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AN ANALYTICAL ASSESSMENT OF LEGAL RISKS IN MULTIMODAL TRANSPORT INVOLVING MARITIME TRANSPORT DURING EMERGENCIES

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The effective organisation of multimodal transport involving maritime shipping during emergencies is significantly hindered by systemic legal conflicts. This study addresses the urgent need for quantitative tools to manage these hidden legal vulnerabilities. Objective: To develop a methodological framework for the Barrier Analysis of Legal Risks (BALR) for multimodal transport operators and to quantitatively assess the probability of these risks materialising under extreme conditions. Methods: The study proposes an exploratory integration of engineering safety models into legal risk analysis. It combines Gibson and Haddon's energy-barrier theory with J. Reason's 'Swiss cheese' model to identify legal conflicts as latent system conditions. Furthermore, it adapts the HEART (Human Error Assessment and Reduction Technique) methodology to mathematically calculate the adjusted probability (P_{scor}) *of a legal risk occurring, utilising error-provoking condition (EPC) coefficients. Results: Based on the analysis of six key legal conflicts, a comprehensive BALR matrix was developed. Three risks were classified as 'CRITICAL'* $(P_{scor} \approx 1.0)$*: the 'patchwork' network liability model, the archaic maritime exemption for navigational errors, and the legal vacuum regarding force majeure under martial law. The original concept of 'legal practical drift' is introduced to explain how emergency stressors erode compliance procedures. Practical implications: The study demonstrates that digital technologies, specifically 'Digital Twins' telemetry and electronic records under the 2025 UN Accra Convention, act as the most effective compensatory barriers. The calculated BALR matrix provides multimodal operators with a practical decision-support tool for internal compliance audits and offers supplementary analytical arguments for international transport arbitration.*
Key words: *multimodal transport; HEART; the 'Swiss cheese' model; legal conflicts; barrier analysis; transport; risk assessment; mathematical model; prognostication; mechanical resilience.*

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Introduction. The effective organisation of multimodal transport involving maritime transport requires not only the technical coordination of different modes of transport, but also the ability of operators to function within a legal framework that is largely uncoordinated. In a previous study by the authors [1], it was established that Ukraine's regulatory framework in this area contains systemic legal inconsistencies. Specifically, the provisions of the 2021 Law 'On Multimodal Cargo Transport' conflict with the Merchant Shipping Code of Ukraine (MSCU), the Civil Code and key international conventions. That article provided a detailed description of the existing conflicts. The aim of this study, however, is to carry out a quantitative analytical assessment. In other words, to determine the mathematically substantiated probability of each legal risk materialising and which of them should be prioritised for managerial intervention.

The issue becomes particularly acute under martial law, when unprecedented physical threats arise: GPS spoofing in the Black Sea, the danger of mines, air raid alerts during cargo inspections at ports, and the urgent need to change logistics corridors. There is a practical and academic need for quantitative tools to identify, assess and manage legal risks. In other words, tools that could serve as a basis of evidence in arbitration proceedings. From a transport systems engineering perspective, legal conflicts are treated in this study not as abstract legal issues, but as operational constraints that directly influence the reliability and safety of multimodal logistics chains.

Problem statement. A significant proportion of academic research in the field of transport law focuses on issues of de lege ferenda – the reform of legislation. This overlooks a fundamentally important practical consideration: how should an operator manage legal risk right now, given the current imperfect legal framework? Legal conflicts (online liability, an outdated provision of the Civil Code of Ukraine regarding navigational errors, differing limitation periods, and the legal vacuum created by martial law) are latent factors. They exist at all times, but are only ‘activated’ when triggered by an insured event or arbitration proceedings. Quantifying them is essential for setting management priorities.

Analyses of recent studies and publications. The legal aspects of multimodal transport are being actively studied by scholars both in Ukraine and abroad. V. V. Dobrovolska [2] examined the commercial and legal nature of multimodal transport contracts. Kirillova, O. V., and Kirillova, V. Yu. [3] identified terminological inconsistencies between the 2021 Law and international standards. Kunda N. T. [4] examined the evolution of liability regimes in international conventions. A parallel area of research concerns security management theory. The fundamental framework here is Gibson and Haddon’s energy-barrier theory [5, 6]. According to this theory, an incident occurs due to the absence or breach of the barrier between the source of danger and the vulnerable target. This approach was further developed in J. Reason’s ‘Swiss cheese’ model [7]. It describes the occurrence of system failures caused by the simultaneous failure of multiple protective barriers. S. Snook’s theory of ‘practical deviation’ [10] explains the mechanism by which practices gradually diverge from normative guidelines. The HEART [11] method is widely used for the mathematical assessment of the probability of error. The role of the human factor in maritime incidents was investigated by V. G. Torsky and L. A. Pozolotin [12]. Data generated by digital twin systems are accepted as evidence in logistics disputes due to their immutability, reproducibility and comprehensive documentation [13].

