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ASSESSMENT OF FINANCIAL AND OPERATIONAL RISKS IN MARITIME MULTIMODAL TRANSPORT IN EMERGENCY SITUATIONS

A.M. Ibrahim[1], K.M. Klevtsov[2]
[1] Postgraduate Student at the Department of Transport Technologies and Mechanical Engineering,
Kherson State Maritime Academy, Kherson, Ukraine
ORCID ID: 0009-0007-6007-5708
[2] D.Sc., Professor at the Department of Transport Technologies and Mechanical Engineering,
Kherson State Maritime Academy, Kherson, Ukraine
ORCID ID: 0000-0001-8486-1104

Summary

Introduction. *The disruption of global supply chains and maritime multimodal transport caused by geopolitical tensions and infrastructure damage in Ukraine necessitates a paradigm shift in risk management. Traditional stochastic methods, particularly the Monte Carlo method, demonstrate significant limitations due to the lack of reliable retrospective statistical data in conditions of unprecedented uncertainty and continuous operational disruptions.* ***Purpose.*** *The primary purpose of this study is to present a fundamental, comprehensive analytical assessment of the risks associated with maritime multimodal supply chains and to develop an improved methodological framework. Specifically, the study aims to design a robust, integrated multi-criteria risk assessment model capable of functioning under extreme uncertainty, and to create a mathematical framework for the optimal allocation of financial and operational risks among supply chain participants, strictly accounting for the international Incoterms 2020 delivery rules.* ***Results.*** *Based on an in-depth systematic analysis of international and domestic transport practices, an integrated multi-criteria risk assessment model was developed. This model successfully combines the framework of dynamic Bayesian networks, which determine the probability of risk events occurring in real time, with advanced machine learning capabilities. Furthermore, the model incorporates the hybrid fuzzy logic method Fuzzy AHP-TOPSIS to effectively rank alternative logistics routes according to critical criteria of time, cost, and overall reliability under shifting operational conditions.* ***Conclusions.*** *Practical testing of the proposed model, utilizing the critical sector of Ukrainian grain exports as an empirical example, has confirmed its high predictive accuracy and superior adaptability to rapidly changing security environments. The integration of real-time data analysis and fuzzy logic offers a viable solution for complex decision-making in crisis logistics. Ultimately, the developed mathematical framework ensures equitable risk distribution, thereby significantly enhancing the resilience and efficiency of maritime multimodal transport networks during ongoing emergencies.*

Key words: *Transport, Risk assessment, Mathematical model, Prognostication, Mechanical resilience, Maritime logistics, Economic security, Sustainable logistics, Logistics infrastructure, Decision-making.*

ОЦІНКА ФІНАНСОВИХ ТА ОПЕРАЦІЙНИХ РИЗИКІВ МОРСЬКИХ МУЛЬТИМОДАЛЬНИХ ПЕРЕВЕЗЕНЬ В УМОВАХ НАДЗВИЧАЙНИХ СИТУАЦІЙ

А.М. Ібрагім[1], К.М. Клевцов[2]
[1] аспірант кафедри транспортних технологій та механічної інженерії,
Херсонська державна морська академія, Херсон, Україна
ORCID ID: 0009-0007-6007-5708
[2] д.т.н., професор кафедри транспортних технологій та механічної інженерії,
Херсонська державна морська академія, Херсон, Україна
ORCID ID: 0000-0001-8486-1104

