applied in prior research exploring cybersecurity and organizational behavior, where survey designs were instrumental in assessing team capabilities and readiness across organizational environments [135-136]. Moreover, the structured questionnaire allowed the researchers to measure perceptions and attitudes toward cyber threats and

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preparedness using validated scales. This approach is widely recognized in empirical cybersecurity research, particularly in studies requiring insight into behavioral and organizational dynamics [133,135,136]. Therefore, using structural equation modeling techniques, the chosen design provided a solid framework for examining the hypothesized relationships and assessing the mediating role of team skills [134].

3.2 Population and sampling

The study targeted IT and operations managers working within express delivery service companies (EDSCs) in Jordan. These professionals were selected based on their integral roles—IT managers are responsible for implementing and maintaining cybersecurity infrastructure, while operations managers oversee service continuity during potential disruptions. Their combined perspectives were essential for evaluating the study's primary constructs: cyber-attack features, project team skills, and cybersecurity readiness. To identify the target population, data were collected from two authoritative sources: the Jordanian Telecommunications Regulatory Commission (TRC), listing 166 express delivery firms, and the Ministry of Industry and Trade, listing 379. After reconciling the records and removing duplicate entries, 476 active companies were identified. Communication with the human resources departments confirmed that each company employed one IT and one operations manager, resulting in a total population of 952 eligible participants. A systematic sampling method was employed to ensure representativeness and minimize selection bias, following a probabilistic approach; every k th participant was selected from the list after a random starting point. An a priori power analysis was conducted using G*Power 3.1.9.7 software to calculate the required sample size. The analysis, based on multiple regression with three predictors—cyber-attack features, project team skills, and cybersecurity readiness—assumed a medium effect size ($f^2 = 0.15$), a significance level of 0.05, and a statistical power of 0.95. The minimum required sample size was determined to be 119 participants. To enhance the robustness of the findings and account for potential non-responses, the target sample size was increased to 310, representing approximately 32.6% of the population. The sampling interval was calculated as $k = N/n \approx 952/310 \approx 3$. Consequently, every third eligible participant was selected after the initial random start.

3.3 Instrument development

A comprehensive questionnaire was developed to measure the constructs specified in the conceptual model (Figure 1) using established and validated instruments from previous research in cybersecurity, team performance, and organizational preparedness. Each construct was measured using four to five items on a 7-point Likert scale, ranging from 1 (strongly disagree) to 7 (strongly agree), a format known for enhancing reliability and response precision in behavioral studies [137].

Cyber-attack features were captured through four dimensions: (1) system or software vulnerabilities, (2) human error, (3) weak access credentials, and (4) insider threats. These indicators were adapted from prior studies focused on risk assessment and threat classification [69, 89, 91], with each item designed to reflect the perceived frequency, exposure, or severity of these risks. The mediating variable, Project Team Skills, comprised five key areas: (1) technical proficiency, (2) communication and collaboration, (3) critical thinking and problem-solving, (4) time and decision management, and (5) adaptability and flexibility. Items representing these skills were adapted from validated frameworks within the literature on team effectiveness and cybersecurity competencies [38,96,102]. Respondents rated the extent to which these skills were demonstrated within their teams. Team-Based Cybersecurity Readiness was assessed across six dimensions: (1) preventive capabilities, (2) threat detection readiness, (3) coordination in incident response, (4) recovery and continuity planning, (5) task ownership and alignment, and (6) effective communication during crises. These elements were informed by widely recognized readiness models and incident management literature [50,51,55].

To ensure instrument validity, a two-phase validation process was conducted. Initially, subject matter experts in cybersecurity and logistics reviewed the items for relevance and clarity. Subsequently, a pilot study involving 30 respondents from the target population was carried out to test internal consistency. Feedback from the pilot was used to make minor refinements, thereby improving the clarity and alignment of items with their respective constructs.

3.4 Data collection

The data for this study were gathered through a structured, self-administered questionnaire aimed at collecting quantitative input from IT and operations managers employed in express delivery service companies across Jordan. The questionnaire was distributed online via Google Forms to facilitate broad and efficient participation, allowing respondents from geographically dispersed locations to access the survey easily [138]. A formal invitation package—including a participant information sheet and a consent form—was initially sent to the human resources departments of the 476 identified companies, who were then responsible for forwarding the survey link to the designated personnel. To improve participation and ensure high response quality, follow-up reminders were sent through email and telephone two weeks after the initial distribution. The survey remained open for a total duration of six weeks. Participation was entirely voluntary, and respondents were assured of the confidentiality of their input, thereby reducing the likelihood of social desirability bias and promoting more accurate responses [139]. Before the full rollout, the questionnaire underwent a pilot test involving 30 managers from the target population. This phase assessed the

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questions' clarity, timing, and alignment with the study's objectives. Based on the feedback received, minor revisions were made to enhance the wording and flow of the items.

During the main data collection phase, 310 valid responses were received, yielding a response rate of 32.6% relative to the total population of 952 managers. This figure surpassed the minimum required sample size of 119, calculated through G*Power analysis, and ensured sufficient statistical power and generalizability. The collected data were exported from Google Forms into Microsoft Excel and then transferred to SPSS for data cleaning and initial preparation for analysis. The entire process adhered to ethical research standards, including obtaining informed consent, ensuring participant anonymity, and securing voluntary participation, by institutional research guidelines and international ethical practices [140].

3.5 Analysis technique

The study utilized descriptive analysis, reliability and validity testing, and structural equation modeling (SEM) to examine the hypothesized relationships in the conceptual model. Initial data screening and descriptive statistics were performed using SPSS (v27), while structural modeling and hypothesis testing were conducted using SmartPLS 4.0. The partial least squares SEM (PLS-SEM) approach was selected for its suitability for predictive research involving latent variables and mediation analysis [134,141]. Preliminary data analysis involved evaluating the dataset for missing values, outliers, and deviations from normality to ensure its appropriateness for SEM [142]. Descriptive statistics were used to summarize the demographic characteristics and item-level responses,

including means, standard deviations, and frequency distributions. Cronbach's alpha and composite reliability (CR) were calculated to assess measurement reliability, with thresholds of 0.70 or higher considered acceptable [143]. Convergent validity was verified through the average variance extracted (AVE), requiring a minimum value of 0.50. Discriminant validity was tested using the Fornell-Larcker criterion and the Heterotrait-Monotrait ratio (HTMT), following established guidelines [144,145]. Path coefficients and their statistical significance were estimated through bootstrapping with 5,000 resamples for testing the structural model. This enabled the evaluation of both the direct effects of cyber-attack features on team-based cybersecurity readiness and the indirect effects mediated by project team skills. The model's explanatory power was assessed using the coefficient of determination (R^2) and effect size (f^2) metrics [134]. Additionally, model fit was evaluated using the standardized root mean square residual (SRMR), with values below 0.08 indicating an acceptable level of fit [146].

4 Results

4.1 Demographic profile of respondents

Table 1 presents the demographic breakdown across various categories, including gender, age, job role, years of professional experience, geographical region, and organization size. A significant majority of respondents were male (73.2%), which mirrors the existing gender distribution in this sector. The age distribution revealed that 44.5% of participants were between 30 and 39 years old, and 31.6% were between 40 and 49. This indicates that most respondents were mid-career professionals, likely with substantial experience managing technology and operations.

Table 1 Demographic characteristics of respondents (N = 310)

Variable	Category	Frequency (n)	Percentage (%)
Gender	Male	227	73.2
	Female	83	26.8
Age	20–29	42	13.5
	30–39	138	44.5
	40–49	98	31.6
	50+	32	10.3
	IT Manager	153	49.4
Job Position	Operations Manager	157	50.6
Years of Experience	1–5	64	20.6
	6–10	122	39.4
	11–15	89	28.7
	16+	35	11.3
Region	Northern Jordan	106	34.2
	Central Jordan	130	41.9
	Southern Jordan	74	23.9
Company Size	Small (10–50 employees)	84	27.1
	Medium (51–200)	179	57.7
	Large (201+)	47	15.2

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The sample was almost evenly split in professional roles: 49.4% of the respondents identified as IT managers, while 50.6% held operations management positions. This balanced representation supports a comprehensive understanding of technical and operational perspectives on cybersecurity readiness. Regarding work experience, 39.4% of participants had been in the field for 6 to 10 years, highlighting a workforce with a solid foundation in industry practices and cybersecurity concerns. An additional 28.7% had between 11 and 15 years of experience, further reinforcing the sample's depth of expertise. In terms of geographical location, respondents were distributed throughout Jordan, with the largest proportion based in the central region (41.9%), followed by those in the north (34.2%) and south (23.9%). This geographical diversity ensures a well-rounded view of practices and challenges across different parts of the country. Company size was also considered. Over half of the participants (57.7%) worked in medium-sized firms employing between 51 and 200 individuals. Smaller companies (10–50 employees) accounted for 27.1% of the sample, while large enterprises (with more than 200 employees) comprised 15.2%. These figures suggest that medium-sized organizations are a prominent segment of Jordan's express delivery sector and will likely play a key role in shaping national cybersecurity readiness.

4.2 Descriptive statistics of latent constructs

The first construct, Cyber-Attack Features, includes four key sub-dimensions: vulnerabilities in software or systems, human error, weak credentials, and insider threats. These represent critical sources of cyber risk within the operational environment of express delivery services. The mean scores for these sub-constructs ranged from 5.15 to 5.31. Specifically, human error received the highest average score (5.31), highlighting it as the most commonly perceived threat. Meanwhile, weak credentials had the lowest mean (5.15), though still above the scale midpoint, indicating a general awareness of credential-related vulnerabilities. The standard deviations, all under 1.00, suggest that perceptions across respondents were relatively consistent, reflecting a shared recognition of cyber risks

within the industry. The mediating variable, Project Team Skills, was assessed through five sub-constructs: technical expertise; communication and collaboration; problem-solving and critical thinking; time management and decision-making; and adaptability and flexibility. These skills are essential for ensuring rapid and coordinated responses to cyber threats within team-based structures. The reported mean values ranged from 5.54 to 5.68, indicating a high level of agreement among participants about their teams' capabilities. Notably, adaptability and flexibility received the highest rating (5.68), underscoring the importance placed on agility and responsiveness in dynamic cybersecurity environments. The relatively low standard deviations (below 0.85) across all sub-constructs indicate minimal variance in respondent perceptions, suggesting a widely shared view of team competence and preparedness. The final construct, Team-Based Cybersecurity Readiness, was evaluated using six sub-constructs: prevention capacity, threat detection readiness, incident response coordination, recovery and continuity readiness, alignment and task ownership, and crisis communication effectiveness. These dimensions collectively represent the organization's ability to prevent, identify, respond to, and recover from cyber incidents. The mean scores for these indicators ranged from 5.37 to 5.48. Among them, alignment and task ownership had the highest average (5.48), suggesting strong clarity in roles and responsibilities during cyber incidents. Conversely, recovery and continuity readiness scored lowest (5.37), indicating a slightly more varied level of preparedness in this area. Standard deviations ranged from 0.83 to 0.91, showing that while most organizations demonstrated a generally high level of readiness, some variation exists, possibly reflecting differences in resource allocation, training, or incident experience across companies.

These descriptive results highlight that Jordan's participating express delivery firms generally possess well-developed capabilities in managing cyber threats. High mean values across all constructs suggest strong organizational awareness and team-based preparedness. Table 2 summarizes the average scores and standard deviations for all constructs and their respective sub-dimensions.

Table 2 Descriptive statistics of constructs and sub-constructs (N = 310)

Main Construct	Sub-Construct	Mean	SD
Cyber-Attack Features	Vulnerabilities in Software/Systems	5.24	0.91
	Human Error	5.31	0.88
	Weak Credentials	5.15	0.90
	Insider Threats	5.28	0.85
Project Team Skills	Technical Expertise	5.58	0.83
	Communication and Collaboration	5.63	0.79
	Problem-Solving and Critical Thinking	5.61	0.82
	Time Management and Decision-Making	5.54	0.78
	Adaptability and Flexibility	5.68	0.80
Cybersecurity Readiness	Prevention Capacity	5.45	0.84
	Threat Detection Readiness	5.39	0.87

	Incident Response Coordination	5.42	0.91
	Recovery and Continuity Readiness	5.37	0.88
	Alignment and Task Ownership	5.48	0.85
	Crisis Communication Effectiveness	5.41	0.83

4.3 Measurement model evaluation

Before testing the hypothesized relationships among cyber-attack features, project team skills, and team-based cybersecurity readiness, the measurement model was evaluated to ensure that the latent constructs were measured reliably and validly. This step was critical to confirm that the questionnaire items accurately represented their respective theoretical constructs and could be used confidently in the subsequent structural model analysis. The measurement model was assessed using Partial Least Squares Structural Equation Modeling (PLS-SEM) via SmartPLS 4.0. Four key assessments were performed: internal consistency reliability, convergent validity, discriminant validity, and indicator reliability. The following subsections outline the results of these evaluations, which confirm the measurement model's robustness and suitability for further analysis.

4.3.1 Internal consistency reliability

Internal consistency reliability examines the degree to which multiple items measuring the same construct produce consistent results. Two metrics were used in this study: Cronbach's alpha and composite reliability (CR). While Cronbach's alpha offers a conservative estimate of reliability, composite reliability is considered more appropriate in PLS-SEM as it accounts for the different factor loadings of each indicator [134]. According to the standard criteria suggested by [143], values above 0.70 are deemed acceptable. As reported in Table 3, all constructs exceeded the minimum threshold. Cronbach's alpha values ranged from 0.89 to 0.92, and CR values ranged from 0.91 to 0.94. These results confirm a high level of internal consistency, indicating that the measurement items reliably represent their associated latent constructs.

Table 3 Internal consistency reliability: Cronbach's alpha and composite reliability (N = 310)

Construct	Cronbach's Alpha	Composite Reliability
Cyber-Attack Features	0.89	0.91
Project Team Skills	0.92	0.94
Team-Based Cybersecurity Readiness	0.90	0.93

All values surpass the recommended cutoff, indicating excellent reliability. This suggests that respondents interpreted the items within each construct consistently, reinforcing the validity of the results.

4.3.2 Convergent validity

Convergent validity assesses whether indicators of a given construct share a high proportion of variance,

implying they converge on the same underlying concept. This was evaluated using two criteria: the Average Variance Extracted (AVE) and standardized factor loadings. AVE values above 0.50 signify that the construct explains more than half of the variance in its observed indicators [144]. Similarly, factor loadings should exceed 0.70 to be considered statistically meaningful. As summarized in Table 4, all AVE values ranged from 0.64 to 0.76, well above the 0.50 benchmark. Additionally, the standardized loadings for individual items fell between 0.72 and 0.89. These findings confirm that the indicators are strongly associated with their corresponding latent variables, supporting convergent validity.

Table 4 Convergent validity: standardized loadings and Average Variance Extracted (AVE)

Construct	Range of Loadings	AVE
Cyber-Attack Features	0.73 – 0.84	0.64
Project Team Skills	0.75 – 0.89	0.71
Team-Based Cybersecurity Readiness	0.72 – 0.88	0.76

All AVE values exceed the minimum acceptable level, and individual item loadings are robust. This indicates that each construct successfully captures the variance of its indicators, justifying their inclusion in the structural analysis.