However, a critical review of the literature reveals a fundamental gap: none of the aforementioned approaches has integrated the legal aspects of cargo liability with the methodology of engineering barrier analysis. This gap defines the scope of this study.

Aims and objectives of the study. The aim of the study is to conduct an analytical assessment of the organisational and legal risks associated with cargo loss in multimodal transport during emergencies. To achieve this aim, a special toolkit for barrier analysis and risk forecasting (BALR) is being developed. The toolkit is based on the integration of three methodological approaches: energy-barrier theory, the Reason model and the HEART methodology.

Research objectives:

1. To systematise the legal conflicts identified in [1] in terms of safety management theory (active failures / latent conditions);

2. To develop an original concept of the ‘legal practical drift’ as a mechanism for the erosion of legal compliance in emergency situations;

3. Adapt the HEART methodology and calculate the adjusted probability (Pscor) of legal risks materialising;

4. Develop a BALR matrix and formulate recommendations on the use of digital technologies as compensatory barriers.

Main part. The main part of the study is structured into six interconnected sections. The first section presents a comparative analysis of international maritime liability regimes and the Ukrainian Merchant Shipping Code. The second section applies Gibson–Haddon energy-barrier theory and Reason's "Swiss cheese" model to reframe legal conflicts as latent systemic conditions. The third section introduces the original concept of "legal practical drift" to explain how compliance procedures erode under emergency conditions. The fourth section adapts the HEART methodology for the mathematical quantification of legal risk probabilities. The fifth section synthesises the findings into an integrated BALR risk matrix. The sixth section formulates practical recommendations, with particular emphasis on digital technologies as compensatory barriers.

1. A comparative analysis of legal regimes: from the Hague Rules to the Merchant Shipping Code of Ukraine (MSCU). A fundamental factor contributing to legal uncertainty is the absence of a single, unified international regime. Attempts to establish such a regime have failed to secure the necessary number of ratifications. A comparative analysis of the key regimes is provided in Table 1.

Table 1 – Comparative analysis of international maritime transport regimes and the Merchant Shipping Code of Ukraine (MSCU)

Characteristics	*The Hague-Visby Rules (1924/68)*	*The Hamburg Rules (1978)*	*The Rotterdam Rules (2008)*	*The Merchant Shipping Code of Ukraine (1995)*
Scope of application	Port-to-port («from hook to hook»)	Port-to-port + overland transport under a single contract	«Door-to-door», including multimodal stages	Port-to-port (similar to the Hague-Visby Rules)*
Basis for liability	Guilt + a wide range of exemptions (navigational error, fire, etc.)	Presumption of guilt, limited list of exemptions	Presumption of guilt, extended list of circumstances	Fault + Retention of dismissal for a navigational error*
Limits (maritime)	666.67 SDR per package or unit, or 2 SDR per kilogram	835 SDR per package or unit, or 2.5 SDR per kilogram	875 SDR per package or unit, or 3 SDR per kilogram	666.67 SDR per package or unit, or 2 SDR per kilogram
Limitation period	1 year	2 years	2 years	1 year (Civil Code / MSCU)*
Navigation error	Grounds for dismissal	not an exemption	not an exemption	Grounds for exemption*
Electronic documents	Not regulated	Mentioned	Dedicated chapter	Not provided for*

Note. indicates an archaic provision generating legal risk. Source: compiled by the authors based on [1, 14–17].*

As demonstrated in Table 1, the MSCU aligns most closely with the archaic liability model, offering the least protection for cargo owners' interests. The network liability model of the 2021 Law generates a 'patchwork' system: the sea leg – 2 SDR/kg, road transport (Convention on the Contract for the International Carriage of Goods by Road, CMR) – 8.33 SDR/kg, rail transport (Agreement on International Goods Transport by Rail, SMGS) – full value. The amount of compensation depends not on the actual damage sustained, but on the ability to localise the place of loss or damage – which, in the context of armed conflict, is frequently impossible.

2. Legal Conflicts as «Latent Conditions» in Gibson–Haddon Energy-Barrier Theory and Reason's Model. The central theoretical proposition of the BALR framework is the integration of energy-barrier theory and the 'Swiss cheese' model into the domain of transport law. According to Gibson and Haddon [5, 6], a hazard materialises when the barrier between the source of danger and the vulnerable target is breached. Reason's model [7] elaborates the anatomy of this failure. According to this model, the defensive system comprises multiple layers («slices of cheese»), each containing 'holes' – that is, vulnerabilities. This multi-level barrier concept effectively illustrates how independent technical or organizational vulnerabilities can align to trigger systemic failures [8]. Reason draws a fundamental distinction between:

1. active failures – unsafe acts committed by frontline operators with a direct and immediate impact (erroneous decisions made by crew members or freight forwarders);
2. latent conditions – concealed regulatory and organisational deficiencies that exist long before an incident occurs.