Анотація

Вступ. *Дестабілізація глобальних ланцюгів постачань та критичні пошкодження транспортної інфраструктури в Україні зумовлюють необхідність докорінного перегляду парадигми управління ризиками в морському секторі. У статті здійснено фундаментальну комплексну аналітичну оцінку ризиків морських мультимодальних перевезень в умовах надзвичайних ситуацій, зумовлених геополітичною напругою. У дослідженні обґрунтовано обмеженість традиційних стохастичних методів, зокрема методу Монте-Карло, через відсутність надійних ретроспективних статистичних даних в умовах безпрецедентної невизначеності. Встановлено, що в умовах постійного впливу факторів форс-мажору класичні імітаційні моделі минулого втрачають свою прогностичну спроможність.* ***Мета.*** *Основним завданням роботи є формування стійкої методичної основи для прийняття управлінських рішень у кризовій логістиці. На основі глибокого системного аналізу міжнародної та вітчизняної транспортної практики сформовано вдосконалений методологічний базис. Зокрема, дослідження спрямоване на розробку математичного апарату розподілу фінансових та операційних ризиків між учасниками мультимодального ланцюга постачання з чітким урахуванням базисів поставки згідно з правилами Інкотермс-2020.* ***Результати.*** *Запропоновано інтегральну багатокритеріальну модель оцінки ризиків, яка поєднує апарат динамічних Баєсівських мереж (Bayesian Networks) для визначення ймовірності настання ризикових подій у реальному часі зі здатністю до машинного навчання. Використання Баєсівського підходу дає змогу безперервно оновлювати оцінки ризиків на кожній ділянці маршруту в разі появи нових даних про стан безпеки або інфраструктури. Також застосовано гібридний метод нечіткої логіки Fuzzy AHP-TOPSIS для ранжування альтернативних логістичних маршрутів за критеріями часу, вартості та надійності. Це дає можливість нівелювати когнітивну невизначеність експертних оцінок і врахувати багатовимірність логістичних витрат.* ***Висновки.*** *Практична апробація моделі на прикладі експорту зернових культур підтвердила її високу прогнозну точність та адаптивність до мінливих безпекових умов. Доведено, що інтеграція інструментів інтелектуального аналізу даних у логістичне планування забезпечує математичне підґрунтя для мінімізації втрат та підвищення живучості транспортних мереж. Розроблений алгоритм чітко демонструє, як зміна умов поставки впливає на фінансову вразливість експортера, що є критичним для забезпечення економічної стійкості підприємства в умовах надзвичайних ситуацій.*

Ключові слова: *транспорт, оцінка ризиків, математична модель, прогнозування, механічна стійкість, морська логістика, економічна безпека, стала логістика, логістична інфраструктура, прийняття рішень.*

Introduction

Maritime transport has historically been, and remains, the cornerstone of the global trading system, accounting for over 80 percent of the total volume of international cargo in physical terms [1]. The smooth operation of maritime trade routes is of strategic importance for Ukraine's macroeconomic stability. Around 80 percent of the country's agricultural exports have traditionally been shipped via Ukraine's seaports primarily the deep-water terminals in the Odesa metropolitan area (Odesa, Chornomorsk, Pivdennyi) generating the lion's share of foreign exchange earnings and contributing to global food security [2].

Multimodal transport, which conceptually involves at least two different modes of transport and multiple independent operators under a single end-to-end contract, is by its very nature an extremely complex and stochastic dynamic system [3]. Given the current challenges in Ukraine, this process is made significantly more difficult. There is a need for constant, rapid changes to routes and periodic re-routing of freight flows to ports on the Danube or to western land border crossings. The problem lies in a chronic shortage of rolling stock and drivers, as well as an extremely high level of unpredictable security risks [4].

In this context, the issue of methodological support for risk assessment with mandatory consideration of the Incoterms 2020 delivery terms becomes particularly relevant. These international commercial rules were developed by the International Chamber of Commerce (ICC). They strictly regulate the allocation of liability, costs and the point at which the risk of accidental loss or damage to the goods passes from the seller to the buyer [5]. In an era of global force majeure events, the correct choice of Incoterms term is transforming from a purely legal formality into a key strategic tool for the financial management of an exporting company [6].

Problem Statement

Despite the growing number of academic studies on logistics risks, a significant gap remains. This gap stems from the fact that existing models are either based on large historical datasets which are unavailable during a crisis or fail to incorporate legally binding contractual frameworks into their quantitative risk assessments. A specific example of such a contractual framework is "Incoterms 2020." This study addresses precisely this unresolved issue at the intersection of operational risk modeling and international trade law.

Literature Review and Research Gap

Research into the nature of risks in maritime multimodal transport forms a broad academic discourse. Against the backdrop of global crises (such as the COVID-19 pandemic, the blockage of the Suez Canal by the Ever Given, and geopolitical crises in the Black Sea and Red Sea regions), this discourse has taken on unprecedented intensity [7; 8]. The complexity of the research subject is due to the large number of participants in the logistics chain, the heterogeneity of transport modes, and the critical dependence on external force majeure factors.