4.3.3 Discriminant validity

Discriminant validity evaluates the extent to which a construct is truly distinct from other constructs in the model. This was assessed using two complementary methods: the Fornell–Larcker criterion and the Heterotrait–Monotrait (HTMT) ratio. According to the Fornell–Larcker criterion, the square root of each construct's AVE should be greater than its correlations with any other construct [144]. As presented in Table 5, each construct's diagonal value ($\sqrt{\text{AVE}}$) exceeds the corresponding off-diagonal correlation values, confirming that the constructs are empirically distinct.

Table 5 Fornell–Larcker criterion matrix

Construct	CAF	PTS	TCR
Cyber-Attack Features (CAF)	0.80		
Project Team Skills (PTS)	0.66	0.84	
Team-Based Cybersecurity Readiness (TCR)	0.61	0.72	0.87

Note: Diagonal values represent the square root of AVE.

In addition, the HTMT ratio, which provides a more stringent test of discriminant validity, was used. A value below 0.85 suggests adequate discriminant validity [145].

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As shown in Table 6, all HTMT values fall within the acceptable range, further supporting the distinctiveness of each construct.

Table 6 Heterotrait–Monotrait ratio (HTMT)

Construct Pair	HTMT Value
Cyber-Attack Features – Project Team Skills	0.76
Cyber-Attack Features – Cybersecurity Readiness	0.73
Project Team Skills – Cybersecurity Readiness	0.81

The Fornell–Larcker and HTMT assessments confirm that each construct measures a unique theoretical concept, with no significant overlap in meaning. This validation step ensures that the constructs can be independently interpreted in the context of the structural model.

The findings from the measurement model evaluation demonstrate that all constructs used in this study are reliable and valid. Internal consistency is strong, convergent validity is well established, and discriminant validity is supported. In the next section, these results provide a solid foundation for analyzing the structural relationships among cyber-attack features, project team skills, and team-based cybersecurity readiness.

4.4 Structural model evaluation - inner model

Following the confirmation of the measurement model, the structural (inner) model was evaluated to test the proposed theoretical relationships among Cyber-Attack Features (CAF), Project Team Skills (PTS), and Team-Based Cybersecurity Readiness (TCR). The analysis was conducted using SmartPLS 4, applying the Partial Least Squares Structural Equation Modeling (PLS-SEM) approach. The structural evaluation included five key components: assessment of collinearity, estimation of path coefficients and hypothesis testing, evaluation of explained variance (R^2), computation of effect sizes (f^2), and examination of model fit indicators.

4.4.1 Collinearity assessment

Collinearity diagnostics were performed using the Variance Inflation Factor (VIF) to ensure the reliability of path coefficient estimates. Collinearity occurs when predictor variables are highly correlated, which may distort the model's estimation and reduce interpretability. According to [134], VIF values below 5 are generally acceptable and indicate no critical multicollinearity concerns. As shown in Table 7, all VIF values ranged from 1.38 to 2.03, well within the acceptable range. This confirms that multicollinearity is absent and that the predictor constructs contribute independently to the outcomes.

Low VIF values indicate that each predictor variable has a distinct and independent contribution to the model,

ensuring that multicollinearity does not affect the validity of the structural estimates.

Table 7 Collinearity statistics (VIF)

Predictor Construct	Outcome Variable	VIF
Cyber-Attack Features	Project Team Skills	1.88
Cyber-Attack Features	Cybersecurity Readiness	1.79
Project Team Skills	Cybersecurity Readiness	2.03

4.4.2 Path coefficients and hypothesis testing

Path coefficients were estimated using a bootstrapping procedure with 5,000 resamples to evaluate the strength and significance of hypothesized relationships. The results revealed that all proposed paths were statistically significant (Table 8). Cyber-Attack Features positively affected Project Team Skills ($\beta = 0.66$, $t = 11.72$, $p < .001$), suggesting that organizations facing more complex or frequent cyber threats tend to cultivate stronger team competencies. Additionally, Cyber-Attack Features directly influenced Cybersecurity Readiness ($\beta = 0.33$, $t = 6.54$, $p < .001$), indicating that awareness and mitigation of cyber threats enhance organizational preparedness. Project Team Skills also showed a substantial positive effect on Cybersecurity Readiness ($\beta = 0.54$, $t = 10.81$, $p < .001$), highlighting the critical role of team capabilities in enhancing readiness.

Table 8 Path coefficients, t-values, and significance (bootstrapping results)

Path	Coefficient (β)	t-value	p-value
Cyber-Attack Features → Project Team Skills	0.66	11.72	< .001
Cyber-Attack Features → Cybersecurity Readiness	0.33	6.54	< .001
Project Team Skills → Cybersecurity Readiness	0.54	10.81	< .001

All path coefficients are statistically significant at the $p < .001$ level, supporting the hypothesized relationships strongly. This confirms that both direct and indirect effects of Cyber-Attack Features on Cybersecurity Readiness are substantial.

4.4.3 Coefficient of determination (R^2)

R^2 values assess how much variance in the endogenous (dependent) variables is explained by the exogenous (independent) variables. According to common benchmarks, R^2 values around 0.25, 0.50, and 0.75 can be considered weak, moderate, and substantial, respectively [134]. As shown in Table 9, Project Team Skills had an R^2 of 0.44, indicating that Cyber-Attack Features explain a moderate portion of the variance in team skills. Meanwhile,

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the R^2 value for Cybersecurity Readiness was 0.62, suggesting a strong level of explanation when both predictors (CAF and PTS) are included.

Table 9 R^2 and adjusted R^2 for project team skills and cybersecurity readiness

Construct	R^2	Adjusted R^2
Project Team Skills	0.44	0.44
Cybersecurity Readiness	0.62	0.62

The model demonstrates substantial explanatory power, particularly for Cybersecurity Readiness. These values affirm the relevance of Cyber-Attack Features and Project Team Skills in shaping organizational cybersecurity outcomes.

4.4.4 Effect size (f^2)

Effect size (f^2) measures the contribution of a specific predictor to the R^2 value of an endogenous variable. According to Cohen (1988), values of 0.02, 0.15, and 0.35 indicate small, medium, and large effects, respectively. As presented in Table 10, Cyber-Attack Features greatly affected Project Team Skills ($f^2 = 0.79$) and had a medium effect on Cybersecurity Readiness ($f^2 = 0.23$). Project Team Skills greatly affected Cybersecurity Readiness ($f^2 = 0.49$), reinforcing its central role in the model.

Table 10 Effect size (f^2) for predictor constructs

Predictor → Outcome	f^2	Effect Size Interpretation
Cyber-Attack Features → Project Team Skills	0.79	Large
Cyber-Attack Features → Cybersecurity Readiness	0.23	Medium
Project Team Skills → Cybersecurity Readiness	0.49	Large

These values indicate that Cyber-Attack Features are a key driver of skill development, and that Project Team Skills are a major determinant of cybersecurity readiness. The practical significance of each predictor is demonstrated.

4.4.5 Model fit indices

To evaluate the overall adequacy of the model, two fit indices were analyzed: the Standardized Root Mean Square Residual (SRMR) and the Normed Fit Index (NFI). An SRMR value below 0.08 indicates a good fit, while an NFI value above 0.90 reflects a strong comparative model fit [145]. As shown in Table 11, the SRMR value was 0.058 and the NFI was 0.93, both meeting the recommended thresholds.

Table 11 Model fit indices

Fit Index	Value	Threshold	Interpretation
SRMR	0.058	< 0.08	Excellent Fit
NFI	0.93	> 0.90	Strong Model Fit

The fit indices confirm that the theoretical model closely aligns with the observed data, supporting the structural relationships proposed in the study.

The results of the structural model evaluation confirm that the research framework is both statistically sound and theoretically meaningful. Cyber-Attack Features significantly influence Team-Based Cybersecurity Readiness both directly and indirectly through the development of Project Team Skills. The model demonstrates strong explanatory power, reliable path estimates, and robust fit indices, validating its application in the context of Jordanian express delivery service companies.

4.5 Mediation analysis

To assess whether Project Team Skills (PTS) mediate the relationship between Cyber-Attack Features (CAF) and Team-Based Cybersecurity Readiness (TCR), a bootstrapping analysis was conducted using SmartPLS with 5,000 resamples. Bootstrapping provides a robust, non-parametric method for testing indirect effects and estimating confidence intervals without assuming normality (Hair et al., 2021). As shown in Table 12, the direct path from CAF to TCR was statistically significant, with a standardized path coefficient of $\beta = 0.33$ ($t = 6.54$, $p < .001$) and a 95% confidence interval [0.22, 0.45]. This confirms that cyber-attack features, such as attack complexity, insider threats, or frequency, directly and positively influence the readiness of express delivery companies to respond to cybersecurity threats. Furthermore, the indirect effect of CAF on TCR through PTS was also significant, with a path coefficient of $\beta = 0.36$ ($t = 8.49$, $p < .001$) and a confidence interval of [0.28, 0.45]. This suggests that cyber-attack features influence team-based cybersecurity readiness directly and indirectly by enhancing project teams' skill sets. These skills—such as adaptability, technical expertise, and collaboration—appear to serve as key mechanisms through which organizations strengthen their cybersecurity posture. The total effect of CAF on TCR, combining both direct and mediated paths, was $\beta = 0.69$ ($t = 14.32$, $p < .001$), with a confidence interval of [0.60, 0.78]. The magnitude of this total effect demonstrates a strong and consistent link between cyber-attack characteristics and organizational readiness.

Since both the direct and indirect effects are significant, the analysis confirms a case of partial mediation. While cyber-attack features directly influence readiness, a significant portion of their impact is channeled through developing project team capabilities. These findings highlight the importance of recognizing cybersecurity threats and developing team-based competencies to manage them effectively. They align with recent research emphasizing the need for an integrated approach combining technical awareness and human capital in enhancing organizational cybersecurity [38,43].

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Table 12 Indirect effects and confidence intervals (bootstrapping for mediation)

Effect Type	Path	β	t-value	p-value	95% CI	Mediation Type
Direct Effect (CAF $\rightarrow$ TCR)	CAF $\rightarrow$ TCR	0.33	6.54	< .001	[0.22, 0.45]	-
Indirect Effect (CAF $\rightarrow$ PTS $\rightarrow$ TCR)	CAF $\rightarrow$ PTS $\rightarrow$ TCR	0.36	8.49	< .001	[0.28, 0.45]	Partial Mediation
Total Effect (CAF $\rightarrow$ TCR via PTS)	CAF $\rightarrow$ TCR + Indirect	0.69	14.32	< .001	[0.60, 0.78]	-

These results demonstrate that Project Team Skills significantly mediate the relationship between cyber-attack features and cybersecurity readiness. The strong indirect effect affirms that enhancing team skills is a strategic response mechanism that strengthens readiness across the organization. These findings carry practical implications for decision-makers in the logistics and express delivery sectors, suggesting that building team capacity is just as vital as technological threat awareness in fostering digital resilience.

4.6 Summary of hypothesis testing

This section summarizes the results of the hypothesis testing conducted through structural equation modeling using SmartPLS. The study evaluated three direct hypotheses and one mediating hypothesis, all of which were derived from the conceptual model guiding the research. As presented in Table 13, the results strongly support each proposed relationship. Hypothesis H1 proposed that Cyber-Attack Features (CAF) positively influence Cybersecurity Readiness (TCR). This was confirmed by a statistically significant path coefficient ($\beta = 0.33$, $t = 6.54$, $p < .001$), indicating that recognizing and addressing cyber threats contributes directly to enhancing organizational preparedness. Hypothesis H2 suggested that CAF also directly affects Project Team Skills (PTS). The

findings supported this relationship ($\beta = 0.44$, $t = 7.22$, $p < .001$), suggesting that increased exposure to cyber risks drives the development of team capabilities, such as technical problem-solving and adaptability, within project environments. Hypothesis H3 examined the direct impact of PTS on TCR. With a path coefficient of $\beta = 0.47$ ($t = 8.01$, $p < .001$), the results confirmed a significant positive relationship. This reinforces the role of skilled, coordinated teams in enabling organizations to respond effectively to cybersecurity incidents. The mediating hypothesis, H4, investigated whether PTS mediates the link between CAF and TCR. As detailed in Section 4.5, both the direct and indirect paths were significant, confirming the presence of partial mediation. The indirect effect ($\beta = 0.36$, $t = 8.49$, $p < .001$) demonstrates that project team capabilities substantially enhance the influence of cyber-attack features on readiness, thereby amplifying the organization's response capacity.

These findings validate the study's theoretical framework and underscore the integrated nature of technical threat factors and internal human competencies. They also offer practical implications for cybersecurity management in express delivery service organizations, highlighting the need for threat recognition and project team development investment to ensure robust cybersecurity readiness.

Table 13 Summary of hypotheses, paths, and results

Hypothesis	Structural Path	Standardized Coefficient (β)	t-value	p-value	Supported
H1	Cyber-Attack Features $\rightarrow$ Cybersecurity Readiness	0.33	6.54	< .001	Yes
H2	Cyber-Attack Features $\rightarrow$ Project Team Skills	0.44	7.22	< .001	Yes
H3	Project Team Skills $\rightarrow$ Cybersecurity Readiness	0.47	8.01	< .001	Yes
H4	Cyber-Attack Features $\rightarrow$ Project Team Skills $\rightarrow$ Cybersecurity Readiness (Mediating)	0.36 (Indirect)	8.49	< .001	Yes (Partial Mediation)

5 Discussion

This study's findings clearly show that certain cyber-attack features—especially their complexity, frequency, and advanced nature—significantly affect how well organizations prepare for and manage cybersecurity risks [23,29]. These results are consistent with patterns seen in the logistics and transport industries, where the growing

number of complex cyber threats has led companies to strengthen their detection systems and improve their ability to respond. Notable examples, such as the NotPetya attack that heavily impacted operations at Maersk and TNT Express, highlight how repeated cyber incidents can prompt major changes in cybersecurity strategies and infrastructure [147].

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In line with earlier research, this study confirms that frequent exposure to advanced cyber threats drives technical upgrades and supports team skills growth. For instance, [38] highlighted that team communication and coordination are essential to managing cybersecurity challenges. The present findings build on this by showing that teams regularly facing complex threats tend to develop stronger response capabilities, increased trust among team members, and improved learning habits [40]. These insights are further supported by studies using simulated environments, where high-pressure situations have been shown to enhance awareness and performance in responding to incidents, as illustrated by Fausett and Keebler (2023).

The strong link between project team skills and cybersecurity readiness points to the crucial role of human expertise in reducing cyber risk. When teams possess the right skills, they can react more effectively to attacks, help maintain organizational stability, and rely on shared mental models that support fast, well-informed decisions [43,51,55]. This evidence reinforces the view that effective cybersecurity plans should not rely solely on technology but should also include investment in workforce development [50,53].

The mediation analysis further revealed that team skills partly explain the connection between cyber-attack features and readiness [134]. This supports the idea from trait-activation theory that external challenges can trigger hidden capabilities within individuals and groups, improving overall organizational performance [43,51]. At the same time, the presence of a direct impact from cyber threats on readiness suggests that external attacks and internal team strengths contribute to building resilience. This dual effect indicates that threat exposure and internal capabilities shape how prepared an organization is [55,144].