Losses occur exclusively when the 'holes' across different layers align, forming a «trajectory of accident opportunity». Applying this framework to multimodal transport:

– vulnerable target: the cargo owner's guaranteed right to financial compensation;

– source of danger (kinetic trigger): emergencies – consequences of armed conflict, GPS spoofing, air raid alerts at ports;

– protective barriers: a through-transport contract, an insurance policy, cargo inspection records;

– latent conditions ('holes'): legal conflicts – network liability, the outdated MSCU provision, differing limitation periods.

The protective barriers operate at four levels [9]: 1) the liability limits barrier – the 'hole' of unlocalised loss; 2) the negligence protection barrier – the 'hole' of the MSCU navigational error exemption; 3) the procedural barrier – the 'hole' of conflicting limitation periods; 4) the force majeure barrier – entirely absent due to the legal vacuum surrounding martial law.

3. The Concept of 'Legal Practical Drift' under Emergency Conditions. Snook's theory of «practical drift» [10] describes the phenomenon of gradual divergence of actual practices from normative guidelines. The authors' concept of «legal practical drift» explains the degradation of cargo control procedures during crises. During an air raid alert at a port, personnel accelerate container handling operations, as a result of which seal verification and the drawing up of commercial acts may be overlooked – a 'normalisation' in the interest of physical safety. The activation phase occurs at the moment of arbitration proceedings: the evidentiary basis (a cargo inspection record at the modal interface) is absent, the loss becomes 'unlocalised' and triggers the lowest liability limit under the network model.

4. Adaptation of the HEART Methodology: Analytical Calculation of the Adjusted Probability. The HEART methodology [11, 18] provides a quantitative measurement by classifying the operator's actions according to task types and adjusting the baseline error probability by multiplying it by the environmental probability of failure (EPC). The adapted task types are shown in Table 2.

Table 2 – Types of HEART tasks adapted to the legal decisions of a multimodal transport operator

Code	*Task type description*	*Pbase*	*90% confidence interval*	*Legal context for the multimodal transport operator during emergencies*
A	Totally unfamiliar task performed under stress without analysis of consequences	0.55	0.35–0.97	Operator actions in an unforeseen emergency (infrastructure shelling, GPS signal loss)
B	Restoring a system without feedback	0.26	0.14–0.42	Restoration of the logistics chain following the destruction of a transshipment hub
C	Complex task requiring deliberation and specialist knowledge	0.16	0.12–0.28	Route planning under new legal conditions (EU overland transit corridors)
D	Simple task under time pressure or with reduced attention	0.09	0.06–0.13	Documentation processing and cargo inspection during transshipment under an air raid alert
E	Routine, highly practised task requiring no special demands	0.02	0.007–0.045	Verification of standard documentation

Source: compiled by the authors based on the adaptation of the HEART methodology [11].

Note: P_{base} *and* P_{scor} *are dimensionless probability values ranging from 0 to 1.0.*

The error-producing conditions (EPC) are presented in Table 3. Each condition represents an external factor that elevates the baseline probability of operator error beyond the nominal level established by the HEART methodology. The weighting coefficient of condition presence (wi) reflects the degree of its actual influence in a given situation: from 0 (condition absent) to 1.0 (condition fully active). For conditions of elevated operational stress, a value of $wi = 1.0$ is adopted in this study.

Table 3 – Specific error-prone conditions (EPCs) in the adaptation to the legal context

№	*Error-provoking condition (EPC)*	*Max*	*Legal context in multimodal transport*
EPC-1	Underestimating the potential significance of the situation	17.0	Failure to comply with legal formalities prior to the occurrence of an insured event or arbitration
EPC-2	Lack of time to identify and correct errors	11.0	Severe time pressure when processing documents due to logistical delays or the threat of shelling
EPC-3	Lack of independent oversight	3.0	Failure to carry out a legal review of the contractual documentation prior to signing
EPC-4	Lack of experience in unusual situations	3.0	First experience of using alternative routes during martial law
EPC-5	Ambiguous objectives and conflicting demands	2.5	Conflict between the provisions of the MSCU, the 2021 Law, and the Civil Code
EPC-6	Lack of feedback on the results of actions	2.5	There is no mechanism for notifying the operator of changes in law enforcement practice
EPC-7	Emotional stress / a state of heightened anxiety	1.3	Martial law conditions, mine hazards, GPS spoofing, threats to the crew
EPC-8	The impact of an unfavourable operating environment	1.15	Use of ports and routes under dual jurisdiction

Source: compiled by the authors based on an adaptation of the HEART methodology [11].
Note: 'Max' column represents the maximum weight of the error-producing condition as per the HEART methodology.