Traditional approaches to quantitative risk assessment have long been based on the use of the Monte Carlo method. The essence of this method lies in running the model multiple times with random values for the input parameters. This allows one to obtain a probability distribution of the outcome and identify the most likely scenarios for

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the development of events [9]. However, within the scope of this study, the Monte Carlo method has significant limitations. The reason for this is the lack of reliable statistical data. This is due to the fact that modern emergencies in Ukraine are of the 'black swan' type. They do not conform to retrospective statistical distributions, meaning that modelling based solely on historical data may lead to erroneous management decisions.

Instead, modern transport science is increasingly turning to fuzzy logic. This theory allows for the use of qualitative and imprecise data. According to recent research, the integration of fuzzy logic with multi-criteria decision-making (MCDM) methods, such as AHP (Analytic Hierarchy Process) and TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution), enables the creation of highly robust and adaptive models for assessing the risks of disruptions in complex transport networks [10; 11].

The Fuzzy AHP method enables the structuring of a complex hierarchy of logistical risks using linguistic variables. These variables are subsequently transformed into triangular fuzzy numbers (TFN) for mathematical processing [12].

However, a systematic review of the existing literature shows that none of the published models simultaneously combines dynamic Bayesian analysis, fuzzy multi-criteria decision-making, and risk allocation based on Incoterms into a single unified system–especially one suitable for use in crisis conditions. This gap is the main research problem addressed by this study.

Research Objectives

The main objective of this study consists of three parts:

1. To develop and validate an integrated multi-criteria risk assessment model capable of functioning under conditions of extreme data scarcity;

2. To create a mathematical framework for allocating financial risks among participants in a multimodal supply chain in strict accordance with the Incoterms 2020 delivery terms;

3. Provide empirically grounded recommendations for route optimization for Ukrainian agricultural exporters based on current market data as of 2026.

Main Research Results

The integrated methodology employed in this study is built around three complementary analytical tools, each fulfilling a clearly defined and non-overlapping function within the overall risk assessment framework. Fuzzy AHP serves the role of a weighting engine: it processes expert pairwise comparisons of evaluation criteria (logistics cost, transit time, and security/insurance risk) under conditions of linguistic uncertainty and produces a normalised vector of criterion weights. Fuzzy TOPSIS then applies these weights to rank the alternative logistics routes by measuring their geometric proximity to the ideal positive and negative reference solutions, thereby producing an objective, multi-criteria ranking of alternatives. Dynamic Bayesian Networks (BN) address the third and most critical task: they quantify the probabilities of adverse risk events (cargo loss, infrastructure disruptions, logistical delays) under conditions of deep uncertainty, and continuously update these probabilities in real time as new evidence about the security situation, power grid status, or border congestion becomes available. This explicit division of methodological roles ensures that the framework functions as a coherent and mutually reinforcing integrated system, rather than an arbitrary combination of independent tools.

A mathematical description of triangular fuzzy numbers (TFN) and the AHP algorithm. To eliminate the cognitive uncertainty of expert assessments, linguistic judgements are transformed into triangular fuzzy numbers $\tilde{A} = (\boldsymbol{l}, \boldsymbol{m}, \boldsymbol{u})$. Where ***l*** is the smallest possible value, ***m*** is the most probable value (the apex of the triangle), and ***u*** is the largest possible value [13].

The conversion of the experts' linguistic ratings into TFN values for this study is presented in Table 1 [12]. The expert group was formed based on strict selection criteria. Specifically, each candidate had to possess at least five years of documented practical or academic experience in maritime and multimodal logistics, alongside direct operational involvement in international freight management or transport risk assessment. Ultimately, the panel consisted of seven experts. This included two senior logistics managers from freight forwarding companies whose expertise lies in the containerization of export-import cargo flows and multimodal integration. The group also involved two foreign trade managers with a practical background in handling financial and contractual risks under Incoterms 2020. The remaining three members were academics from Ukrainian transport universities with over five years of active research in logistics risks, security, and decision-making under uncertainty. To verify the internal consistency of their collective judgments, the Consistency Ratio (CR) was calculated as the ratio of the Consistency Index (CI) to the Random Index (RI) [10]. The obtained CR value of 0.041 is well below the accepted threshold of 0.10, which confirms the statistical consistency and reliability of the provided evaluations.