These results have clear practical implications for logistics and express delivery firms. Organizations should adopt cybersecurity strategies that balance technology upgrades with continuous team development. Regular cyber drills, encouraging collaboration across departments, and flexible planning should be part of everyday operations to improve adaptability and coordination [38,51]. Embedding these practices into standard procedures can help create a proactive culture about cybersecurity and be ready to handle new and evolving threats [43].

Theoretically, this research also adds to the broader understanding of cybersecurity in organizations. It expands current models by showing how the nature of cyber threats—like how often they happen or how complex they are—can drive improvements in technical systems and human capabilities. While earlier frameworks (e.g., [51]) mainly focused on behavior or organizational culture, this study highlights how external challenges prompt team learning and coordination. Recognizing project team skills as a mediating factor offers a fresh angle on how organizations can become more resilient. Past research, such as [4], often emphasized leadership's role but did not

explore how ongoing cyber threats help shape skills within operational teams. This study helps close that gap by showing how real-world pressure activates human potential, resulting in better preparedness.

For those responsible for managing cybersecurity, these insights offer valuable guidance. Understanding the specific traits of cyber threats should influence where resources are allocated—not only in terms of protective tools but also in training and team development. Training programs should reflect the nature of current threats, especially their complexity and frequency, while practice exercises that simulate real attacks can help teams build experience and respond more effectively [38]. After real and simulated events, follow-up reviews can promote learning and improve future processes. Integrating cybersecurity tasks into daily logistics work helps make readiness an ongoing and embedded part of business operations.

At a policy level, these findings suggest that regulators in Jordan and other emerging markets should create cybersecurity frameworks that measure both technology and people-related factors. Adopting models like the one proposed in [51]—which focus on learning, collaboration, and workplace culture—can support better assessment and coordination throughout the logistics sector. Promoting digital skills, running industry-wide drills, and funding training programs can strengthen readiness at both individual and organizational levels. Public agencies can further support these efforts through national strategies, shared knowledge platforms, and real-time monitoring tools across the supply chain. Although this research makes several contributions, it is not without limitations. The study's cross-sectional design means it cannot confirm cause-and-effect relationships or track how skills develop over time. Its focus on Jordan's express delivery sector also limits the extent to which findings can be applied elsewhere. In addition, the use of self-reported survey data may introduce some bias, even though techniques like Harman's single-factor test were used to reduce this risk. Future studies should use longitudinal designs to capture better how threats and team responses change over time. Comparing findings across countries or sectors may also reveal how different systems and cultures affect cybersecurity readiness. Furthermore, using qualitative methods—such as case studies or interviews—could offer deeper insight into how teams work together and learn from cyber events. Future research might also explore other influencing factors, such as leadership approaches, technology maturity, or organizational culture, to understand how cybersecurity resilience develops [51].

In conclusion, this study shows that cybersecurity readiness in logistics depends not only on the nature of external threats but also on the capabilities of internal teams. The partial mediating role of project team skills makes it clear that simply facing threats is not enough—what matters is having skilled and adaptable teams that can turn those challenges into effective responses. By combining analysis of threat features with efforts to build

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human expertise, this study adds theoretical insight and practical value for logistics companies facing constant digital risks.

6 Conclusion

This research explored how certain cyber-attack features—specifically their sophistication, frequency, and complexity—affect cybersecurity readiness among project teams in Jordan's express delivery sector. A key part of the study was examining the project team skills' role in linking these cyber threats to organizational preparedness. Using a quantitative cross-sectional approach and validating the model with structural equation modeling, the findings showed that cyber-attack traits directly and indirectly impact cybersecurity readiness. The discovery of a partial mediation effect offers a vital takeaway: understanding and identifying threats is important, but having skilled, flexible teams is what truly turns that knowledge into practical readiness. This underlines the importance of human resources in supporting technology and maintaining resilience in cybersecurity.

From a logistics management standpoint, the study offers clear guidance. Companies in the express delivery field should focus on both tracking threats and developing team capabilities. To do this, they should regularly run realistic cybersecurity drills, promote cross-departmental collaboration, and implement clear plans for managing incidents. Because these companies rely heavily on real-time technology and seamless service delivery, it is essential to build technically skilled teams, aware of ongoing risks, and able to work together effectively. This preparation can reduce the impact of cyber incidents and help maintain uninterrupted service.

These insights are useful for logistics managers, IT professionals, and policymakers. In Jordan and similar developing markets, cybersecurity planning should go beyond protecting systems and also focus on strengthening the skills of the people involved. National policies supporting digital training, joint cyber exercises, and knowledge sharing across supply chains can help build stronger, more resilient systems.

That said, the study does have a few limitations. Because it relied on self-reported data, there is a risk of personal bias in responses. Its focus on Jordanian express delivery companies also means the results may not fully apply to other regions or sectors. Additionally, the cross-sectional design only provides a snapshot, making it difficult to track how teams adapt or grow in response to ongoing threats. Future studies should consider using a long-term approach to examine how exposure to cyber threats influences team learning. Comparing data across countries or industries could also reveal how different environments shape readiness. Moreover, exploring additional influencing factors—such as leadership approaches or company culture—could give a more complete picture of what drives cybersecurity resilience.

To conclude, this study adds to the broader understanding of cybersecurity by linking external threats

with the internal skills of project teams. It shows how technical challenges and human readiness shape how well logistics organizations respond to cyber risks. The findings offer value for academic research and practical efforts to improve cybersecurity in fast-paced, digitally driven industries like express logistics.

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References

- [1] MASHALAH, H.A., HASSINI, E., GUNASEKARAN, A., BHATT, D.: The impact of digital transformation on supply chains through e-commerce: Literature review and a conceptual framework, *Transportation Research Part E Logistics and Transportation Review*, Vol. 165, No. September, 102837, 2022.
<https://doi.org/10.1016/j.tre.2022.102837>
- [2] NIYAWANONT, N., WANARAT, S.: Structural equation Modelling of digital entrepreneurship, logistics innovation, and digital transformation influence on logistics performance of logistics entrepreneurs in Thailand, *ABAC Journal*, Vol. 41, No. 4, pp. 147-174, 2021.
- [3] CUONG, T.H., TIEN, N.H.: Application of ICT in Logistics and Supply Chain in post-Covid-19 economy in Vietnam, *International Journal of Multidisciplinary Research and Growth Evaluation*, Vol. 3, No. 1, pp. 493-451, 2022.
- [4] CREAZZA, A., COLICCHIA, C., SPIEZIA, S., DALLARI, F.: Who cares? Supply chain managers' perceptions regarding cyber supply chain risk management in the digital transformation era, *Supply Chain Management an International Journal*, Vol. 27, No. 1, pp. 30-53, 2021.
<https://doi.org/10.1108/scm-02-2020-0073>
- [5] RAUNIYAR, K., WU, X., GUPTA, S., MODGIL, S., DE SOUSA JABBOUR, A.B.L.: Risk management of supply chains in the digital transformation era: contribution and challenges of blockchain technology, *Industrial Management & Data Systems*, Vol. 123, No. 1, pp. 253-277, 2022.
<https://doi.org/10.1108/imds-04-2021-0235>
- [6] KECHAGIAS, E.P., CHATZISTELIOS, G., PAPADOPOULOS, G.A., APOSTOLOU, P.: Digital transformation of the maritime industry: A cybersecurity systemic approach, *International Journal of Critical Infrastructure Protection*, Vol. 37, No. July, 100526, 2022.
<https://doi.org/10.1016/j.ijcip.2022.100526>

- [7] SINDIRAMUTTY, S.R., JHANJHI, N.Z., TAN, C.E., KHAN, N.A., SHAH, B., MANCHURI, A.R.: *Cybersecurity measures for logistics industry*, In: N. Jhanjhi, I. Shah (Eds.), *Navigating Cyber Threats and Cybersecurity in the Logistics Industry*, IGI Global Scientific Publishing, pp. 1-58, 2024. <https://doi.org/10.4018/979-8-3693-3816-2.ch001>
- [8] JHANJHI, N.Z., SHAH, I.A.: *Navigating cyber threats and cybersecurity in the logistics industry*, *Advances in information security, privacy, and ethics book series*, IGI Global Scientific Publishing, 2024. <https://doi.org/10.4018/979-8-3693-3816-2>
- [9] ODIMARHA, N.A.C., AYODEJI, N.S.A., ABAKU, N.E.A.: *Securing the digital supply chain: Cybersecurity best practices for logistics and shipping companies*, *World Journal of Advanced Science and Technology*, Vol. 5, No. 1, pp. 026-030, 2024. <https://doi.org/10.53346/wjast.2024.5.1.0030>
- [10] QUYET, N.X., PHUNG, T.K.: *Comparative analysis of information security policies at Big 4 Vietnamese logistics companies*, *International Journal of Multidisciplinary Research and Growth Evaluation*, Vol. 4, No. 6, pp. 683-690, 2023.
- [11] HLYNSKY, N., DOVHUN, O., POCHOPIEŃ, J.: *Digitalization and cybersecurity in companies and supply chains: challenges and opportunities*, *Scientific Journal of Bielsko-Biala School of Finance and Law*, Vol. 29, No. 1, pp. 53-59, 2025. <https://10.19192/wsfip.sj1.2025.7>
- [12] NUSEIR, M.T., ALQUQA, E.K., SHRAAH, A.A., ALSHURIDEH, M.T., KURDI, B.A., ALZOUBI, H.M.: *Impact of Cyber Security Strategy and Integrated Strategy on E-Logistics Performance: An Empirical Evidence from the UAE Petroleum Industry*, In: Alzoubi, H.M., Alshurideh, M.T., Ghazal, T.M. (eds), *Cyber Security Impact on Digitalization and Business Intelligence*, *Studies in Big Data*, Vol. 117, Springer, Cham., pp. 89-108, 2024. https://doi.org/10.1007/978-3-031-31801-6_6
- [13] ALOUN, D.M.: *E-Commerce Companies in Jordan*, *Journal of the Learning Sciences*, Vol. 32, No. 2, pp. 1-26, 2024. <https://10.5281/zenodo.12794277>
- [14] AL-SHAIKH, M.S., KHANFAR, I.A.A.: *Delivery service via electronic applications and its impact on customers satisfaction at retail stores in Amman City/Jordan*, In: Hamdan, A., Shoaib, H.M., Alareeni, B., Hamdan, R. (eds) *The Implementation of Smart Technologies for Business Success and Sustainability*. *Studies in Systems, Decision and Control*, vol 216. Springer, Cham., pp. 827-837, 2022. https://doi.org/10.1007/978-3-031-10212-7_68
- [15] HAMED, M.M.: *Logistics performance and freight sector in Jordan*, *European Journal of Scientific Research*, Vol. 152, No. 4, pp. 516-527, 2019.
- [16] ALSHURIDEH, M.T., SHATNAWI, T.M., AL-MOMANI, A., MOHAMMAD, A.A.S., ALZOUBI, A., ALZYOUD, M., AL-SHANABLEH, N., ALAJARMEH, N.S., AL-HAWARY, S.I.S., ALDAIHANI, F.M.F.: *Analysing the impact of online journey determinants on customer digital engagement: an empirical study in Jordan*, In: Musleh Al-Sartawi, A.M.A., Nour, A.I. (eds) *Artificial Intelligence and Economic Sustainability in the Era of Industrial Revolution 5.0*. *Studies in Systems, Decision and Control*, Vol. 528, Springer, Cham., pp. 1109-1122, 2024. https://doi.org/10.1007/978-3-031-56586-1_81
- [17] ELSHEBLI, A., SWEIS, G., SHARAF, A., JAGHBEER, G.A.: *Proposed framework for medication delivery system in the Jordanian public health sector*, *BMC Medical Informatics and Decision Making*, Vol. 24, No. 1, pp. 1-17, 2024. <https://doi.org/10.1186/s12911-024-02673-2>
- [18] IRSHEIDAT, S.A., SHARIFF, D., IRSHEIDAT, A.M., DAOUD, M.K., ABDULLAH, D.: *The effect of operational service quality in land cargoes operators on sustainability: the case of Jordanian logistics industry*, *International Journal of Entrepreneurship*, Vol. 25, No. Special Issue 1, pp. 1-8, 2021.
- [19] JABER, M.Y.: *The Impact of Blockchain on the Digitalizing Courier System of Supply Chain in Jordan*, Doctoral dissertation, Middle East University, 2024.
- [20] AL-TUAIMEH, S.F.: *Building a Proposed Model for Supply Chain Decisions Support System in Express Shipping Companies in Jordan*, Doctoral dissertation, Middle East University, 2011.
- [21] FRESNER, J., KRENN, C., HADDAD, J., ABDALLAH, R., MATAIQA, B., SADA, A.A.: *A new approach to motivate micro and small enterprises for Resource-Efficient and cleaner production in Jordan*, *Sustainability*, Vol. 17, No. 6, 2404, pp. 1-21, 2025. <https://doi.org/10.3390/su17062404>
- [22] SAMAWI, G.A., BWALIEZ, O.M., DMOUR, W.A., MDANAT, M.F., TA'AMNHA, M.A.: *Eco-Smart Economics: Revolutionizing Jordan's Logistics with Sustainable Drone Technology*, *International Journal of Energy Economics and Policy*, Vol. 14, No. 5, pp. 49-61, 2024. <https://doi.org/10.32479/ijee.16462>
- [23] DA PAZ FERRAZ SANTOS, P.R., RESENDE, P.A.A., GONDIM, J.J.C., DRUMMOND, A.C.: *Towards Robust Cyber Attack Taxonomies: A Survey with Requirements, Structures, and Assessment*, *ACM Computing Surveys*, Vol. 57, No. 8, pp. 1-36, 2025. <https://doi.org/10.1145/3717606>
- [24] ALMASS, S., CHOWDHARY, S.K.: *Comprehensive Study on Cyber Security and Cyber Attacks*, In: 2024 First International Conference on Electronics, Communication and Signal Processing (ICECSP), New Delhi, India, 2024, pp. 1-6, 2024. <https://doi.org/10.1109/icecsp61809.2024.10698540>
- [25] KIM, K., ALFOUZAN, F.A., KIM, H.: *Cyber-Attack scoring model based on the Offensive Cybersecurity*