To clarify the analytical mechanism of the BALR framework, it is essential to trace how legal conflicts enter the HEART calculation. Initially, existing legal conflicts create a latent systemic vulnerability. During an emergency, this vulnerability manifests as specific Error-Producing Conditions (EPCs), such as severe time pressure (EPC-2) or emotional stress (EPC-7). These EPCs directly influence the operator's decisions, forcing deviations from standard compliance procedures to prioritise physical safety. Finally, this degraded decision-making environment is mathematically quantified in the HEART model by applying the corresponding EPC multipliers to the base probability. Furthermore, for the calculations in this study, the condition presence multiplier (w_i) is deliberately set to 1.0. This represents a worst-case scenario modelling approach, reflecting the reality that under extreme emergency conditions (e.g., active shelling or sudden infrastructure destruction), negative environmental factors exert their maximum disruptive impact on human cognitive performance.

The HEART mathematical procedure involves calculating the adjusted probability (P_{scor}) using Formula 1:

$$P_{scor} = P_{base} \times \Pi\left[\left(EPC_i - 1\right) \times wi + 1\right] \quad (1)$$

Where P_{base} is the nominal probability; EPC_i – the maximum coefficient of the $i-th$ condition; wi – the weighting coefficient for the presence of a condition $(0 \leq wi \leq 1)$. For critical risks during emergencies, wi is taken as 1.0. The numerical values for EPC coefficients (e.g., 17.0, 11.0) are standardized metrics derived from the original HEART methodology validation studies

[11], representing the maximum potential multiplier of error for specific environmental conditions. Let us present a detailed calculation in Formula 2 for a «patchwork» liability scenario (type C, $P_{base} = 0.16$; EPC-1 × 17.0; EPC-2 × 11.0):

$$P_{scor} = 0.16 \times \left[(17.0 - 1) \times 1.0 + 1 \right] \times \left[(11.0 - 1) \times 1.0 + 1 \right] = 29.92 \quad (2)$$

Since the probability cannot exceed 1.0, the result is recorded as $P_{scor} = 1.0$ (CRITICAL). For the MSCU standard regarding navigation error, the calculation is performed using Formula 3 (Type A, $P_{base} = 0.55$; EPC-7 × 1.3; EPC-3 × 3.0):

$$P_{scor} = 0.55 \times 1.3 \times 3.0 = 2.145 \rightarrow 1.0\,(CRITICAL) \quad (3)$$

In the event of a conflict of limitation periods, the period is calculated using Formula 4 (type D, $P_{base} = 0.09$; EPC-5 × 2.5; EPC-6 × 2.5):

$$P_{scor} = 0.09 \times 2.5 \times 2.5 = 0.563\,(HIGH) \quad (4)$$

In the absence of electronic document flow, it is calculated using the Formula 5 (type E, $P_{base} = 0.02$; EPC-2 × 11.0; EPC-8 × 1.15):

$$P_{scor} = 0.02 \times 11.0 \times 1.15 = 0.253\,(MEDIUM) \quad (5)$$

This calculation transforms the subjective assertion that «the operator acted negligently» into a supporting analytical argument for arbitration.

5. The BALR risk matrix: a synthesis of qualitative and quantitative analysis. By integrating the results of comparative legal analysis, Reason's model and HEART's mathematical calculations, the author's BALR matrix systematises key conflicts (Table 4). The risk level is colour-coded: red – critical ($P_{scor} \geq 0.90$), yellow – high (0.40–0.89), green – medium (< 0.40).

Table 4 – Matrix for the barrier analysis of legal risks (BALR) during emergencies

Legal conflict / risk factor	*HEART type*	*Pbase*	*EPCs (coefficients) involved*	*Pscor*	*BALR risk level*
«Patchwork» liability: non-localised loss of cargo (network model)	C (0.16)	0.16	EPC-1 (×17.0) EPC-2 (×11.0)	1.0**	CRITICAL
Retention in the UMSC of the provision on exemption from liability for navigational errors	A (0.55)	0.55	EPC-7 (×1.3) EPC-3 (×3.0)	1.0**	CRITICAL
A legal vacuum regarding force majeure and insurance against military risks	A (0.55)	0.55	EPC-7 (×1.3) EPC-4 (×3.0)	1.0**	CRITICAL
Conflict of limitation periods (1 year under CMSU vs 2 years under the Hamburg Rules)	D (0.09)	0.09	EPC-5 (×2.5) EPC-6 (×2.5)	0.563	HIGH
Absence of mandatory electronic document management (vs Regulation (EU) 2020/1056)	E (0.02)	0.02	EPC-2 (×11.0) EPC-8 (×1.15)	0.253	MEDIUM
Terminological inconsistency: «multimodal» vs «intermodal»	D (0.09)	0.09	EPC-5 (×2.5)	0.225	MEDIUM

*Note 1. ** – a calculated value of ≥ 1.0 is recorded as the maximum probability. Source: compiled by the authors.*

Note 2: P_{base} and P_{scor} are dimensionless probability values ranging from 0 to 1.0.