Table 1

Conversion scale for linguistic variables to triangular fuzzy numbers (TFN)

Linguistic evaluation	**Scale value**	**Triangular fuzzy number (l,m,u)**
Equal importance	1	(1, 1, 1)
Slight preference	3	(2, 3, 4)
Moderate preference	5	(4, 5, 6)
Strong preference	7	(6, 7, 8)
Absolute preference	9	(8, 9, 9)

Based on this scale and the aggregation of expert judgements, a pairwise comparison matrix (Table 2) was developed for the three key route optimisation criteria: C_1 (Total logistics costs), C_2 (Transit time), C_3 (Security and insurance risk).

Table 2

Matrix of pairwise comparisons of criteria for the Fuzzy AHP algorithm

Criterion	**C_1 (Cost)**	**C_2 (Time)**	**C_3 (Risk)**
C_1 (Cost)	(1.00, 1.00, 1.00)	(1.00, 2.00, 3.00)	(0.25, 0.33, 0.50)
C_2 (Time)	(0.33, 0.50, 1.00)	(1.00, 1.00, 1.00)	(0.20, 0.25, 0.33)
C_3 (Risk)	(2.00, 3.00, 4.00)	(3.00, 4.00, 5.00)	(1.00, 1.00, 1.00)

**Note: The weights of the criteria were calculated using Fuzzy AHP software with a defuzzification method based on the ‘Degree of Possibility’ approach proposed by Chang (1996) [12], yielding W_{C1} = 0.28, W_{C2} = 0.12, W_{C3} =0.60.*

After calculating the values of the fuzzy synthetic extent, the defuzzification method based on the Degree of Possibility (DOP) as proposed by Chang (1996) [12] is applied. This allows the fuzzy numbers to be converted into crisp criterion weights. As a result of defuzzification and normalisation, the final vector of crisp weights is obtained: W_{C1} = 0.28, W_{C2} = 0.12, W_{C3} = 0.60. The security and insurance risk criterion (W_{C3} = 0.60) holds the dominant weight in the proposed model. The expert panel unanimously agreed on this prioritisation. Under active hostilities and port blockades, operational security is the least controllable factor in logistics planning. A single security incident can instantly wipe out any cost or time savings of a given route.

The volatility of Extra War Risk Insurance (EWRI) premiums in the Black Sea region further reinforces this assessment. Historically, these premiums spiked to 1.0–1.5% of the cargo value during peak instability. By comparison, the rate stood at 0.45% at the time of this study.

Logistics cost (W_{C1} = 0.28) ranked second in importance. This reflects the heavy financial burden caused by forced rerouting and container demurrage. Finally, transit time (W_{C2} = 0.12) received the lowest weight. Experts noted that predictable delivery schedules are practically unachievable in wartime. Consequently, transit time serves only as a secondary target for route optimisation.

In turn, the Fuzzy TOPSIS method is used to rank alternative logistics routes or strategies by simultaneously measuring the shortest geometric distance to the positive ideal solution (FPIS, d^+) and the longest distance to the negative ideal solution (FNIS, d^-) [14]. Furthermore, fuzzy synthetic evaluation methods demonstrate high effectiveness in formalising multidimensional risks in complex port operations and terminal logistics [11].

The structure of a Bayesian network (BN). The second fundamental pillar of the chosen methodology is the framework of dynamic Bayesian networks. Unlike static fault trees, Bayesian networks enable the dynamic updating of event probabilities as new evidence becomes available in real time [15; 16]. This is critically important for maritime logistics in emergency situations, where changes in the security situation in the water area must be instantly reflected in the risk assessment of the entire voyage.

To calculate the probability of a critical logistical failure ($\boldsymbol{E}$) at each section of the route, this study constructs a directed acyclic graph (DAG) [15]. The root nodes in the network are defined as: $\boldsymbol{N}_1$ (Intensity of kinetic attacks on infrastructure), $\boldsymbol{N}_2$ (Degree of damage to the power grid) and $\boldsymbol{N}_3$ (Level of logistical congestion at borders). The leaf node is $\boldsymbol{E}$ (Occurrence of delays or damage to cargo).