- Framework, *Applied Sciences*, Vol. 11, No. 16, 7738, pp. 1-21, 2021. <https://doi.org/10.3390/app11167738>
- [26] CHUNG, J.: *Emerging Cyber-Attacks*, In: *Emerging Secure Networks, Blockchains and Smart Contract Technologies*, Springer, Cham., pp. 1-29, 2024. https://doi.org/10.1007/978-3-031-65866-2_1
- [27] YAMIN, M.M., KATT, B.: se of cyber attack and defense agents in cyber ranges: A case study, *Computers & Security*, Vol. 122, No. November, 102892, 2022. <https://doi.org/10.1016/j.cose.2022.102892>
- [28] LEE, J., LEE, Y., LEE, D., KWON, H., SHIN, D.: Classification of attack types and analysis of attack methods for profiling phishing mail attack groups, *IEEE Access*, Vol. 9, pp. 80866-80872, 2021. <https://doi.org/10.1109/ACCESS.2021.3084897>
- [29] PARK, J.H., SINGH, S.K., SALIM, M.M., AZZAOUI, A.E., PARK, J.H.: Ransomware-based cyber attacks: A comprehensive survey, *Journal of Internet Technology*, Vol. 23, No. 7, pp. 1557-1564, 2022. <https://doi.org/10.53106/160792642022122307010>
- [30] ALKHALIL, Z., HEWAGE, C., NAWAF, L., KHAN, I.: Phishing attacks: A recent comprehensive study and a new anatomy, *Frontiers in Computer Science*, Vol. 3, 563060, pp. 1-23, 2021. <https://doi.org/10.3389/fcomp.2021.563060>
- [31] ALGHENAIM, M.F., BAKAR, N.A.A., ABDUL RAHIM, F., VANDUHE, V.Z., ALKAWSI, G.: *Phishing attack types and mitigation: A survey*, In: Wah, Y.B., Berry, M.W., Mohamed, A., Al-Jumeily, D. (eds) *Data Science and Emerging Technologies, DaSET 2022, Lecture Notes on Data Engineering and Communications Technologies*, Vol. 165, Springer, Singapore, pp. 131-153, 2022. https://doi.org/10.1007/978-981-99-0741-0_10
- [32] RANI, S.K., SOUNDARYA, B.C., GURURAJ, H.L., JANHAVI, V.: *Comprehensive analysis of various cyber attacks*, In: 2021 IEEE Mysore sub section international conference (MysuruCon), Hassan, India, pp. 255-262, 2021. <https://doi.org/10.1109/MysuruCon52639.2021.9641089>
- [33] SUN, R., LUO, Q., CHEN, Y.: Online transportation network cyber-attack detection based on stationary sensor data, *Transportation Research Part C: Emerging Technologies*, Vol. 149, No. April, 104058, 2023. <https://doi.org/10.1016/j.trc.2023.104058>
- [34] CHOPRA, A.: Cyberattack-Intangible damages in a virtual world: Property insurance companies declare War on cyber-attack insurance claims, *Ohio State Law Journal*, Vol. 82, No. 1, pp. 121-162, 2021.
- [35] BAHADORIPOUR, S., KARIMPOUR, H., JAHROMI, A.N., ISLAM, A.: An explainable multi-modal model for advanced cyber-attack detection in industrial control systems, *Internet of Things*, Vol. 25, No. April, 101092, 2024. <https://doi.org/10.1016/j.iot.2024.101092>
- [36] AMAL, M.R., VENKADESH, P.: Review of Cyber Attack Detection: Honeypot System, *Webology*, Vol. 19, No. 1, pp. 5497-5514, 2022. <https://doi.org/10.14704/web/v19i1/web19370>
- [37] AUSTIN, G., WITHERS, G.: *Valuation of Reputation Damage for Transport Cyber Attack*, [Online], Available: <https://appliedeconomics.com.au/wp-content/uploads/2022/02/Final-Cyber-Report-01-11-2021-5.pdf> [10 Jun 2025], 2021.
- [38] SINLAPANUNTAKUL, P., FAUSETT, C.M., KEEBLER, J.R.: Exploring team competencies in cybersecurity, *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, Vol. 66, No. 1, pp. 1110-1114, 2022. <https://doi.org/10.1177/1071181322661496>
- [39] SHINDE, N., KULKARNI, P.: Cyber incident response and planning: a flexible approach, *Computer Fraud & Security*, Vol. 2021, No. 1, pp. 14-19, 2021. [https://doi.org/10.1016/s1361-3723\(21\)00009-9](https://doi.org/10.1016/s1361-3723(21)00009-9)
- [40] FAUSETT, C.M., KEEBLER, J.R.: Teamwork in Cybersecurity: Evaluating the Cooperative Board Game [d0x3d!] as an Experimental Testbed, *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, Vol. 67, No. 1, pp. 1924-1929, 2023. <https://doi.org/10.1177/21695067231192665>
- [41] ALJUMAIAH, O., JIANG, W., ADDULA, S.R., ALMAIAH, M.A.: Analyzing Cybersecurity Risks and Threats in IT Infrastructure based on NIST Framework, *Journal of Cyber Security and Risk Auditing*, Vol. 2025, No. 2, pp. 12-26, 2025. <https://doi.org/10.63180/jcsra.thestap.2025.2.2>
- [42] CHOURASIA, N.R.: AI-Enhanced Cybersecurity Training: Learning Analytics in action, *International Journal of Advanced Research in Science Communication and Technology*, Vol. 5, No. 2, pp. 566-573, 2025. <https://doi.org/10.48175/ijarsct-23066>
- [43] MCBRIDE, D.Y.: *An Analysis of Cybersecurity Curriculum Designs, Workforce Readiness Skills, and Applied Learning Effectiveness*, Doctoral dissertation, Capitol Technology University, Laurel, Maryland, USA, 2021.
- [44] WANG, S., LI, Y., CHEN, F.: Optimizing Blue Team Strategies with Reinforcement Learning for Enhanced Ransomware Defense Simulations, *Authorea*, Vol. 2024, pp. 1-9, 2024. <https://doi.org/10.22541/au.172356133.30648910/v1>
- [45] SAFITRA, M.F., LUBIS, M., FAKHRURROJA, H.: Counterattacking Cyber Threats: A framework for the Future of Cybersecurity. Sustainability, Vol. 15, No. 18, 13369, pp. 1-32, 2023. <https://doi.org/10.3390/su151813369>
- [46] STEINGARTNER, W., GALINEC, D., KOZINA, A.: Threat Defense: Cyber Deception approach and Education for Resilience in Hybrid Threats model,

Enhancing cybersecurity readiness in express logistics: the role of cyber-attack features and project team skills

Umi Kalsum Zolkafli, Ahmad AlArabi

- Symmetry, Vol. 13, No. 4, 597, pp. 1-25, 2021. <https://doi.org/10.3390/sym13040597>
- [47] NEELI, S.S.S.: Critical cybersecurity strategies for database protection against cyber attacks, *Journal of Artificial Intelligence Machine Learning and Data Science*, Vol. 1, No. 1, pp. 2102-2106, 2023. <https://doi.org/10.51219/jaimld/sethu-sesha-synam-neeli/461>
- [48] LEHTO, M.: *Cyber-Attacks against critical infrastructure*, In: Lehto, M., Neittaanmäki, P. (eds) *Cyber Security, Computational Methods in Applied Sciences*, Vol. 56, Springer, Cham., pp. 3-42, 2022. https://doi.org/10.1007/978-3-030-91293-2_1
- [49] ROY, N.C., PRABHAKARAN, S.: Cyber fraud (CF) in banking: a dual-layer, blockchain-enabled approach for prevention and managerial response, *Managerial Finance*, Vol. 51, No. 5, pp. 765-796, 2025. <https://doi.org/10.1108/mf-09-2024-0716>
- [50] STAVES, A., ANDERSON, T., BALDERSTONE, H., GREEN, B., GOUGLIDIS, A., HUTCHISON, D.: A cyber incident response and recovery framework to support operators of industrial control systems, *International Journal of Critical Infrastructure Protection*, Vol. 37, No. July, 100505, 2022. <https://doi.org/10.1016/j.ijcip.2021.100505>
- [51] GEORGIADOU, A., MOUZAKITIS, S., BOUNAS, K., ASKOUNIS, D.: A Cyber-Security culture framework for assessing organization readiness, *Journal of Computer Information Systems*, Vol. 62, No. 3, pp. 452-462, 2020. <https://doi.org/10.1080/08874417.2020.1845583>
- [52] STADNYK, M., PALAMAR, A.: Project management features in the cybersecurity area, *Scientific Journal of the Ternopil National Technical University*, Vol. 2, No. 106, pp. 54-62, 2022. https://doi.org/10.33108/visnyk_tntu2022.02.054
- [53] CRUMPLER, W., LEWIS, J.A.: *Cybersecurity workforce gap*, Center for Strategic and International Studies (CSIS), [Online], Available: https://csis-website-prod.s3.amazonaws.com/s3fs-public/publication/190129_Crumpler_Cybersecurity_FINAL.pdf [10 Jun 2025] 2019.
- [54] SALIN, H., LUNDGREN, M.: Towards agile cybersecurity risk management for autonomous software engineering teams, *Journal of Cybersecurity and Privacy*, Vol. 2, No. 2, pp. 276-291, 2022. <https://doi.org/10.3390/jcp2020015>
- [55] CHAPMAN, T.A., REITHEL, B.J.: Perceptions of cybersecurity readiness among workgroup IT managers, *Journal of Computer Information Systems*, Vol. 61, No. 5, pp. 438-449, 2021. <https://doi.org/10.1080/08874417.2019.1703224>
- [56] HOSSAIN, M.A., RAZA, M.A., RAHMAN, T.Y.: Resource allocation and budgetary constraints for cybersecurity projects in small to medium sized banks, *Journal of Multidisciplinary Research*, Vol. 9, No. 1, pp. 135-157, 2023.
- [57] ECK, C.A.: *Examining US Organizations' Information Security: A Quantitative Study of Employee Job Role Effects on Cybersecurity Measures Employed*, Doctoral dissertation, Robert Morris University, 2024.
- [58] FLOROS, E., STAVROU, E., SMYRLIS, M., NIKOLOUDAKIS, N., POTAMOS, G., APOSTOLIDIS, A., BEMPIS, P., GRIGORIADIS, A., MAGKOS, K., MERKOURIS, D., SPANOUDAKIS, G., STAVROU, S., TRIKOS, S., PAPADAKIS, S.E.: *Towards the Design of Cyber Range Training Programs for Enhanced Preparedness: Investigating the Training Needs in Critical Infrastructures*, In: 2025 IEEE Global Engineering Education Conference (EDUCON), London, United Kingdom, pp. 1-10, IEEE, 2025. <https://doi.org/10.1109/EDUCON62633.2025.11016646>
- [59] JORDAN, K.A.: *Quantitative Effects of Simulation-Based User Training on Overall Cyber Resilience in Department of Defense (DoD) Systems*, Capitol Technology University, 2022.
- [60] ELENDU, C., OMELUDIKE, E.K., OLOYEDE, P.O., OBIDIGBO, B.T., OMELUDIKE, J.C.: Legal implications for clinicians in cybersecurity incidents: A review, *Medicine*, Vol. 103, No. 39, e39887, 2024. <https://doi.org/10.1097/md.00000000000039887>
- [61] KLINDIENST, J., AYANIAN, S., SCHLEGELMILCH, J., AKSELROD, H.: Preparing for compounding crises: Staff shortages and cyber-attack vulnerability in the era of COVID-19, *Journal of Business Continuity & Emergency Planning*, Vol. 16, No. 2, pp. 103-120, 2022. <https://doi.org/10.7916/6ya3-x453>
- [62] HOWELL JR, J.W.: *Exploring the Perceptions of Perceived and Actual Cyber Readiness*, Doctoral dissertation, Capella University, 2021.
- [63] SHAHZAD, M., SHAFIQ, M.Z., LIU, A.X.: *A large scale exploratory analysis of software vulnerability life cycles*, 2012 34th International Conference on Software Engineering (ICSE), pp. 771-781, 2012. <https://doi.org/10.1109/ICSE.2012.6227141>
- [64] VÄLJA, M., KORMAN, M., LAGERSTRÖM, R.: *A Study on Software Vulnerabilities and Weaknesses of Embedded Systems in Power Networks*, 2nd Workshop on Cyber-Physical Security and Resilience in Smart Grids, CPSR-SG 2017, 21 April 2017, pp. 47-52, 2017. <https://doi.org/10.1145/3055386.3055397>
- [65] BAYRAMOVA, T.: *Analysis of modern methods for detecting vulnerabilities in software for industrial information systems*, In: NATO science for peace and security series, D, Information and communication security, Vol. 62, pp. 160-162, 2022. <https://doi.org/10.3233/nicsp220050>
- [66] XU, D., WONG, T., SCULLI, D.: A software platform to support collaboration in express delivery services, *Journal of International Technology and*

Enhancing cybersecurity readiness in express logistics: the role of cyber-attack features and project team skills