6. Recommendations: digital technologies as compensatory barriers. At the legislative level (de lege ferenda), the priorities are: 1) the removal from the Ukrainian Code of Merchant Shipping of the exemption from liability for navigational errors; 2) a gradual transition from a networked to a unified model of liability; 3) the development of provisions regarding force majeure and insurance against military risks.

At the operational level, given that paper-based document workflows are vulnerable to ‘practical disruption’ during emergencies, digital technologies become the key mitigating factors:

1. Digital Twins technology [13]. The use of IoT sensors (temperature, vibration, geolocation), integrated into the container’s digital twin, allows the exact time and location of an incident to be determined. This approach aligns with the broader trajectory of maritime safety research, which increasingly identifies digital twinning and data-driven simulation as key tools for risk mitigation [19]. This eliminates the legal problem of ‘unlocalised loss’. After all, arbitrators receive indisputable telemetry data to apply the correct liability limit.

2. The 2025 UN Accra Convention [21, 22]. This UNCITRAL instrument legalises electronic cargo management documents (eNCDs) for all modes of transport. The introduction of eNCDs physically prevents a «legal practical drift». As the electronic system will not allow the cargo verification step to be skipped during transit, it creates a reliable evidential basis regardless of infrastructure damage.

Main results and discussion. The developed BALR matrix objectively identified three critical risks $(P_{scor} \approx 1.0)$: «patchwork» liability under the network model, the retention of an archaic provision in the Ukrainian Code of Merchant Shipping concerning navigational errors, and a legal vacuum regarding martial law. One risk is classified as «HIGH» $(P_{scor} = 0.563)$: conflict of limitation periods. Two risks are «MEDIUM» $(P_{scor} < 0.40)$.

An important methodological outcome is the ability to compare heterogeneous risks using a single numerical criterion. In particular, the risk of the absence of e-document flow $(P_{scor} = 0.253)$ (is significantly lower in priority than the conflict of limitation periods $(P_{scor} = 0.563)$). However, it should be noted that both conflicts are often mentioned in academic works as being of equal significance. The HEART calculation transforms subjective assessments into a supporting analytical argument. This can serve as a supplementary justification in international transport arbitration: quantitative proof of systemic shortcomings in legislation successfully refutes opponents’ references to the ‘unpredictability’ of events.

The proposed concept of a ‘'Legal Practical Drift’ explains the actual mechanism by which even companies with skilled legal departments systematically find themselves unprotected. The problem lies not in a lack of knowledge, but in the absence of a mechanism for continuously monitoring the compliance of operational practices with legal standards – the equivalent of an internal security audit under the ISM Code.

Validation of the BALR Framework: A Simulated Case Study. To demonstrate how the BALR matrix applies in practice, consider a simulated scenario based on current emergency realities. A multimodal operator is transporting high-value energy equipment from a European port to Ukraine. During the modal interface (transshipment from ship to truck), an air-raid alert occurs. Operating under severe time pressure and stress (EPC-2 = 11.0, EPC-1 = 17.0), the terminal personnel rush the transshipment without proper cargo inspection and documentation—a classic manifestation of '*legal practical drift*'. Upon arrival, the cargo is found damaged. Because the exact location of the damage is 'unlocalised', the operator faces the 'patchwork' liability conflict. Consequently, the carrier successfully invokes the lowest maritime liability limit (2 SDR/kg) instead of the higher road transport limit or full compensation. The BALR matrix accurately anticipates this systemic failure, identifying it as a CRITICAL risk $(P_{scor} = 1.0)$. Furthermore, the framework dictates the solution: had the operator deployed the recommended compensatory barrier (IoT sensors integrated into a Digital Twin), the irrefutable telemetry data would have pinpointed the exact time and location of the damage. This would override the human procedural error, circumvent the 'patchwork' liability loophole, and ensure fair compensation. This example illustrates how BALR effectively transforms abstract legal uncertainties into manageable engineering parameters for decision-making.