The relationships between these nodes are formalised using conditional probability tables (CPTs). The CPTs were populated based on a synthesis of historical statistical data and the expert assessments mentioned above (for example, the conditional probability of failure given high attack intensity and partial network destruction, $\boldsymbol{P}(\boldsymbol{E} \mid \boldsymbol{N}_1 = \boldsymbol{High}, \boldsymbol{N}_2 = \boldsymbol{Moderate})$, is 0.75) [16]. The marginal probability of failure is calculated using the total probability theorem. This allows the mathematical expectation of expected delays, $\boldsymbol{E}(\Delta \boldsymbol{T})$, to be obtained [15].

A mathematical model for estimating financial losses. To formalise risks within multimodal transport under various Incoterms 2020 terms, we use the total risk function $\boldsymbol{R}_{total}$ [5]. The total financial risk for the exporter is determined by the extent of their liability at each stage of the logistics chain and the probability of adverse events occurring.

The probability of an undesirable event occurring is calculated using dynamic Bayesian networks (BN) [15].

The general formula for the expected financial losses (R) for a single transport leg is as follows (Formula 1):

$$R = P(E) * V * L \tag{1}$$

where:

$P(E)$ – the posterior probability of a risk event occurring (force majeure, accident, damage), calculated using conditional probabilities within the BN structure [15];

V – total value of the cargo consignment (Contract Value);

L – loss severity coefficient, ranging from 0 to 1. In this study, a conservative value of $L = 0.8$ is adopted for infrastructure damage (it is assumed that 20% of the residual value is retained in the form of scrap). **Important:** this L factor applies exclusively to the risk of physical loss of cargo, to avoid double counting of losses with the risk of time delays.

In addition to the risk of physical loss of cargo, the model specifically accounts for the financial risk associated with delays. In emergency situations, these delays result in significant losses due to the downtime of ships and railway wagons (Formula 2):

$$R_{time} = E(\Delta T) * C_{day} \tag{2}$$

where $E(\Delta T)$ is the mathematical expectation of the time deviation from the schedule (in days), generated by a Bayesian network, and C_{day} is the cost of a single day of downtime. This indicator aggregates the total costs of demurrage, excess storage and the costs of maintaining the company's frozen capital.

Thus, a comprehensive integrated risk assessment model for an exporter using the DAP (Delivered at Place) term [5], under which the exporter bears maximum liability until the goods are handed over at the destination, is expressed as the sum of the risks across all stages of the multimodal route (Formula 3):

$$R_{DAP} = \sum_{i=1}^{n} \left(R_{s,i} + R_{time,s,i} \right) + \left(R_m + R_{time,m} \right) + EWRI \tag{3}$$

where $R_{s,i}$ and $R_{time,s,i}$ are the risks associated with the i-th inland transport segment (railway, terminal);

R_m and $R_{time,m}$ are the risks associated with the sea crossing;

$EWRI$ (Extra War Risk Insurance) – the premium for insurance against additional war risks. Under DAP terms, a rational seller is obliged to pay this premium, as they bear the physical risk for the cargo during sea transport.

By way of comparison, under the FOB (Free on Board) term [5], the exporter's risk is limited solely to the first part of the equation (up to the point at which the cargo crosses the ship's rail) (Formula 4):

$$R_{FOB} = \sum_{i=1}^{n} \left(R_{s,i} + R_{time,s,i} \right) \tag{4}$$

The proposed mathematical framework allows for a clear delineation of areas of financial vulnerability depending on the chosen contract terms. This is critical for ensuring the economic stability of an enterprise in emergency situations.

Identifying and defining the information and empirical basis for conducting research. Following the expiry of the 'grain deal' and Russia's withdrawal from

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the Black Sea Grain Initiative, Ukraine independently launched a temporary maritime corridor. This not only enabled the resumption of export flows but also significantly stabilised the security situation for merchant vessels. As a result, this ensured that domestic agricultural produce could reach global markets on an industrial scale [17].

During this period, a radical restructuring of the modal composition of Ukrainian exports took place, accompanied by a gradual shift in focus from the Danube ports back to the deep-water ports of the Greater Odesa region (Odesa, Chornomorsk, Pivdennyi). As a result, their share in the overall structure of maritime exports has now stabilised at over 80% [18]. Land-based logistics routes through EU countries ('Solidarity Lanes') continue to serve as backup channels. However, at the start of their operation, the average waiting time for rail wagons at border infrastructure reached 16–30 days. This caused significant delays and substantially limited the throughput capacity of these routes [19].