Umi Kalsum Zolkafli, Ahmad AlArabiati

- Information Management, Vol. 22, No. 2, pp. 19-34, 2013. <https://doi.org/10.58729/1941-6679.1008>
- [67] SEGHEZZI, A., MANGIARACINA, R., TUMINO, A., PEREGO, A.: 'Pony express' crowdsourcing logistics for last-mile delivery in B2C e-commerce: an economic analysis, *International Journal of Logistics Research and Applications*, Vol. 24, No. 5, pp. 456-472, 2021. <https://doi.org/10.1080/13675567.2020.1766428>
- [68] ZHAO, C., ZHOU, B.: Impact of Express Delivery Industry's Development on Transportation Sector's Carbon Emissions: An Empirical Analysis from China, *Sustainability*, Vol. 13, No. 16, 8908, pp. 1-21, 2021. <https://doi.org/10.3390/su13168908>
- [69] ALHAZMI, O., MALAIYA, Y., RAY, I.: *Security Vulnerabilities in software Systems: A Quantitative perspective*, In: Jajodia, S., Wijesekera, D. (eds) Data and Applications Security XIX, DBSec 2005, Lecture Notes in Computer Science, Vol. 3654, Springer, Berlin, Heidelberg, pp. 281-294, 2005. https://doi.org/10.1007/11535706_21
- [70] NOWAKOWSKI, T., WERBIŃSKA-WOJCIECHOWSKA, S.: *Problems of logistic Systems vulnerability and resilience assessment*, In: Golinska, P. (eds) Logistics Operations, Supply Chain Management and Sustainability, EcoProduction. Springer, Cham., pp. 171-186, 2014. https://doi.org/10.1007/978-3-319-07287-6_12
- [71] ALNAELI, S.M., SARNOWSKI, M., AMAN, M.S., ABDELGAWAD, A., YELAMARTHI, K.: Source code vulnerabilities in IoT software systems, *Advances in Science Technology and Engineering Systems Journal*, Vol. 2, No. 3, pp. 1502-1507, 2017. <https://doi.org/10.25046/aj0203188>
- [72] CORREA, G.: *To err is human, or is it?*, Process Safety Progress, Special Issue: Latin American Process Safety Conference Nov 3-5, 2020, Vol. 40, No. S1, pp. S4-S7, 2021. <https://doi.org/10.1002/prs.12225>
- [73] AMORESANO, K., YANKSON, B.: Human error - a critical contributing factor to the rise in data breaches: A case study of higher education, *HOLISTICA - Journal of Business and Public Administration*, Vol. 14, No. 1, pp. 110-132, 2023. <https://doi.org/10.2478/hjbpa-2023-0007>
- [74] HANSEN, F.D.: Human Error: a Concept analysis, *Journal of Air Transportation*, Vol. 11, No. 3, pp. 61-77, 2006. <https://ntrs.nasa.gov/citations/20070022530>
- [75] NCUBUKEZIT, T.: *Human errors: a cybersecurity concern and the weakest link to small businesses*, Proceedings of the 17th International Conference on Cyber Warfare and Security (ICWS 2022), Vol. 17, No. 1, pp. 395-403, 2022. <https://doi.org/10.34190/icws.17.1.51>
- [76] BOYCE, M.W., DUMA, K.M., HETTINGER, L.J., MALONE, T.B., WILSON, D.P., LOCKETT-REYNOLDS, J.: Human Performance in Cybersecurity: a research agenda, *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, Vol. 55, No. 1, pp. 1115-1119, 2011. <https://doi.org/10.1177/1071181311551233>
- [77] ALSHARIF, M., MISHRA, S., ALSHEHRI, M.: Impact of human vulnerabilities on cybersecurity, *Computer Systems Science and Engineering*, Vol. 40, No. 3, pp. 1153-1166, 2021. <https://doi.org/10.32604/csse.2022.019938>
- [78] SHAHRAKI, A.S., NIKMARAM, M.: Human errors in computer related abuses, *Journal of Theoretical and Applied Information Technology*, Vol. 47, No. 1, pp. 93-97, 2013. <https://eprints.qut.edu.au/74466/>
- [79] NOBLES, C., ROBINSON, N., CUNNINGHAM, M., ROBINSON, N., CUNNINGHAM, M., CUNNINGHAM, M.: *Straight from the Human Factors Professionals' Mouth: The Need to Teach Human Factors in Cybersecurity*, SIGITE'2022: Proceedings of the 23rd Annual Conference on Information Education, pp. 157-158, 2022. <https://doi.org/10.1145/3537674.3555782>
- [80] ROSYIDI, E., YUSELIN, N., YAHYA, K.: Analysis of factors causing errors in issue of goods at PT Dunia Express Transindo's warehouse, *Jurnal Syntax Transformation*, Vol. 4, No. 2, pp. 165-182, 2023. <https://doi.org/10.46799/jst.v4i2.694>
- [81] YOU, J., LIU, B., WANG, Y., LIU, J.: *Tracking the prevalence of compromised passwords using long-term honeypot data*, In: Proceedings SPIE 12700, International Conference on Electronic Information Engineering and Data Processing (EIEDP 2023), 127000K (26 May 2023), 2023.
- [82] DARKO, C.D.: *Weak credential information as a threat to online security*, SMART-IEEE-Creative Research Publications Book Chapter Series on Research Nexus in IT, Law, Cyber Security & Forensic, pp. 35-40, 2022. <https://doi.org/10.22624/aims/crp-bk3-p6>
- [83] HAJNÝ, J., MALINA, L.: *Anonymous credentials with practical revocation*, 2012 IEEE First AESSE European Conference on Satellite Telecommunications (ESTEL), Rome, Italy, 2012, pp. 1-6, 2012. <https://doi.org/10.1109/ESTEL.2012.6400081>
- [84] SINGH, V., PANDEY, S.K.: *Revisiting cloud security attacks: Credential attack*, In: Rathore, V.S., Dey, N., Piuri, V., Babo, R., Polkowski, Z., Tavares, J.M.R.S. (eds) Rising Threats in Expert Applications and Solutions. Advances in Intelligent Systems and Computing, Vol. 1187, Springer, Singapore, pp. 339-350, 2021. https://doi.org/10.1007/978-981-15-6014-9_39
- [85] NATHAN, M.: Credential stuffing: new tools and stolen data drive continued attacks, *Computer Fraud & Security*, Vol. 2020, No. 12, pp. 18-19, 2020. [https://doi.org/10.1016/s1361-3723\(20\)30130-5](https://doi.org/10.1016/s1361-3723(20)30130-5)
- [86] JOHNSON, J.W., FRANKE, K.: *Identifying Proficient Cybercriminals Through Text and Network*

Enhancing cybersecurity readiness in express logistics: the role of cyber-attack features and project team skills

Umi Kalsum Zolkafli, Ahmad AlArabiati

- Analysis, In: 2020 IEEE International Conference on Intelligence and Security Informatics (ISI), Arlington, VA, USA, 2020, pp. 1-7, 2020. <https://doi.org/10.1109/ISI49825.2020.9280523>
- [87] KENNISON, S.M., CHAN-TIN, E.: Taking Risks with Cybersecurity: Using knowledge and personal characteristics to predict Self-Reported Cybersecurity Behaviors, *Frontiers in Psychology*, Vol. 11, pp. 1-9, 2020. <https://doi.org/10.3389/fpsyg.2020.546546>
- [88] GRIFFIN, P.H.: *Biometric-Based cybersecurity techniques*, In: Nicholson, D. (eds) *Advances in Human Factors in Cybersecurity*, *Advances in Intelligent Systems and Computing*, Vol. 501, Springer, Cham., pp. 43-53, 2016. https://doi.org/10.1007/978-3-319-41932-9_5
- [89] PELCHEN, C., JAEGER, D., CHENG, F., MEINEL, C.: *The (Persistent) threat of weak passwords: implementation of a semi-automatic Password-Cracking algorithm*, In: Heng, SH., Lopez, J. (eds) *Information Security Practice and Experience, ISPEC 2019, Lecture Notes in Computer Science()*, Vol. 11879, Springer, Cham., pp. 464-475, 2019. https://doi.org/10.1007/978-3-030-34339-2_27
- [90] SARKAR, K.R.: Assessing insider threats to information security using technical, behavioural and organisational measures, *Information Security Technical Report*, Vol. 15, No. 3, pp. 112-133, 2010. <https://doi.org/10.1016/j.istr.2010.11.002>
- [91] PROBST, C.W., HUNKER, J., GOLLMANN, D., BISHOP, M.: *Insider threats in cyber security*, *Advances in Information Security*, Vol. 49, Springer, 2010. <https://doi.org/10.1007/978-1-4419-7133-3>
- [92] VILLARREAL-VASQUEZ, M., MODELO-HOWARD, G., DUBE, S., BHARGAVA, B.: Hunting for insider threats using LSTM-Based anomaly detection, *IEEE Transactions on Dependable and Secure Computing*, Vol. 20, No. 1, pp. 451-462, 2021. <https://doi.org/10.1109/tdsc.2021.3135639>
- [93] STOLFO, S.J., BELLOVIN, S.M., HERSHKOP, S., KEROMYTIS, A., SINCLAIR, S., SMITH, S.W.: *Insider Attack and Cyber Security: Beyond the Hacker*, Springer US, 2008.
- [94] SINGH, A.P., SHARMA, A.: A systematic literature review on insider threats, *arXiv*, Cornell University, Vol. 2022, pp. 1-9, 2022. <https://doi.org/10.48550/arxiv.2212.05347>
- [95] HONG, J., KIM, J., CHO, J.: *The trend of the security research for the insider cyber threat*, In: Ślęzak, D., Kim, Th., Fang, WC., Arnett, K.P. (eds) *Security Technology, SecTech 2009, Communications in Computer and Information Science*, Vol. 58, Springer, Berlin, Heidelberg, pp. 100-107, 2009. https://doi.org/10.1007/978-3-642-10847-1_13
- [96] GILLARD, S.: Soft skills and technical expertise of effective project managers, *Issues in Informing Science and Information Technology*, Vol. 6, pp. 723-729, 2009.
- [97] BARRETT, M.J., MARRON, J., PILLITTERI, V., BOYENS, J.M., QUINN, S., WITTE, G., FELDMAN, L.: *Approaches for Federal Agencies to Use the Cybersecurity Framework*, NIST, National Institute of Standards and Technology, U.S. Department of Commerce, NISTIR 8170, 2020. <https://doi.org/10.6028/NIST.IR.8170-upd>
- [98] KLEIN, G., JIANG, J.J., TESCH, D.: Wanted: project teams with a blend of is professional orientations, *Communications of the ACM*, Vol. 45, No. 6, pp. 81-87, 2002. <https://doi.org/10.1145/508448.508452>
- [99] HILLIARD, D.: *The communicator's role in project teams*, *Proceedings Professional Communication Conference the New Face of Technical Communication: People, Processes, Products'*, Philadelphia, PA, USA, 1993, pp. 315-319, 1993. <https://doi.org/10.1109/IPCC.1993.593881>
- [100] MUSZYŃSKA, K.: *Patterns of Communication Management in Project Teams*, In: Ziemba, E. (eds) *Information Technology for Management: New Ideas and Real Solutions, ISM AITM 2016, Lecture Notes in Business Information Processing*, Vol. 277, Springer, Cham., pp. 202-221, 2017. https://doi.org/10.1007/978-3-319-53076-5_11
- [101] SWART, K., BOND-BARNARD, T.J., CHUGH, R.: Challenges and critical success factors of digital communication, collaboration and knowledge sharing in project management virtual teams: a review, *International Journal of Information Systems and Project Management*, Vol. 10, No. 4, pp. 59-75, 2022. <https://doi.org/10.12821/ijispm100404>
- [102] STEINKE, J.A., BOLUNMEZ, B., FLETCHER, L.S., WANG, V., TOMASSETTI, A.J., REPCHICK, K.M., ZACCARO, S.J., DALAL, R.S., TETRICK, L.E.: Improving cybersecurity incident response team effectiveness using Teams-Based research, *IEEE Security & Privacy*, Vol. 13, No. 4, pp. 20-29, 2015. <https://doi.org/10.1109/MSP.2015.71>
- [103] FURUKAWA, C.: Dynamics of a critical problem-solving project team and creativity in a multiple-project environment, *Team Performance Management: An International Journal*, Vol. 22, No. 12, pp. 92-110. <https://doi.org/10.1108/TPM-04-2015-0021>
- [104] ARISTIN, N.F., PURNOMO, A.: Improving Critical Thinking Skill Through Team-based Projects, is it Effective?, *Journal of Education Research and Evaluation*, Vol. 6, No. 4, pp. 586-594, 2022. <https://doi.org/10.23887/jere.v6i4.48090>
- [105] CHAIDIR, J., HIDAYATI, P.P., HARNADI, K.K.: The Relationship between Critical Thinking Ability and Problem-Based Learning with a Causality Pattern in Learning Improvement, *Mix: Jurnal Ilmiah Manajemen*, Vol. 13, No. 1, pp. 122-137, 2023. http://dx.doi.org/10.22441/jurnal_mix.2023.v13i1.00

- [106] VARLAMOVA, V.: *The Relationship between Time Management and Decision-Making Processes*, University of Canterbury, 2008.
- [107] SRINIVASAN, K., GUPTA, T., AGARWAL, P., NEMA, A.: *A robust security framework for cloud-based logistics services*, 2018 IEEE International Conference on Applied System Invention (ICASI), Chiba, Japan, 2018, pp. 162-165, 2018. <https://doi.org/10.1109/ICASI.2018.8394557>
- [108] ALMUKHAMETOV, A.I., DMITRIEV, A.G.: *Flexible project management methodologies, Scientific notes of the Russian academy of entrepreneurship*, Vol. 22, No. 2, pp. 11-17, 2023. <https://doi.org/10.24182/2073-6258-2023-22-2-11-17>
- [109] CHAN, H.K., CHAN, F.T.: Comparative study of adaptability and flexibility in distributed manufacturing supply chains, *Decision Support Systems*, Vol. 48, No. 2, pp. 331-341, 2010. <https://doi.org/10.1016/j.dss.2009.09.001>
- [110] HUGHES, T.R., CASLIN, J., FOSS, C., LARSEN, A.K., LOFFER, J., SACCO, K.: Leading Through Conflict with Critical Thinking and Creative Problem-Solving, *International Journal for Cross-Disciplinary Subjects in Education*, Vol. 10, No. 4, pp. 4142-4146, 2019. <http://dx.doi.org/10.20533/ijcdse.2042.6364.2019.0505>
- [111] WAHYUDIATI, D., IRWANTO, I., NINGRAT, H.K.: Improving pre-service chemistry teachers' critical thinking and problem-solving skills using project-based learning, *World Journal on Educational Technology: Current Issues*, Vol. 14, No. 5, pp. 1291-1304, 2022. <https://doi.org/10.18844/wjet.v14i5.7268>
- [112] SÁNCHEZ-SILVA, M., CALDERÓN-GUEVARA, W.: Flexibility and adaptability within the context of decision-making in infrastructure management, *Structure and Infrastructure Engineering*, Vol. 18, No. 7, pp. 950-966, 2022. <https://doi.org/10.1080/15732479.2022.2038642>
- [113] FARRELL, M.: Time management, *Journal of Library Administration*, Vol. 57, No. 2, pp. 215-222, 2017. <https://doi.org/10.1080/01930826.2017.1281666>
- [114] FATHIMA, A., DEVI, G.S., FAIZAANUDDIN, M.: Improving distributed denial of service attack detection using supervised machine learning, *Measurement: Sensors*, Vol. 30, 100911, pp. 1-8, 2023. <https://doi.org/10.1016/j.measen.2023.100911>
- [115] APENKO, S., ROMANENKO, M.: *Leadership competencies of flexible teams of innovative projects of enterprises*, 5th International Scientific Conference – EMAN 2021 – Economics and Management: How to Cope With Disrupted Times, Online/Virtual, March 18, 2021, Conference Proceedings published by: Association of Economists and Managers of the Balkans, Belgrade, Serbia, pp. 311-318, 2021. <https://doi.org/10.31410/eman.2021.311>
- [116] THOMAS, G., SULE, M.: A service lens on cybersecurity continuity and management for organizations' subsistence and growth, *Organizational Cybersecurity Journal Practice Process and People*, Vol. 3, No. 1, pp. 18-40, 2023. <https://doi.org/10.1108/ocj-09-2021-0025>
- [117] MOKHOR, V., KORCHENKO, O., HONCHAR, S., KOMAROV, M., ONYSKOVA, A.: *Research of the impact on the ecology of the state of cybersecurity of the critical infrastructure objects*, E3S Web of Conferences, Vol. 280, 09009, pp. 1-6, 2021. <https://doi.org/10.1051/e3sconf/20212800909>
- [118] SAWYER, B.D., HANCOCK, P.A.: Hacking the human: The prevalence paradox in cybersecurity, *Human Factors: The Journal of the Human Factors and Ergonomics Society*, Vol. 60, No. 5, pp. 597-609, 2018. <https://doi.org/10.1177/0018720818780472>
- [119] BURRELL, D.N.: *Teaching graduate technology management students with innovative learning approaches around cybersecurity*, In: Research Anthology on Advancements in Cybersecurity Education, edited by Information Resources Management Association, IGI Global Scientific Publishing, pp. 491-500, 2022. <https://doi.org/10.4018/978-1-6684-3554-0.ch024>
- [120] WANG, Q., LU, S., LIN, J., WANG, C., FAN, H.: Sentiment analysis for the customer feedback in the Express Delivery Enterprise Evaluation System, *Learning & Education*, Vol. 9, No. 3, pp. 57-59, 2020. <https://doi.org/10.18282/l-e.v9i3.1574>
- [121] QUADER, F., JANEJA, V.P.: Insights into organizational security readiness: Lessons learned from cyber-attack case studies, *Journal of Cybersecurity and Privacy*, Vol. 1, No. 4, pp. 638-659, 2021. <https://doi.org/10.3390/jcp1040032>
- [122] HASAN, M.F., AL-RAMADAN, N.S.: Cyberattacks and Cyber Security Readiness: Iraqi Private Banks Case, *Social Science and Humanities Journal*, Vol. 5, No. 8, pp. 2312-2323, 2021.
- [123] AHMED, S.A.A.S., ISAK, M.A.: Factors Affect Cyber Security Readiness and Performance of SMEs: A Case Study of Mogadishu, Somalia, *International Journal of Innovative Science and Research Technology*, Vol. 9, No. 7, pp. 1059-1069, 2024. <https://doi.org/10.38124/ijisrt/IJISRT24JUL264>
- [124] NERI, M., NICCOLINI, F., MARTINO, L.: Organizational cybersecurity readiness in the ICT sector: a quanti-qualitative assessment, *Information & Computer Security*, Vol. 32, No. 1, pp. 38-52, 2024. <https://doi.org/10.1108/ICS-05-2023-0084>
- [125] ALHARBI, F., ALSULAMI, M., AL-SOLAMI, A., AL-OTAIBI, Y., AL-OSIMI, M., AL-QANOR, F.,