The integration of smart contracts and electronic negotiable documents (eNCDs) into the Digital Twins ecosystem as a technological mechanism for managing legal risks. A pragmatic solution for mitigating critical risks $(P_{scor} \approx 1.0)$, identified in the BALR matrix, is the creation of a closed technological ecosystem that combines the regulatory framework with engineering functionality. The foundation for such a system was the UN Accra Convention on Negotiable Cargo Documents. It was adopted by the General Assembly on 15 December 2025. This revolutionary convention legalised electronic negotiable documents (eNCDs). As a result, they became fully-fledged documents of title for all modes of transport. eNCDs are based on the principles of the UNCITRAL Model Law on Electronic Negotiable Records (MLETR).

The risk mitigation mechanism is implemented through the integration of electronic transaction documents with Digital Twins technology, based on a blockchain platform and smart contracts. The logic behind this interaction works as follows:

1. *Generation of objective data (digital twins):* The multimodal container is equipped with a network of IoT sensors that continuously monitor its precise location, temperature, vibration levels and the integrity of the seals. This telemetry data forms a virtual copy (digital twin) of the cargo. It reflects its physical condition in real time during transit.

2. *Data security and immutability (Blockchain):* As traditional centralised systems are vulnerable to tampering, telemetry data from sensors is transmitted directly to a distributed ledger (blockchain). This ensures the integrity, traceability and cybersecurity of the data.

3. *Compliance automation (Smart contracts):* A smart contract acts as the legal bridge between the physical cargo and the electronic certificate of ownership (eNCD). The blockchain cannot retrieve external information on its own. This is why special intermediary programmes – ‘oracles’ – are used. They transfer telemetry from the Digital Twin to the smart contract. If an emergency arises during transport (for example, a seal is damaged at the port or there is a critical change in temperature as a result of an emergency), the smart contract immediately records this breach of conditions.

The smart contract immediately records this breach of terms. The key legal consequence of such integration is that the smart contract automatically, consistently and without human intervention records the exact time and location of the incident. This provides arbitration with a 100% reliable evidence base. Specifically, it completely resolves the problem of ‘unlocalised loss’ in a fragmented (networked) liability system. The technological architecture simply does not allow the system to pass the cargo on without digital recording. In doing so, it physically blocks the possibility of a ‘legal practical drift’ arising, as discussed in this study.

Limitations of the Study The proposed BALR methodology is subject to several limitations. First, the model currently lacks a large empirical dataset of arbitration cases to statistically calibrate the outcomes. Second, the adaptation of standard HEART metrics to legal scenarios inherently involves subjective EPC weighting by experts. Third, the fact that several risks reach the probability ceiling $(P_{scor} = 1.0)$ indicates the extreme nature of the modelled emergency conditions, rather than serving as an exact statistical prediction. Consequently, this framework is intended primarily as an exploratory decision-support tool for prioritising managerial interventions and legal compliance audits, rather than a tool for exact mathematical prognostication.

Conclusions. Firstly, the BALR concept developed here is a first in Ukrainian transport science. It integrates Gibson-Haddon’s energy barrier theory [5, 6], Reason’s ‘Swiss cheese’ model [7] and the HEART methodology [11] into the field of regulatory compliance. This demonstrates that emergencies act as kinetic triggers, exploiting hidden legal ‘loopholes’ to cause financial harm. Moreover, the three such loopholes identified in this study have a calculated probability of materialisation, $P_{scor} = 1.0$ (CRITICAL).

Secondly, distinguishing between active failures and latent conditions opens up new avenues for arbitration arguments. In particular, analytical justification of systemic legislative shortcomings, expressed through specific ratios such as EPC-1 × 17.0 and EPC-2 × 11.0, provides a strong basis to challenge opponents' claims regarding the «unpredictability» of staff errors.

Thirdly, the concept of 'legal drift' [10] explains the mechanism by which security barriers break down under extreme pressure. In such cases, routine procedural oversights turn into legally irreversible losses.

Fourthly, the HEART calculation [11] (Pscor) has mathematically demonstrated how emergency conditions transform legal errors into virtual guarantees. Specifically: «patchwork» liability (type C, $P_{base} = 0.16$) resulted in $P_{scor} = 0.16 \times 17.0 \times 11.0 = 29.92 \rightarrow 1.0\,(CRITICAL)$; exemption from navigational error (type A, $P_{base} = 0.55$) resulted in $P_{scor} = 0.55 \times 1.3 \times 3.0 = 2.145 \rightarrow 1.0\,(CRITICAL)$; the legal vacuum regarding force majeure in a state of martial law (type A, $P_{base} = 0.55$) also reached $P_{scor} = 1.0\,(CRITICAL)$. The conflict of limitation periods (type D, $P_{base} = 0.09$) resulted in $P_{scor} = 0.09 \times 2.5 \times 2.5 = 0.563\,(HIGH)$. Whereas the absence of electronic document management (type E, $P_{base} = 0.02$) resulted in $P_{scor} = 0.02 \times 11.0 \times 1.15 = 0.253\,(MEDIUM)$. This value, whose priority is 2.2 times lower than that of conflicting limitation periods, despite the fact that both are often regarded as equally significant in academic literature.