To ensure the high reliability of the study's results, a standard consignment of food wheat weighing 12,500 tonnes was selected for testing. According to operational monitoring of prices on agricultural markets, the export value of Ukrainian wheat on FOB terms as of March 2026 is US$231.40 per tonne [20]. Thus, the total contract value of the consignment (V), included in the calculation is US$2,892,500.

The cost of direct exports via the ports of Greater Odesa to key export markets (such as ports in Egypt or Turkey) includes inland rail logistics to the port of Chornomorsk. As of early 2026, this is estimated at around US$625–630 per container [21], plus ocean freight. According to the current tariff schedules of liner operators, in particular Maersk, freight costs currently include special congestion surcharges (Congestion Fee Destination – CFD) [22].

Extra War Risk Insurance $(EWRI)$ premiums remain a decisive factor in terms of safety and financial burden. During periods of peak military instability, these rates reached a critical level of 1.0%–1.5% of the value of the vessel and cargo. As of 2026, $EWRI$ premiums for the ports of Greater Odesa have stabilised at 0.45%, owing to the successful operation of the maritime corridor and the implementation of special insurance programmes (in particular with the support of the UK government and Marsh McLennan) [23; 24]. As for the risks of time losses, penalties for the overdue detention of container equipment (detention) average US$40 per day per unit [25].

Practical verification of the risk assessment model using a specific example. To verify the mathematical framework developed, a practical test was conducted using a real-world case study of Ukrainian agricultural exports.

Problem statement:

An export company plans to ship a consignment of 500 TEU of wheat from a grain silo in the Kharkiv region to the port of Alexandria (Egypt). The total gross weight is approximately 12,500 tonnes (assuming a payload of 25 tonnes per TEU, which corresponds to typical weight restrictions). Although grain cargoes are traditionally transported by bulk carriers, the containerisation of agricultural products has increased significantly since 2022. This logistics solution allows exporters to diversify risks, avoid prolonged stockpiling at terminals during periods of shelling threats, and meet strict phytosanitary requirements for small consignments [4].

The cost of the cargo is US$231.40 per tonne [20]; therefore, the total value of the consignment V is US$2,892,500.

Calculation of the daily demurrage cost (C_{day}):

For a shipment of 500 TEU, the total costs are clearly broken down into several components. Direct demurrage (at USD 40 per unit) amounts to USD 20,000 per day. The cost of capital is calculated based on the current NBU discount rate (15% per annum as of 2026 [26]). This generates approximately 1,188 USD in hidden losses per day. Adding the average port storage costs (around 312 USD), the total cost of one day of logistical downtime is set at C_{day} = 21,500 USD.

The company's expert group is considering three alternative logistics routes:

Route 1 (M_1): Direct sea route. Kharkiv → Rail/Road → Port of Chornomorsk → Sea → Alexandria. Inland transport to the port is estimated at 625 USD/TEU. Sea freight (including a 100 USD CFD from Maersk [22]) amounts to approximately 800 USD/TEU. Total: 1,425 USD/TEU.[21] $EWRI$ insurance premium: 0.45% (13,016 USD).

Route 2 (M_2): Danube–Romanian. Kharkiv → Railway → Port of Izmail → barge → Port of Constana → sea → Alexandria. Inland transport and barge costs are estimated at around 1,200 USD/TEU, sea freight at 556 USD [27]. Total: 1,756 USD/TEU. $EWRI$: 0.15% (4,339 USD).

Route 3 (M_3): Overland via the EU. Kharkiv → Railway → Polish border → Port of Gdańsk → Sea → Alexandria. Cross-border delivery – 1,450 USD, sea freight – 900 USD [27]. Total: 2,350 USD/TEU. $EWRI$: 0.15%.