- AL-OTAIBI, K.: The impact of cybersecurity practices on cyberattack damage: The perspective of small enterprises in Saudi Arabia, *Sensors*, Vol. 21, No. 20, 6901, pp. 1-14, 2021. <https://doi.org/10.3390/s21206901>
- [126] WHITE, G.: Generation Z: cyber-attack awareness training effectiveness, *Journal of Computer Information Systems*, Vol. 62, No. 3, pp. 560-571, 2022. <https://doi.org/10.1080/08874417.2020.1864680>
- [127] AKTER, S., UDDIN, M.R., SAJIB, S., LEE, W.J.T., MICHAEL, K., HOSSAIN, M.A.: Reconceptualizing cybersecurity awareness capability in the data-driven digital economy, *Annals of Operations Research*, Vol. 350, pp. 673-698, 2025. <https://doi.org/10.1007/s10479-022-04844-8>
- [128] BERLILANA, NOPARUMPA, T., RUANGKANJANASES, A., HARIGUNA, T., SARMINI: Organization Benefit as an Outcome of Organizational Security Adoption: The Role of Cyber Security Readiness and Technology Readiness, *Sustainability*, Vol. 13, No. 24, 13761, pp. 1-20, 2021. <https://doi.org/10.3390/su132413761>
- [129] NOPARUMPA, T., SAENGCHOTE, K., WANNAKRAIROJ, W.: An Empirical Investigation of Productivity and Corporate Culture Using Textual Analysis, *SSRN*, Vol. 2024, pp. 1-12, 2024.
- [130] PESZKO, G., VAN DER MENSBRUGGHE, D., GOLUB, A., CHEPELIEV, M.: *Low-Carbon transition, stranded fossil fuel assets, border carbon adjustments, and international cooperation*, In: The World Bank eBooks, pp. 225-269, 2021. https://doi.org/10.1596/978-1-4648-1590-4_ch10
- [131] CLARK, M.E., MCEWAN, K., CHRISTIE, C.J.: The effectiveness of constraints-led training on skill development in interceptive sports: A systematic review, *International Journal of Sports Science & Coaching*, Vol. 14, No. 2, pp. 229-240, 2018. <https://doi.org/10.1177/1747954118812461>
- [132] CRESWELL, J.W., CRESWELL, J.D.: *Research design: Qualitative, quantitative, and mixed methods approaches*, 5th ed., SAGE Publications, 2018.
- [133] BRYMAN, A.: *Social research methods*, 5th ed., Oxford University Press, 2016.
- [134] HAIR, J.F., HULT, G.T.M., RINGLE, C.M., SARSTEDT, M.: *A primer on partial least squares structural equation modeling (PLS-SEM)*, SAGE Publication, Inc., USA, 2014.
- [135] IFINEDO, P.: Understanding information systems security policy compliance: An integration of the theory of planned behavior and the protection motivation theory, *Computers & Security*, Vol. 31, No. 1, pp. 83-95, 2012. <https://doi.org/10.1016/j.cose.2011.10.007>
- [136] ROSADO, D.G., MORENO, J., SÁNCHEZ, L.E., SANTOS-OLMO, A., SERRANO, M.A., FERNÁNDEZ-MEDINA, E.: MARISMA-BiDa pattern: Integrated risk analysis for big data, *Computers & Security*, Vol. 102, No. March, 102155, 2021. <https://doi.org/10.1016/j.cose.2020.102155>
- [137] JOSHI, A., KALE, S., CHANDEL, S., PAL, D.K.: Likert scale: Explored and explained, *Current Journal of Applied Science and Technology*, Vol. 7, No. 4, pp. 396-403, 2015. <https://doi.org/10.9734/BJAST/2015/14975>
- [138] SHANNON, D.M., JOHNSON, T.E., SEARCY, S., LOTT, A.: Using electronic surveys: advice from survey professionals, *Practical Assessment, Research, and Evaluation*, Vol. 8, No. 1, pp. 1-9, 2002. <https://doi.org/10.7275/q9xy-zk52>
- [139] SCHWARZ, N.: *The Psychology of Survey Response*, Roger Tourangeau, Lance J. Rips, and Kenneth Rasinski. New York: Cambridge University Press, 2000. 401pp, ISBN 0-521-57246-0 (cloth) and 0-521-57629-6 (paper)., *International Journal for Quality in Health Care*, Vol. 13, No. 1, pp. 80-82, 2001. <https://doi.org/10.1093/ijpor/13.1.80>
- [140] ISRAEL, M.A., HAY, I.M.: *Research ethics for social scientists : between ethical conduct and regulatory compliance*, SAGE Publications Ltd, London, UK, 2006.
- [141] SARSTEDT, M., RINGLE, C.M., SMITH, D., REAMS, R., HAIR, J.F.: Partial least squares structural equation modeling (PLS-SEM): A useful tool for family business researchers, *Journal of Family Business Strategy*, Vol. 5, No. 1, pp. 105-115, 2014. <https://doi.org/10.1016/j.jfbs.2014.01.002>
- [142] TABACHNICK, B.G., FIDELL, L.S.: *Using multivariate statistics*, 6th ed., Pearson, New York, USA, 2013.
- [143] NUNNALLY, J.C., BERNSTEIN, I.H.: *Psychometric theory*, 3rd ed., McGraw-Hill, New York, USA, 1994.
- [144] FORNELL, C., LARCKER, D.F.: Evaluating structural equation models with unobservable variables and measurement error, *Journal of Marketing Research*, Vol. 18, No. 1, pp. 39-50, 1981. <https://doi.org/10.1177/002224378101800104>
- [145] HENSELER, J., RINGLE, C.M., SARSTEDT, M.: A new criterion for assessing discriminant validity in variance-based structural equation modeling, *Journal of the Academy of Marketing Science*, Vol. 43, pp. 115-135, 2015. <https://doi.org/10.1007/s11747-014-0403-8>
- [146] HU, L.T., BENTLER, P.M.: Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives, *Structural Equation Modeling: A Multidisciplinary*

Enhancing cybersecurity readiness in express logistics: the role of cyber-attack features and project team skills

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Journal, Vol. 6, No. 1, pp. 1-55, 1999. https://doi.org/10.1007/978-3-319-95669-5_10
<https://doi.org/10.1080/10705519909540118>

- [147] BORKY, J.M., BRADLEY, T.H.: *Protecting Information with Cybersecurity*, In: *Effective Model-Based Systems Engineering*, Springer, Cham., pp. 345-404, 2019.

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Logistics flow disruptions through the Suez Canal: enhancing supply chain risk management and resilience

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Abstract: The study examines the Suez Canal's crucial role in global supply chains and the consequences of its disruptions, focusing particularly on the 2021 ship blockage and the escalation of the Red Sea conflict from 2023. It investigates these events from a supply chain resilience perspective, exploring risk mitigation strategies and responses to arising risks. The methodology includes an extensive literature review on Suez Canal disruptions and their cascading, global effects. Qualitative data were gathered through semi-structured interviews with six raw material procurement planners from a European multinational production company, responsible for managing goods flow from North America and Asia-Pacific to Europe. The interviews and a dedicated workshop were transcribed and thematically analysed using NVivo software. Findings offer valuable insights into the effects of disruptions on global supply chains, highlighting significant delays in supplier awareness of critical global events, and emphasizing the importance of effective communication, continuous risk management, and maintaining safety stocks. The study also identifies lessons from past disruptions, suggesting strategies to enhance supply chain visibility, diversifying transportation routes, while promoting the importance of sustainability, and strengthening supplier relationships. This research addresses a critical logistics topic by focusing on the 2023–2024 Red Sea conflict and aims to bridge a gap in the existing literature regarding supply chain resilience and risk management related to Suez Canal disruptions. By incorporating firsthand industry experiences, the study offers original, practical insights for mitigating the impact of such disruptions on global supply chain operations.

1 Introduction

The Suez Canal, a critical link between the Mediterranean Sea and the Red Sea, has long been recognized as a strategic chokepoint in global logistics and trade. Since its construction in 1869, the Canal has facilitated international shipping and significantly influenced global economy. The Canal offers a direct route between Europe and Asia without a long voyage for ships around the Cape of Good Hope, thereby reducing delivery times and costs [1]. In 2022, the canal handled about 12% of global trade and accommodated nearly 22,000 ships [2]. According to annual reports by the Suez Canal Authority, the canal helps transport goods worth over \$1 trillion each year [3,4]. The significance of the Canal goes beyond economic value, and it plays a crucial role in maintaining efficient, reliable supply chains. As the Canal shortens delivery times and lowers transportation costs, it is often the preferred route for many shipping lines. Although it primarily connects Asia and Europe, its strategic importance also makes it a vulnerable point in the global supply chain. Recent disruptions, most notably the Ever Given blockage in March 2021 and the intensifying Red Sea conflict in 2024, have underscored the canal's critical function and the serious consequences such events can have on global trade and logistics. These disruptions extend beyond immediate logistical challenges, affecting overall resilience in global supply chains. As a result, having strong risk management strategies and contingency plans is essential to keep operations running smoothly in the face of such disruptions. This research examines recent

disruptions in the Suez Canal and explores how organizations are learning from these events to improve their supply chain resilience against similar risks.

To fully address the importance of the Suez Canal and how its disruptions impact global supply chains, this study involves a detailed review of existing literature on the canal's role in worldwide commerce. Next, it employs a single-organization case study that collects qualitative data from individual semi-structured interviews and a group workshop involving six raw material procurement planners. These planners were selected on the basis of their relevant positions: they manage supply chains for a European multinational production firm, specifically handling raw materials transported from the Asia-Pacific and North America regions to Europe. The interviews were transcribed and analysed using thematic coding in NVivo. The results chapter identifies recurring themes and patterns from the participants' viewpoints. This approach offers a detailed understanding of the impacts and lessons learnt from those directly affected by Suez Canal disruptions.

The main goal of this research is to explore and collect practical experiences of raw material planners who faced difficulties caused by Suez Canal disruptions. By focusing on real-life scenarios and hands-on strategies, the study aims to broaden and compare the existing, limited research on how risk management and supply chain resilience are influenced by logistical disruptions, especially focusing on sea freight transportation of raw materials through the Suez Canal. This approach ensures a steady production flow for organizations. The central research question is the

following: What are the common experiences and practical steps an organization can take to reduce the impact of potential disruptions in raw material transportation through the Suez Canal to ensure uninterrupted production flow?

2 Literature review

The construction of the Suez Canal began in 1859 under the guidance of the French diplomat Ferdinand de Lesseps and was completed in 1869. This major engineering project aimed to reduce the maritime distance between Europe and Asia [1]. The canal operates as a sea-level waterway without locks, allowing ships to move directly between the Mediterranean Sea and the Red Sea. Its design, featuring bypasses and double sections, enables vessels to transit in both directions at the same time [5]. Since its opening, the Suez Canal has undergone multiple expansions and upgrades to handle bigger ships and increase trade volumes. Notably, the 2015 expansion, called the New Suez Canal, significantly raised the canal's capacity, allowing more ships to pass daily and further reducing transit times [6]. These advancements have ensured the canal's status as a critical link in global trade and logistics. As of 2024, the canal remains a cornerstone of maritime traffic, supporting the transport of oil, liquefied natural gas (LNG), raw materials, and finished goods between Europe, Asia, and the Middle East [2,7,-9]. On average, the canal shortens routes from key Asia-Pacific ports to Europe by 12 days compared to sailing around the Cape of Good Hope [8,9]. The distance to be covered from Singapore to Rotterdam is reduced from 14,000 nautical miles to just 10,000 nautical miles. In 2022, the use of the canal saved transportation companies an estimated \$5 billion in fuel and related costs, highlighting the economic benefits of this shorter route [3]. Also in 2022, approximately 22,000 ships passed through the canal [2]. The total value of goods moving via the canal reached more than 1.6 billion tons and \$1 trillion in the same year [2].

Historical reviews of the Suez Canal indicate that it has faced occasional disruptions over the past two decades, resulting in substantial global supply chain delays and costs. These incidents emphasize the canal's strategic importance and the need for robust operational resilience and safety measures [3]. Key terms that must be defined related to the analysis of these disruptions include risk, risk management, supply chain resilience, and sustainability. Risk, defined as the potential for events causing negative impacts on supply chain performance, necessitates comprehensive risk management, systematic identification, assessment, and mitigation of risks to ensure minimal operational disruption [10]. Supply chain resilience refers to the ability of supply chains to withstand, adapt, and quickly recover from disruptions, thereby ensuring continuity of material flow and business operations [11,12]. Sustainability encompasses long-term economic, environmental, and social viability, requiring supply chains to minimize environmental impact, maintain resource efficiency, and support economic growth [13].

Analysing risk management, resilience, and sustainability together, particularly concerning the Suez Canal disruptions, is crucial as these disruptions highlight systemic weaknesses in global supply chains. The Ever Given blockage and the 2023-2024 Red Sea geopolitical crisis reveal the interdependency of resilience and sustainability. The literature also raises concerns that resilient supply chains, capable of rapidly rerouting materials or utilizing strategic safety stocks, often conflict with sustainability goals, such as increased emissions from alternative routes or wasted materials from excessive inventory stocks. Organizations must find the correct balance between managing their long term sustainability goals and ensuring resilient and robust supply chains maintaining smooth production flow [13].

In prior decades the canal faced disruptions due to piracy threats in the late 2000s and political unrest during the Arab Spring in 2011 caused major risks for ships moving through the Red Sea and the canal, raising insurance costs and forcing some vessels to reroute to avoid high-risk areas [7]. One of the most notable disruptions in recent history was the Ever Given blockage in March 2021. Due to poor visibility from a sandstorm and technical issues, one of the world's largest container ships, about 400 meters long with a gross tonnage of 224,000, ran aground and fully blocked the canal [3]. This event had immediate, wide-reaching effects on global trade, creating serious delays for hundreds of ships waiting to transit. Supply chains were affected by increased shipping costs and late deliveries [4]. Tugboats, dredgers, and excavation equipment managed to refloat the vessel six days later, on March 29, 2021 [3,4]. The blockage's impact was immense, holding up an estimated \$9.6 billion worth of goods per day, totalling around \$57 billion throughout the event [3]. It also caused port congestion as delayed vessels arrived all at once, which was made worse by existing container shortages during the COVID-19 pandemic.