Fifthly, it has been demonstrated that the most effective compensatory barriers are the implementation of eNCDs in accordance with the 2025 UN Accra Convention [20, 21] and digital twin technology [13]. These provide strong analytical support based on telemetry. In particular, these technologies are capable of legally pinpointing the loss of cargo, thereby directly eliminating the highest-priority risk $(P_{scor} = 1.0)$ in the BALR matrix.

Prospects for Further Research. A prospect for future research is the applied verification of the BALR matrix. In other words, this should be based on real-life court and arbitration cases involving Ukrainian logistics operators in emergency situations or during periods of martial law. Future research may also involve the development of standardised contractual clauses for the main configurations of multimodal routes.

REFERENCES

1. Ibrahim, A. M., & Klevtsov, K. M. (2025). Pravovi kolizii v praktytsi orhanizatsii multymodalnykh perevezen za uchastiu morskoho transportu: ryzyky ta upravlinski naslidky v umovakh nadzvychainykh sytuatsii [Legal conflicts in the practice of organizing multimodal transportations involving maritime transport: risks and managerial consequences in emergency situations]. *Visnyk Pryazovskoho derzhavnoho tekhnichnoho universytetu. Seriia: Tekhnichni nauky*, *51*, 340–349. https://doi.org/10.31498/2225-6733.51.2025.344989.

2. Dobrovolska, V. V. (2023). Hospodarsko-pravovyi aspekt zmishanykh (multymodalnykh) morskykh perevezen [Economic and legal aspect of mixed (multimodal) maritime transportations]. *Vcheni zapysky TNU imeni V. I. Vernadskoho. Seriia: Yurydychni nauky*, *34*(73)(3), 33–37. https://doi.org/10.32782/tnu-2707-0581/2023.3/06.

3. Kyryllova, O. V., & Kyryllova, V. Yu. (2024). Multymodalni perevezennia u natsionalnomu zakonodavstvi ta mizhnarodnomu konteksti [Multimodal transportations in national legislation and international context]. *Rozvytok transportu*, *3*(22), 106–122. https://doi.org/10.33082/td.2024.3-22.07.

4. Kunda, N. T. (2022). Mizhnarodni morski perevezennia: aspekty pravovoho rehuliuvannia [International maritime transportations: aspects of legal regulation]. *Scientific Collection «InterConf»*, *121*, 325–336. https://doi.org/10.51582/interconf.19-20.08.2022.031.

5. Haddon, W. (1968). The changing approach to the epidemiology, prevention, and amelioration of trauma: the transition to approaches etiologically rather than descriptively based. *Am J Public Health*, *58*(8), 1431–1438.

6. Hu, Y. (2019). A concise and practical barrier model. *Open Journal of Safety Science and Technology*, *9*(3), 93–111. https://doi.org/10.4236/ojsst.2019.93007.

7. Reason, J. T. (1997). *Managing the risks of organizational accidents*. Routledge. https://www.taylorfrancis.com/books/mono/10.4324/9781315543543/managing-risks-of-organizational-accidents-james-reason.

8. Shabani, T., Jerie, S., & Shabani, T. (2023). A comprehensive review of the Swiss cheese model in risk management. *Safety in Extreme Environments*, *6*, 43–57. https://doi.org/10.1007/s42797-023-00091-7.

9. Maternová, A., Materna, M., Dávid, A., et al. (2023). Exploring the impact of the maritime regulatory framework on the barrier system in ship operations. *Journal of Marine Science and Engineering*, *13*(7), 1361. https://doi.org/10.3390/jmse13071361.

10. Snook, S. A. (2000). *Friendly fire: The accidental shootdown of U.S. Black Hawks over Northern Iraq*. Princeton University Press. https://www.bol.com/nl/nl/p/friendly-fire/1001004011689316/.

11. Williams, J. C. (1986). *HEART – A proposed method for assessing and reducing human error*. Retrieved April 20, 2026, from https://www.epd.gov.hk/eia/files/applications/en/pp_220/eia_1838/progress/action_2120/eia_2242014/EIA/app/app12.10.pdf.

12. Pozolotin, L. A., Torskyi, V. H., & Liubchenko, V. I. (2008). *Okhorona sudna* [Ship security]. Astroprynt. https://www.nautinst.com.ua/uk/oxorona-sudna/.