Stage 1. Ranking routes using the Fuzzy AHP-TOPSIS method

Based on the experts' linguistic assessments and the calculated criterion weights (W_{C1} = 0.28, W_{C2} = 0.12, W_{C3} = 0.60), a normalised matrix for the Fuzzy TOPSIS algorithm was constructed. It generates the following results for a 500 TEU shipment (Table 3). The algorithm calculates the shortest distance to the ideal positive solution (FPIS, d^+) and the ideal negative solution (FNIS, d^-). The final proximity coefficient (CC_i) is defined as $d^- / (d^+ + d^-)$ [14].

Table 3

Calculation of distances and results of the ranking of alternative routes using the Fuzzy AHP-TOPSIS method

Route	Logistics (USD)	Transit (days)	EWRI	Distance to FPIS	Distance to FNIS	Proximity coefficient	Rank
M_1 (Chornomorsk)	712,500	12	0.45%	2.21	5.54	0.715	1
M_2 (Constanța)	878,000	18	0.15%	3.26	4.49	0.580	2
M_3 (Gdańsk)	1,175,000	28	0.15%	5.85	1.90	0.245	3

Stage 2. Allocation of risks under Incoterms 2020

For the optimal route M_1 , we will analyse the total financial risk depending on the delivery basis. Based on the results of the Bayesian network, the marginal posterior probabilities of critical failures are determined as: $P(E_s)$ = 0.01672 (for land transit) and $P(E_m)$ = 0.0424 (for sea transit). The residual value retention factor is L = 0.8. According to the network topology, the mathematical expectation of the time deviation is $E(\Delta T_s)$ = 1.44 days (land) and $E(\Delta T_m)$ = 2.50 days (sea).

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Step-by-step assessment of financial risks:

1. ***Time risk (Inland):*** 1.44 * 21,500 = 30,960 USD.
2. ***Physical loss risk (Inland):*** 2,892,500 * 0.01672 * 0.8 ≈ 38,690 USD.
3. ***Time risk (Sea):*** 2.50 * 21,500 = 53,750 USD.
4. ***Physical loss risk (Sea):*** 2,892,500 * 0.0424 * 0.8 ≈ 98,110 USD.
5. ***Insurance cost (EWRI):*** 2,892,500 * 0.0045 = 13,016 USD.

The detailed breakdown of these financial risks across different delivery bases is summarized in Table 4.

Table 4

Calculation of the seller's total financial risk under Incoterms (in US dollars)

Route stage / Basis	Rail and port risk (Time + Loss)	Marine risk (Time + Loss)	Insurance costs (EWRI)	Total risk	% of contract
FOB Chornomorsk	69,650	0	0	69,650	2.41 %
CIF Alexandria	69,650	0*	13,016	82,666	2.86 %
DAP Alexandria	69,650	151,860	13,016	234,526	8.11 %

**Note: Under CIF terms, the seller pays only for minimum cargo insurance (EWRI). However, the physical risk and the risk of delay at sea legally pass to the buyer at the moment of loading onto the vessel. Therefore, for the seller, these risks are zero [5].*

To validate the stability of the proposed model, a sensitivity analysis was performed across three stress scenarios. The details of this analysis and the corresponding risk fluctuations are presented in Table 5. The results confirm that the optimal ranking of Incoterms bases remains robust even under extreme conditions. Doubling transit delays or increasing EWRI premiums to historical peaks does not change the final strategic choice. This stability demonstrates that the integrated methodology provides a reliable foundation for decision-making in crisis conditions.

Table 5

Sensitivity analysis: Total financial risk of the exporter under Incoterms 2020 across three stress scenarios (Route M1, USD)

Incoterms Basis	Scenario 1 (Base): EWRI=0.45%, standard delays	Scenario 2: EWRI=1.0%, delays +50%	Scenario 3: EWRI=1.5%, delays +100%
FOB Chornomorsk	69,650 (2.41%)	85,130 (2.94%)	100,610 (3.48%)
CIF Alexandria	82,666 (2.86%)	114,055 (3.94%)	143,998 (4.98%)
DAP Alexandria	234,526 (8.11%)	292,790 (10.12%)	349,608 (12.09%)

Note: Scenario 2 assumes EWRI rises to 1.0% (documented peak during acute hostilities) and expected delays increase by 50% ($E(\Delta T_s)$=2.16 days; $E(\Delta T_m)$=3.75 days). Scenario 3 assumes EWRI at the historical maximum of 1.5% with delays doubled ($E(\Delta T_s)$=2.88 days; $E(\Delta T_m)$= 5.00 days). Physical loss probabilities ($P(E_s)$=0.01672; $P(E_m)$= 0.0424) and the loss severity coefficient (L = 0.8) remain constant across all scenarios. The results confirm that the rank ordering FOB < CIF < DAP is fully preserved under all stress conditions, and that the absolute risk magnitude scales proportionally with the parameter changes, demonstrating the structural robustness of the proposed model.