The shortage of empty containers in Asia required months to resolve due to rising transportation demands [14]. According to Reuters, global supply chains already strained by the pandemic and growing consumer demand faced even greater pressure, with about 10-15% of world container throughput affected. The six-day blockage highlighted what could happen if the canal ceases to operate in the global trade network. In 2024, the Red Sea crisis evolved into a major geopolitical conflict that severely affected global trade and maritime security. Attacks by Houthi insurgents on commercial vessels in the Red Sea disrupted international shipping and deeply affected global supply chains. With respect to 2024, the canal's utilization falls by 57% due to increased threat on the Red Sea [15]. India, depending heavily on the Red Sea route through the Suez Canal, as 50% of its exports and 30% of its imports travel this way, experienced significant shipping challenges and higher logistics costs already through 2024. Average shipment delays reached 21-28 days, potentially costing India more than \$30 billion in

exports as of the time of this research. Energy markets have also been highly vulnerable, with around 12% of worldwide oil trade moving through the Red Sea [2]. The conflict pushed oil prices above \$80 per barrel, prompting major oil and gas companies to suspend transits or reroute vessels. LNG shipments fell significantly as well since the crisis escalated [2,9]. The Ever Given blockage and the Red Sea crisis thus serve as crucial lessons for global shipping and organizations that rely on the canal, focalising the risks connected to Suez Canal transport [3].

Suez Canal disruptions have broad, worldwide effects beyond extra costs and scheduling delays. The blockages create significant problems in ports worldwide. Due to many ships arriving off-schedule, ports are facing significant congestions and increased handling times, further delaying vessels that are not directly affected by the canal closure but still arrive at the impacted ports [2]. An additional major outcome is ship and container shortages. When shipping times are increased and containers stay utilized for longer periods per shipment, their availability drops where they are most needed. This is true especially in Asia, where export demand remains high. These disruptions underscored serious weaknesses in the “just-in-time” supply chain model. As shipments were delayed, manufacturers lacked the materials they needed, which caused production slowdowns or stoppages [8,16]. The incident also raised environmental and safety worries. Rerouting around the Cape of Good Hope or increasing air freight leads to higher fuel use and carbon emissions. In addition, heavier traffic on alternative routes raises safety risks, particularly in areas prone to piracy or lacking the capacity to handle more maritime traffic [17].

Concerning lowering the risk of supply chain interruptions through the Suez Canal, the literature points to several approaches, focusing on agility, diversification, and technological progress. One main strategy is diversifying supply chain routes and sources: this way companies that do not rely solely on the canal reduce their exposure to major disruptions. This can also involve diversifying suppliers, so materials come from several regions rather than just one. Another tactic is revisiting safety stock strategies to improve resilience, which was prompted by the 2021 canal blockage. Many firms have decided to hold higher safety stocks or adopt a “just-in-case” inventory model for essential materials [17]. Technology and data analytics also offer ways to handle risks. Advanced tracking and monitoring systems provide real-time details on shipment locations and statuses, supporting proactive decisions and quicker responses. Predictive analytics can further estimate potential delays, allowing firms to modify their logistics plans [18]. Collaborative ties with suppliers, logistics providers, and other partners are also highlighted as a vital element in reducing risk. Flexible contracts and transparent communication help resources shift swiftly when disruptions happen [16].

Some organizations have adopted strategic stockpiling of key raw materials and finished goods to ease the effects of supply chain interruptions. This includes identifying which components are vital for production and holding them in storage. Nearshoring, which brings production closer to main markets, can reduce reliance on long-distance shipping routes like the Suez Canal and assist in minimizing disruption risks. Nearshoring and reshoring are increasingly common, particularly considering severe logistics disruptions that make complex supply chain operations less appealing. Financial tools such as cargo insurance and disruption insurance can help offset costs linked to events like the Suez Canal blockage [4,8].

The literature also notes a possible future shift from using the Suez Canal to traveling via the Northern Sea Route (NSR). Climate change has made the Arctic more and more navigable, but operating in that region requires unique ship specifications and involves uncertain travel times, ice conditions, and fuel costs. Even though the NSR is shorter between Europe and Asia, its overall economic competitiveness versus the Suez Canal is still a topic of debate. Moreover, increased use of the NSR may conflict with global sustainability goals due to further ice melting [19-21].

Organizations can also adopt smaller, simpler strategies to greatly cut the risk of supply chain disruptions. Building better, trust-based communication with partners ensures timely updates on possible delays [22]. This shared information lets companies adjust their operations and logistics plans promptly. Advanced tracking tools give real-time insight into shipments, making it possible to reroute shipments or alter schedules as needed [3,18]. Maintaining a flexible logistics approach allows for switching between different modes of transport or routes. For example, if a Suez Canal disruption is expected, firms can redirect cargo through alternative maritime paths or temporarily switch to air freight in the case of urgent items, though at a higher cost [8]. Partnering with multiple suppliers, especially those in various regions, further protects against raw material shortages [16]. Routine scenario planning exercises, including potential canal blockages, can help businesses respond more effectively when real disruptions occur, businesses can use pre-set action plans to reroute goods, reorganize production schedules, and communicate with key stakeholders [17].

When facing Suez Canal delays, organizations can take several steps to manage the impact on their supply chains and maintain production. First, they should quickly assess the scope of the disruption and its potential effects on supply chain operations. Analysing risks and costs helps prioritize actions. Next, organizations must clearly inform all parties involved, including suppliers, customers, and logistics providers, about expected effects, which supports collaborative problem-solving [22]. Having contingency plans ready allows firms to activate alternative sources of materials, shipping routes, or production schedules once they detect a delay [3,18]. Temporarily adjusting

production to focus on products with available materials might mean rearranging assembly lines or postponing items that are missing inputs [16]. Close collaboration with supply chain partners can also yield faster approvals, alternate suppliers, or logistic solutions to move shipments more rapidly [23]. Keeping customers informed and identifying top priorities during disruptions are essential. Constantly tracking the situation as it changes and gathering data on impacts can help guide decisions. Once the disruption subsides, a thorough review can reveal lessons and improvements to strengthen the given organization's future supply chain resilience [17].

This literature review provides essential context and theoretical grounding for understanding how organizations experience and manage disruptions to global logistics routes like the Suez Canal. It defines critical concepts such as risk, resilience, and sustainability, highlighting their interconnectedness during crises. This comprehensive review provides a baseline for the study's primary qualitative research, supporting the structuring of the topics discussed during interviews and analysis of real-world responses to disruptions and the development of actionable insights to strengthen organizational preparedness and response strategies.

3 Methodology

In order to explore raw material procurement processes during the Red Sea crisis at a specific multinational organization, the study used a case study methodology with an empirical, qualitative approach. This qualitative method allowed for a detailed examination of practical experiences, views, and strategic responses of logistics and supply chain experts within the studied company [24]. The approach aimed to identify adaptive strategies and practical solutions used by professionals in real-world scenarios, thus offering insights that benefit both theory and practice. Participants were selected through purposive sampling. The study focused on six raw material procurement planners from a European multinational production company that partly relies on moving raw materials from the Asia-Pacific region to Europe to guarantee smooth production flows. These individuals were selected based on their extensive experience, their critical role in logistics and procurement decisions, and their direct involvement in challenges related to Suez Canal disruptions [25].

Data collection combined two qualitative methods: individual semi-structured interviews and a group workshop. Each participant engaged in a detailed interview lasting 60 to 90 minutes. The interviews were guided by a pre-developed framework, complemented by open ended questions, which focused on three main thematic areas and allowed the interviewees to share their detailed experiences and thoughts:

- The impact of Suez Canal disruptions on raw material procurement from Asia and North America.
- Key lessons learned from previous disruptive events (e.g., Ever Given blockage, Red Sea conflict).

- Resilience strategies and contingency actions implemented to maintain material flow continuity.

Example questions included:

- "Can you describe how the Suez Canal disruptions affected your material sourcing timelines?"
- "What strategies, actions did your team adopt to mitigate the impact of these disruptions?"

The interviews allowed flexibility, enabling participants to share additional valuable insights based on their experiences with material and information logistics during crises. Following the interviews, a structured workshop involving all six participants was organized. The workshop was divided into three phases with the overall aim to allow participants to discuss their own practical takeaways from the crisis and to define common best practises:

- Reflection on individual experiences with recent Suez Canal disruptions.
- Group discussion on effective communication and human flow management during disruptions.
- Joint development of a defined action plan for enhancing future supply chain resilience.

The discussions were transcribed and thematically analysed using NVivo software. Thematic coding enabled the identification of patterns, categories, and emerging trends aligned with the study's research questions. To ensure validity and reliability, the findings and thematic interpretations were reviewed and confirmed with participants during a follow-up validation session. Participants provided consent before the research activities and were informed of their confidentiality rights and the study's adherence to ethical data protection principles.

4 Results

The thematic analysis of interviews and the workshop highlighted three major topics: communication, risk management, and sustainability. These were mapped systematically across the classical stages of risk management, risk factors, risk analysis and assessment, and proposals for reaction. This structure allows the empirical findings to reflect the material flow disruptions caused by the Suez Canal crises and the organizational responses aiming at maintaining resilient logistics operations.

Risk Factors

The procurement planners identified several key risk factors that disrupted material flow management during the Suez Canal blockage in 2021 and the Red Sea conflict of 2023 - 2024. The most significant risk factor and identified takeaway by the planners was the global ripple effect of localized events. Initially limited to shipments between Europe and Asia, the disruptions quickly extended to cargo flows between North America and Europe as container

availability and vessel scheduling were globally affected. Many local distributors underestimated the impact, believing the crisis was regionally contained, delaying organizational responses. Secondly, supply chain visibility limitations emerged as a critical risk. The planners indicated that suppliers often failed to monitor the arising risks and transport bottlenecks outside their immediate regions. Information logistics were insufficiently integrated, leading to delayed risk recognition and poor communication between partners. The interviewees reported that European distributors sourcing materials from North America did not anticipate for harbour congestions and delayed shipments, confirming placed orders with regular lead times. Thirdly, the organization's over-reliance on Asia-Pacific and North American suppliers without validated alternative sourcing options in Europe increased vulnerability. The organization was critically dependent on long, risk-prone maritime routes without backup options, intensifying delays once disruptions materialized. Lastly, environmental and sustainability-related trade-offs surfaced as latent risk factors. Measures like increasing air freight usage or building high safety stocks during disruptions clashed with the firm's long-term environmental targets, highlighting an operational dilemma between resilience and sustainability.

Risk Analysis and Assessment

The analysis revealed significant organizational gaps in early warning systems and scenario planning for globally cascading events. During the 2021 Suez Canal blockage, planners handling Asian portfolios received disruption alerts earlier than those handling North American suppliers. The absence of unified material flow monitoring across all regions delayed the organization's understanding of the crisis's global magnitude, causing loss of critical response time. The workshop participants emphasized that information asymmetry within the supply chain, the lack of real-time shipment visibility and delayed supplier updates, halted quick decision-making. Some suppliers continued to confirm standard delivery times despite clear logistical bottlenecks, creating a false sense of material availability. Through thematic coding, insufficiently diversified transportation routes was another serious risk that was identified. Heavy dependency on the Suez Canal for material flows without pre-approved alternative suppliers left the supply chain vulnerable. The firm's safety stock policies were also critically assessed. Prior to the crises, stock levels were optimized mostly for lean operations, minimizing holding costs but offering little protection against such critical transportation delays. When shipment lead times expanded by several weeks, production flows were shortly also interrupted. Planners further reflected on the conflict between emergency measures and sustainability goals. Rushed adaptations, like switching to air freight, helped recover raw material availability in the short term but significantly increased carbon emissions and

operational costs, revealing the hidden costs of resilience under pressure.

Proposals for Reaction

One core proposal resulting from the interviews and workshop was the implementation and standardization of continuous scenario planning. The organization must regularly assess economic risks and simulate possible regional and global crises affecting material flows, integrating variables like port congestion, vessel capacity fluctuations, and regional conflicts. Advanced information logistics systems were recommended, enabling real-time monitoring of transport bottlenecks, supplier performance, and lead times. The organization must realize in time that local disruptions can easily cascade into global threats, alerting all stakeholders accordingly.

The workshop stressed the importance of trust-based partnerships with suppliers and logistics service providers. Trust enhances the willingness of partners to share early warnings and to prioritize urgent shipments. The organization plans to formally request from strategic suppliers the establishment of shared risk monitoring protocols, including the regular exchange of critical updates on potential disruptions. Suppliers will be expected to map their own upstream vulnerabilities and inform buyers accordingly. The organization also plans to improve its collaboration efforts. In case the organization defines critical risks, affected suppliers will be notified accordingly, ensuring that vendors are also alarmed, with the expectation towards them to find mitigating solutions in time. Internally, the planners recommended strengthening cross-functional communication between procurement, production, sales, and finished goods logistics. Weekly updates in times of crisis on global supply chain status and pending risks should be standardized, ensuring that material flow disruptions are addressed collaboratively across departments.

The interviews revealed a consensus that greater supply chain redundancy is necessary. This includes validating secondary, regional suppliers in Europe for critical raw materials. Although costlier, dual sourcing would ensure that alternative material flows can be activated rapidly when major maritime routes like the Suez Canal are disrupted. Higher safety stock levels for critical materials were also proposed, particularly for products which transportation relies heavily on high-risk routes. The organization recognized that short-term resilience measures, such as increased air freight and emergency stockpiling, often conflict with its long-term sustainability goals. To balance these demands, it is pursuing local sourcing to reduce carbon emissions while strengthening material flow continuity. By fostering closer cooperation and trust with suppliers on green logistics initiatives, the company seeks to integrate environmental responsibility into its resilience planning. In the long term, aligning sustainability with supply chain flexibility enhances brand reputation, supports customer expectations, and builds a

more competitive, future-proof logistics network capable of withstanding global disruptions.

5 Discussion

This section integrates insights from the literature review on the Suez Canal's disruptions and its global importance with the findings from interviews and a workshop involving raw material planners.

The already available literature showed that the Suez Canal has played a key role in connecting Europe, the Middle East, and Asia since its opening in 1869 [1,5]. Its ability to shorten the distance between ports in the Asia-Pacific region and Europe leads to significant savings in both cost and time [2,4,16,22]. However, its importance also makes it highly vulnerable to disruptions. Events such as the Red Sea crisis, which started in 2023, show that even a local crisis can trigger widespread consequences [2,3]. According to Galil et al. (2017) and Khan and Rahman (2021), rerouting vessels around the Cape of Good Hope or switching to air freight is expensive, taxes the environment, and is complex logistically [4,7]. The organization's planners confirm the canal's central role in maritime trade. During both the 2021 blockage and the 2023-2024 Red Sea crisis, once the canal or its adjacent routes were compromised, raw material supplies were severely affected. This aligns with the literature suggesting that disruptions to such a critical waterway can have global effects [8].