13. Torkay, M. (2025). The use of digital twin technologies as evidence in logistics disputes. *Şengün Law*. Retrieved April 20, 2026, from https://sengunlaw.com/the-use-of-digital-twin-technologies-as-evidence-in-logistics-disputes/.

14. International Convention for the Unification of Certain Rules of Law Relating to Bills of Lading (Hague Rules). (1924, August 25). https://www.jus.uio.no/english/services/library/treaties/07/7-04/hague-rules.html.

15. United Nations Convention on the Carriage of Goods by Sea (Hamburg Rules). (1978, March 31). https://uncitral.un.org/en/texts/transportgoods/conventions/hamburg_rules.

16. Kodeks torhovelnoho moreplavstva Ukrainy [Merchant Shipping Code of Ukraine], No. 176/95-VR. (1995, May 23). https://zakon.rada.gov.ua/laws/show/176/95-вр#Text.

17. United Nations Convention on Contracts for the International Carriage of Goods Wholly or Partly by Sea (Rotterdam Rules). (2008, December 11). https://uncitral.un.org/en/texts/transportgoods/conventions/rotterdam_rules.

18. Ma, X., Shi, G., Li, W., & Shi, J. (2023). Identifying the most probable human errors influencing maritime safety. *Journal of Marine Science and Engineering*, *11*(1), 14. https://doi.org/10.3390/jmse11010014.

19. Xu, M., Ma, X., Zhao, Y., & Qiao, W. (2023). A systematic literature review of maritime transportation safety management. *Journal of Marine Science and Engineering*, *11*(12), 2311. https://doi.org/10.3390/jmse11122311.

20. United Nations Convention on Negotiable Cargo Documents (Accra Convention) (2025). https://uncitral.un.org/en/ncdconvention.

21. United Nations Information Service (2025). *UN General Assembly adopts breakthrough Convention on cargo documents to facilitate global trade*. Retrieved April 19, 2026, from https://unis.unvienna.org/unis/en/pressrels/2025/unisl378.html.

Ібрагім А. М., Клевцов К. М. АНАЛІТИЧНА ОЦІНКА ПРАВОВИХ РИЗИКІВ У МУЛЬТИМОДАЛЬНИХ ПЕРЕВЕЗЕННЯХ ІЗ ЗАЛУЧЕННЯМ МОРСЬКОГО ТРАНСПОРТУ В НАДЗВИЧАЙНИХ СИТУАЦІЯХ

У цій статті представлено дослідження авторів з аналітичної оцінки ризиків у морських мультимодальних перевезеннях під час надзвичайних ситуацій в Україні. Вона базується на попередньому дослідженні, яке систематично виявляло системні правові конфлікти. У статті пропонується оригінальна методологія Бар'єрного аналізу правових ризиків (BA□R) для операторів мультимодальних перевезень. Вперше в українській транспортно□правовій науці методологія інтегрує дві концептуальні рамки: теорію енергетичних бар'єрів Гібсона та Хаддона в поєднанні з моделлю організаційних аварій Різона («швейцарський сир») для якісної ідентифікації правових конфліктів як латентних умов, активованих тригерами надзвичайних ситуацій; та кількісну методологію HEART для математичної оцінки ймовірностей з використанням умов, що породжують помилки (EPC). Побудовано матрицю ризиків BALR з розрахованими скоригованими ймовірностями (Pscor). Три ризики отримали статус КРИТИЧНИЙ (Pscor ≈ 1,0): «клаптикова» система відповідальності за мережевою моделлю, застаріле звільнення від навігаційних помилок у Кодексі торговельного мореплавства України та правовий вакуум щодо форс□мажору та воєнного стану. Один ризик є ВИСОКИМ (Pscor = 0,563); два є СЕРЕДНІМИ. Концепція «правового практичного зсуву» вводиться для пояснення механізму поступового руйнування дотримання правових вимог в умовах надзвичайного операційного навантаження. Технологія цифрових двійників та Аккрська конвенція ООН про переговірні вантажні документи 2025 року визначені як основні компенсаційні бар'єри. Результати дослідження демонструють, що кількісна оцінка ризиків перетворює суб'єктивні правові судження на допоміжні аналітичні аргументи, що можуть бути використані в міжнародному транспортному арбітражі. Структура BA□R застосовна до законодавчої реформи, розподілу контрактних ризиків та розробки систем моніторингу дотримання вимог, узгоджених з моделлю ISM Code.

Ключові слова: *мультимодальні перевезення; HEART; модель «швейцарського сиру»; правові колізії; бар'єрний аналіз; транспорт; оцінка ризиків; математична модель; прогнозування; механічна стійкість.*

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