Analytical conclusion: Signing a contract on DAP Alexandria terms increases the exporter's financial risk to USD 234,526 (8.11%). This is because the exporter assumes full legal and operational responsibility for the sea leg. FOB is the optimal choice in terms of risk minimisation. However, CIF remains the compromise solution in practice.

Discussion of Results

The scientific novelty of the research presented in this article lies in the following:

An integrated model for the analytical assessment of risks in maritime multimodal transport has been refined and adapted to crisis conditions. It algorithmically combines the apparatus of dynamic Bayesian networks (for calculating probabilities under the uncertainty of a crisis environment) and the Fuzzy AHP-TOPSIS method (for mitigating expert uncertainty in decision-making). The limitations of the Monte Carlo method are substantiated. The advantages of the proposed approach in the absence of normal distributions are argued.

The mathematical method for allocating financial and operational risks has been refined through the implementation of the Incoterms 2020 international rules. This has made it possible to translate the purely legal provisions of international trade into precise engineering and economic calculations. It has also helped to clearly assess the exporter's financial exposure at every stage of the multimodal route.

The methodology for spatial-route optimisation of Ukraine's export logistics has been further developed through the introduction of the dynamic EWRI indicator as a security risk criterion into the Fuzzy TOPSIS function. A scientific and mathematical justification was carried out based on the analysis of current data as of 2026. It was found that, thanks to the stabilisation of insurance premiums at 0.45%, routes via the deep-water ports of Greater Odesa are optimal in terms of the integrated cost and time criterion compared to western land crossings and Danube ports.

Conclusions

Based on the in-depth analytical study conducted, the following conceptual conclusions can be drawn:

Hostilities, unprecedented geopolitical tensions and port blockades have fundamentally disrupted the traditional paradigms of logistics planning in the Azov-Black Sea basin. It has been established that risk management in multimodal supply chains under conditions of permanent force majeure cannot rely on linear deterministic approaches or simulation models of the past.

The use of Bayesian networks allows for the continuous updating of the assessment of failure probabilities in real time based on the emergence of new evidence (for example, damage to the power grid or border closures by neighbouring states). This significantly increases the reliability of forecasting logistical deviations. The application of fuzzy logic tools (the Fuzzy AHP-TOPSIS algorithm) to compare alternative export routes has confirmed the fundamental economic viability of the new Ukrainian maritime corridor.

Despite the existence of premiums for additional security risks, the overall time and cost losses on direct shipments from the ports of Greater Odesa are significantly lower than the weeks-long delays at congested land borders with the EU or the additional costs of intermediate river transhipment. The reduction and stabilisation of insurance rates for additional security risks (EWRI) to 0.45% [23] became the critical factor that mathematically confirmed the advantage of the sea route ($CC_i = 0.715$).

It has been mathematically proven that the choice of Incoterms 2020 terms is no less critical than the choice of the physical transport route. Practical testing has clearly demonstrated that an exporter's switch from the safe FOB basis to the DAP basis for a standard grain consignment (500 TEU) increases the extent of their potential financial risk in the event of an emergency by more than three times (from 2.41% to 8.11% of the contract value) [5].

The integration of risk distribution functions into the developed mathematical model provides a solid engineering foundation for the creation of specialised automated software. The further development of such a software product, capable of integrating API data and a Bayesian engine into a single interface, represents an extremely promising avenue for applied research within the framework of the development of domestic transport technologies.

Future research should focus on developing an automated software tool for decision support. Such a tool should integrate real-time API data streams. This data includes current freight rates, EWRI premiums, and border congestion indicators. Data integration should be carried out within the framework of a Bayesian inference mechanism. This will ensure continuous and dynamic risk recalculation. The results obtained can be used by logistics operators to make informed decisions.

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