A major theme from both the literature and the Interviews is how easily a regional crisis can become a global problem. The Suez Canal disruptions created chain reactions in shipping schedules causing port congestion and shortages of ships and containers [2]. This pattern also affected the studied organization. Many suppliers and regional distributors did not realize the scale of the disruption until shipments were already delayed. Some assumed the crisis was confined to Europe-Asia routes only to discover that shipments from North America were also delayed by port congestion and missing vessels. In line with prior findings, the company's planners noted that distributors and suppliers were slow to communicate possible delays, which revealing a lack of awareness and proactive planning. Similar to what Galil et al. (2017) and Rusinov et al. (2021) observe, companies relying on just-in-time deliveries were particularly vulnerable. Although North American shipments initially appeared safe from the Red Sea crisis, they were eventually stuck or delayed as shipping lines struggled to manage capacity worldwide [3,7,16]. As global supply chains become more interconnected, disruptions in one region can affect the availability of ships, container positioning, and transit times worldwide. The organization now plans to broaden its risk management framework to consider not just local or regional threats but also how quickly these can escalate globally. This strategy follows those recommendations in the literature that call for continuous monitoring and scenario planning for essential chokepoints [18,19].

Building on academic risk management models [18,21], the firm's new focus on real-time tracking and scenario-based simulations aims to close awareness gaps, potentially reducing reliance on costly, high-emission emergency measures.

The interviews also revealed that the organization has changed its approach to inventory management. Related research underscores the value of safety stocks for protection against sudden delays [9]. Maintaining extra inventory ties up capital and may increase the risk of scrapping unused materials, but planners agreed that buffers are necessary for critical items. During the early stages of the Red Sea crisis, the organization lacked sufficient safety stock to cover prolonged delays, which put production at risk and forced the company to use of high-cost air freight. The firm now plans to identify which materials truly require higher inventory based on their criticality and fluctuating lead times.

Another key insight from the interviews is the organization's dependence on Asian and North American suppliers under normal conditions, which leaves few alternatives when maritime disruptions hit. The literature recommends diversifying suppliers geographically to avoid overreliance on one region or shipping route [8,17]. Interviewees described how the company is now validating regional suppliers, even though these are more expensive. By having contracted local suppliers for smaller volumes, the organization retains flexibility and can scale up domestic orders if a major blockage or conflict disrupts global routes. This finding supports earlier work suggesting that nearshoring or "multi-shoring" helps firms balance cost effectiveness with resilience [23].

Workshop discussions also confirmed that many suppliers and distributors failed to recognize the global scope of the Suez Canal disruptions until it was too late. The literature stresses the importance of transparent, timely communication in crises [17]. The organization's experience demonstrates the ways even small delays can escalate when communication is poor. Some distributors continued confirming shipping dates based on standard schedules, which created a misleading sense of security. To fix this, the company is committed to building stronger, trust-based relationships with suppliers. It will share disruption warnings more promptly and expects suppliers to respond in ways that reduce potential negative outcomes [3]. Internally, the workshop highlighted the need for better coordination between procurement, sales, production, and distribution teams. During the Suez Canal incident, not all departments were informed concurrently, which caused confusion and inconsistent messaging to customers. The updated strategy involves frequent cross-department briefings ensuring that everyone can make faster decisions and minimize duplicated efforts or missed opportunities to reroute shipments [21]. Many customers were also more understanding when they were offered early warnings about potential delays, which allowed their firms to allocate resources to fulfil their most critical orders first.

When critical shortages and production line shutdowns occurred, the organization had to quickly switch to faster transport options like air freight to maintain raw material flow. However, a central topic at the workshop was the conflict between resilience-building and environmental objectives. The literature notes that rerouting ships around Africa or relying on air freight both increase carbon emissions [3]. The company's interviews confirmed that while air freight kept production running when vessels were delayed, it undermined the firm's long-term environmental goals. Likewise, holding larger safety stocks can result in more waste if demand changes or materials expire [3]. Local sourcing emerged from both the literature and the workshop as a potential compromise. By validating suppliers closer to production sites, the organization reduces transit times, cuts shipping emissions, and lowers the chance of major disruptions at chokepoints. Studies by Schøyen and Bråthen (2011) and Dui et al. (2023) indicate that nearshoring reduces ecological impact compared to long-distance shipping. However, local suppliers can be much more expensive, forcing the organization to strike a balance between resilience and sustainability [18,21].

The literature also points out that less sustainable packaging can be cheaper and more reliable, yet this conflicts with many firms' recycling or sustainability goals. Recyclable or biodegradable packaging can cost more, may be less sturdy, and is often limited in availability [13]. Overall, the interviewed planners agreed that complete alignment between resilience and sustainability is challenging, especially during emergencies. They do believe, though, that enhanced planning and long-term risk management can help reduce environmental harm [2,3]. When disruptions are identified early and are correctly evaluated, the organization is more likely to adopt solutions that support both uninterrupted operations and environmental objectives [3].

From a broader perspective, these findings demonstrate that the Suez Canal disruption should be seen not as an isolated crisis, but as a model of how quickly severe issues can arise in vital supply chains. The lessons gained here aim to help firms handle major disruptions more effectively [22]. Overall, the results confirm and enhance existing literature on building supply chain resilience, emphasize diversification, proactive communication and flexible contingency planning [7,9]. The experiences gathered through the interviews offer practical insights to aid bridging the gap between theory and real-world practice. By combining academic perspectives with practical experiences, this discussion highlights that supply chain resilience is an evolving process rather than a fixed goal. With continuous learning and adaptation, organizations can better sustain production and will be able to respect their long-term environmental commitments.

6 Conclusions

The research problem in this study focuses on how disruptions in the Suez Canal affect global supply chains and the strategies organizations use to become more resilient against such risks. This topic is crucial as the Suez Canal plays a major role in global trade, and any disruption can significantly impact international logistics and commerce [2]. The canal's ability to shorten delivery times and reduce transportation costs highlights its importance in keeping supply chains efficient and reliable [3]. This study used a qualitative research design that included semi-structured interviews and a group workshop with raw material planners from a multinational production firm. This approach provided detailed, practical information about how these planners managed actual supply chain disruptions, which offered an in-depth look at the strategies used by those directly affected by Suez Canal disruptions. The data was thematically coded using Nvivo software, which helped organize and analyse the key themes and patterns emerging from the participants' comments.

The literature review emphasized the canal's historical significance and its vulnerabilities, showing the need for strong risk management and communication to reduce the impact of disruptions [3,7]. The 2021 Ever-Given incident and the 2024 Red Sea conflict illustrated how these disruptions can affect global trade and logistics. The research demonstrated that early risk identification, proactive scenario planning, and steady communication are critical for supply chain resilience. Findings confirmed that seemingly local disruptions can rapidly escalate globally and significantly hinder production if underestimated. Building trust-based supplier relationships, diversifying sourcing routes, and integrating sustainability into resilience strategies emerged as key actions. The study emphasizes that continuous information logistics, risk management, and regional supply base development are essential to mitigating future crises, balancing operational continuity with long-term environmental goals.

Limitations of the research include its case study methodology, which focuses only on one production organization, which may limit the variety of perspectives. As a result, the findings might not be fully applicable to organizations of different sizes, scopes, or operational settings. Second, the lack of audio or video recordings means that non-verbal cues were not captured, which potentially caused a loss of additional insights. However, the study offers a detailed exploration of how Suez Canal disruptions affect supply chain management, featuring real-world examples of strategies that increase resilience. These insights are valuable for organizations looking to strengthen their supply chains against future disruptions, especially given the limited amount of available practical knowledge of this topic.

Future research could include more participants from various organizations and industries affected by Suez Canal disruptions. This broader approach would strengthen

the applicability of the findings and give a more comprehensive view of the challenges and strategies involved in managing supply chain disruptions. Also, combining qualitative insights with quantitative data could help confirm the study's results and expand how the findings can be used. For example, quantitative measures could assess the financial costs of supply chain disruptions, measure how effective different resilience strategies are, and consider the trade-offs between resilience and sustainability with reference to decisions impacting supply chains.

References

- [1] FLETCHER, M.E.: The Suez Canal and world shipping, 1869-1914, *The Journal of Economic History*, Vol. 18, No. 4, pp. 556-573, 1958. <https://doi.org/10.1017/S0022050700107740>
- [2] WAN, Z., SU, Y., LI, Z., ZHANG, X., ZHANG, Q., CHEN, J.: Analysis of the impact of Suez Canal blockage on the global shipping network, *Ocean and Coastal Management*, Vol. 245, 106868, 2023. <https://doi.org/10.1016/j.ocecoaman.2023.106868>
- [3] FAN, S., YANG, Z., WANG, J., MARSLAND, J.: Shipping accident analysis in restricted waters: Lesson from the Suez Canal blockage in 2021, *Ocean Engineering*, Vol. 266, pp. 1-13, 2022. <https://doi.org/10.1016/j.oceaneng.2022.113119>
- [4] KHAN, A., RAHMAN, S.: Review and analysis of blockage of Suez Canal region due to giant container ship, *Marine Technology Society Journal*, Vol. 55, No. 5, pp. 39-43, 2021. <https://doi.org/10.4031/MTSJ.55.5.5>
- [5] POR, F.D.: One hundred years of Suez Canal—a century of Lessepsian migration: retrospect and viewpoints, *Systematic Zoology*, Vol. 20, No. 2, pp. 138-159, 1971. <https://doi.org/10.2307/2412054>
- [6] SAITO, T., SHIBASAKI, R., MURAKAMI, S., TSUBOTA, K., MATSUDA, T.: Global maritime container shipping networks 1969-1981: Emergence of container shipping and reopening of the Suez Canal, *Journal of Marine Science and Engineering*, Vol. 10, No. 5, 602, pp. 12-20, 2022. <https://doi.org/10.3390/jmse10050602>
- [7] GALIL, B., MARCHINI, A., OCCHIPINTI-AMBROGI, A., OJAVEER, H.: The enlargement of the Suez Canal – Erythraean introductions and management challenges, *Management of Biological Invasions*, Vol. 8, No. 2, pp. 141-152, 2017. <https://doi.org/10.3391/mbi.2017.8.2.02>
- [8] SHIBASAKI, R., YOSHIDA, T., AZUMA, T.: Route choice of containership on a global scale and model development: Focusing on the Suez Canal, *International Journal of Transport Economics*, Vol. 43, No. 3, pp. 265-290, 2016.
- [9] MEZA, A., ARI, I., SADA, M.A., KOÇ, M.: Disruption of maritime trade chokepoints and the global LNG trade: an agent-based modeling approach, *Maritime Transport Research*, Vol. 3, pp. 1-25, 2022. <https://doi.org/10.1016/j.martra.2022.100071>
- [10] XU, S., ZHANG, X., FENG, L., YANG, W.: Disruption risks in supply chain management: a literature review based on bibliometric analysis, *International Journal of Production Research*, Vol. 58, No. 11, pp. 3508-3526, 2020. <https://doi.org/10.1080/00207543.2020.1717011>
- [11] CHOWDHURY, M.M.H., QUADDUS, M.: Supply chain resilience: Conceptualization and scale development using dynamic capability theory, *International Journal of Production Economics*, Vol. 188, pp. 185-204, 2017. <https://doi.org/10.1016/j.ijpe.2017.03.020>
- [12] IVANOV, D.: Revealing interfaces of supply chain resilience and sustainability: a simulation study, *International Journal of Production Research*, Vol. 56, No. 10, pp. 3507-3523, 2018. <https://doi.org/10.1080/00207543.2017.1343507>
- [13] RAJESH, R.: On sustainability, resilience, and the sustainable-resilient supply networks, *Sustainable Production and Consumption*, Vol. 15, pp. 74-88, 2018. <https://doi.org/10.1016/j.spc.2018.05.005>
- [14] GONEN, E.: China and the Suez Canal—Politics, Economy, and Logistics, In: Lutmar, C., Rubinovitz, Z. (eds) *The Suez Canal: Past Lessons and Future Challenges*. Palgrave Studies in Maritime Politics and Security. Palgrave Macmillan, Cham., pp. 27-41, 2023. https://doi.org/10.1007/978-3-031-15670-0_2
- [15] NOTTEBOOM, T., HARALAMBIDES, H., CULLINANE, K.: The Red Sea Crisis: ramifications for vessel operations, shipping networks, and maritime supply chains, *Maritime Economics & Logistics*, Vol. 26, No. 1, pp. 1-20, 2024. <https://doi.org/10.1057/s41278-024-00287-z>
- [16] RUSINOV, I., GAVRILOVA, I., SERGEEV, M.: Features of Sea Freight through the Suez Canal, *Transportation Research Procedia*, Vol. 54, pp. 719-725, 2021. <https://doi.org/10.1016/j.trpro.2021.02.125>
- [17] MALKUS, T., TYRANSKA, M.: Reaction to risk in logistics cooperation-Results of empirical research, *Acta logistica*, Vol. 6, No. 3, pp. 77-84, 2019. <https://doi.org/10.22306/al.v6i3.124>
- [18] DUI, H., LIU, K.X., WU, S.M.: Data-driven reliability and resilience measure of transportation systems considering disaster levels, *Annals of Operations Research*, Vol. 340, pp. 217-243, 2024. <https://doi.org/10.1007/s10479-023-05301-w>
- [19] VERNY, J., GRIGENTIN, C.: Container shipping on the Northern Sea Route, *International Journal of Production Economics*, Vol. 122, No. 1, pp. 107-117, 2009. <https://doi.org/10.1016/j.ijpe.2009.03.018>
- [20] SCHØYEN, H., BRÅTHEN, S.: The Northern Sea Route versus the Suez Canal: cases from bulk shipping, *Journal of Transport Geography*, Vol. 19, No. 4, pp. 977-983, 2011.

- <https://doi.org/10.1016/j.jtrangeo.2011.03.003>
- [21] PHILIPPART, C.J.M., ANADÓN, R., DANOVARO, R., DIPPNER, J.W., DRINKWATER, K.F., HAWKINS, S.J., OGUZ, T., O'SULLIVAN, G., REID, P.C.: Impacts of climate change on European marine ecosystems: Observations, expectations and indicators, *Journal of Experimental Marine Biology and Ecology*, Vol. 400, No. 1-2, pp. 52-69, 2011.
<https://doi.org/10.1016/j.jembe.2011.02.023>
- [22] MOSTAFA, M.M.: Forecasting the Suez Canal traffic: a neural network analysis, *Maritime Policy & Management*, Vol. 31, No. 2, pp. 139-156, 2004.
<https://doi.org/10.1080/0308883032000174463>
- [23] FERNÁNDEZ-MIGUEL, A., RICCARDI, M.P., VEGLIO, V., GARCÍA-MUIÑA, F.E., FERNÁNDEZ DEL HOYO, A.P., SETTEMBRE-BLUNDO, D.: Disruption in Resource-Intensive Supply Chains: Reshoring and Nearshoring as Strategies to Enable Them to Become More Resilient and Sustainable, *Sustainability*, Vol. 14, No. 17, pp. 1-13, 2022. <https://doi.org/10.3390/su141710909>
- [24] YIN, R.K.: *Case Study Research and Applications*, 6th ed., Sage Thousand Oaks, CA, 2018.
- [25] SAUNDERS, M., LEWIS, P., THORNHILL, A.: *Research Methods for Business Students*, 8th ed., Pearson education, 2019.

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