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Prioritizing Road Freight Risks: An Integrated Analytic Hierarchy Process-Likelihood Framework

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ABSTRACT

Road freight operations face multiple interdependent risks, yet limited incident data make it difficult for logistics enterprises to determine which risks require priority attention. This study develops an Analytic Hierarchy Process (AHP)-likelihood framework for enterprise-level prioritization of road freight risks in Ho Chi Minh City. Following a literature review and interviews with seven logistics professionals, risk sources and events were separated from downstream consequences; penalty-related additional costs and delayed customer payment were therefore excluded as downstream financial consequences, leaving 25 risk sources and events across seven categories. Twenty experts provided pairwise comparisons of relative managerial importance and five-level perceived-likelihood ratings anchored to the proportion of relevant shipments or operations affected during the preceding 12 months. Group AHP weights were combined with zero-based likelihood scores to calculate a relative priority index. Fuel-price volatility, documentation and customs-procedure errors, incidents involving oversized, overweight, or high-value cargo, congestion at ports or loading facilities, and warehouse or cargo-handling process failure formed the top five. The AHP-only and integrated rankings were highly correlated (Spearman's rho = 0.9904), showing that likelihood refined rather than replaced the AHP structure. Robustness checks covered alternative normalization and aggregation rules, 14 category-weight scenarios, and 20,000 joint simulations of weight and likelihood uncertainty. The first four risks remained among the top five in at least 99.9% of iterations, while the fifth did so in 92.2% of iterations. The findings provide context-specific priorities for the participating logistics enterprises in Ho Chi Minh City.

1. INTRODUCTION

Road freight is essential to supply-chain continuity but is exposed to interconnected operational, infrastructural, financial, regulatory, environmental, and cargo-related risks. These risks can disrupt deliveries, increase costs, damage goods, and reduce service reliability [1, 2]. Their management is particularly challenging because freight risks are multidimensional, interdependent, and context-dependent, while the information needed to estimate their likelihood and consequences is often incomplete [2, 3]. Under such conditions, expert judgment remains important, but it should be incorporated into a structured prioritization framework that makes priorities transparent and supports defensible resource allocation decisions [4, 5].

This challenge is particularly relevant to Vietnam, where the rapid expansion of freight activity places increasing pressure on transport and logistics systems. In 2024, the country transported approximately 2.67 billion tons of freight, representing a 14.0% increase from the previous year, while freight traffic reached 545.1 billion ton-kilometers [6]. Road transport remains central to domestic freight distribution because it connects production centers, ports, inland container depots, warehouses, and consumer markets. This role is especially pronounced in Ho Chi Minh City and its surrounding industrial region, where concentrated port, manufacturing, and consumption activities generate substantial truck traffic and expose operators to congestion, restricted delivery windows, and bottlenecks at port access points and on urban roads. These operational pressures extend beyond physical transportation, as freight firms must coordinate warehousing, documentation, customs clearance, cargo handling, and regulatory compliance among multiple parties. The challenge is compounded by the fragmented structure and limited technological capacity of many domestic logistics enterprises, while Vietnam ranked 43rd among 139 economies in the World Bank's 2023 Logistics Performance Index, behind several regional competitors [7, 8]. Because resource-constrained firms cannot address all potential risks simultaneously, identifying which risks require earlier intervention offers greater managerial value than compiling an extensive but unranked risk register.

Previous studies have identified diverse risks in road freight and supply chain operations and applied multi-criteria decision-making methods to support risk assessment [9, 10]. Among these methods, the Analytic Hierarchy Process (AHP)

is useful because it structures complex decisions, derives relative weights from pairwise comparisons, and permits the examination of the consistency of expert judgments [11]. AHP and related approaches have consequently been used to prioritize supply-chain, transport, customs, and logistics risks [12, 13]. However, conventional AHP rankings primarily represent the relative importance assigned to risk factors. A highly important risk may occur infrequently, whereas a moderately weighted risk may require more immediate attention because it is encountered repeatedly. Studies that consider occurrence often embed it as one criterion within more complex models, leaving limited evidence on a transparent procedure that combines hierarchical importance with separately assessed occurrence in data-constrained road freight settings. Moreover, the robustness of the resulting rankings is not always systematically tested.

To address these limitations, this study develops an AHP-likelihood framework for prioritizing enterprise-level road freight risks in Ho Chi Minh City. Risks identified from the literature were refined through interviews with logistics professionals and screened to distinguish risk sources and events from downstream consequences. Expert pairwise comparisons were used to derive group-level AHP weights, which were combined with zero-based perceived-likelihood scores to calculate a relative Risk Priority Index (RPI). Robustness was evaluated using category-weight scenarios, alternative normalization and aggregation rules, and joint simulations of weight and likelihood uncertainty.

The study makes three contributions. First, it develops a contextually validated hierarchy of road freight risk sources and events for the participating Ho Chi Minh City logistics enterprises. Second, it distinguishes expert-perceived relative managerial importance from perceived likelihood and examines the incremental ranking information contributed by likelihood. Third, it evaluates the stability of the leading priorities across alternative analytical specifications and simultaneous uncertainty.

2. LITERATURE REVIEW

2.1 Risks in road freight transportation

Risk in supply chains refers to uncertain events that may disrupt the flows of materials, information, or finance and consequently impair operational performance [1, 14]. Within this broader system, road freight transportation is particularly vulnerable because its performance depends on interactions among vehicles, drivers, infrastructure, logistics facilities, information systems, regulators, customers, and external conditions. A disruption affecting one component may propagate through subsequent transport and supply-chain activities, causing delivery delays, cargo damage, additional costs, safety incidents, or reduced service reliability [2, 15].

Previous research has classified logistics and transportation risks from different perspectives. Supply-chain studies commonly distinguish supply, demand, operational, disruption, information-system, regulatory, and environmental risks [14-17]. Transportation-focused research identifies traffic accidents, driver behavior, vehicle defects, cargo damage and loss, infrastructure constraints, congestion, equipment failures, cyber threats, and natural hazards as distinct but potentially interacting exposures [18-24]. Road freight enterprises may also face documentation and customs-procedure errors, fuel-price volatility, warehouse and cargo-handling failures, and specialized requirements for hazardous, oversized, overweight, perishable, or high-value cargo [10, 12, 25-28].

These classifications demonstrate that road freight risks are multidimensional and interconnected [1, 2]. The present hierarchy distinguishes risk sources and events from their downstream consequences so that factors at different causal levels are not ranked together. Consistent with ISO 31000, evidence from the literature was combined with practitioners' contextual knowledge; the resulting taxonomy is used as a screening structure rather than a causal model [29].

2.2 Analytic Hierarchy Process-based risk prioritization

Risk prioritization enables enterprises to allocate limited control resources to risks that require the greatest managerial attention. Conventional assessments frequently use probability-impact matrices, but their broad categories may produce tied rankings and provide limited means of representing trade-offs among heterogeneous risk factors. Multi-criteria decision-making methods offer a more structured alternative when reliable incident data are unavailable, and assessment therefore depends substantially on expert judgment [10, 13].

The AHP decomposes a complex decision problem into a hierarchy and derives priority weights from pairwise comparisons using Saaty's scale [11, 30]. Its consistency ratio (CR) provides a diagnostic check on the internal coherence of a comparison matrix. These characteristics have supported the application of AHP to logistics, transportation, and supply-chain risk management [9, 31-33]. In this study, experts compared the general relative managerial importance of categories and factors for prioritizing intervention. The resulting weights do not separately measure severity, financial loss, controllability, urgency, or disruption probability. Multiplying category and local-factor weights produces global weights that represent relative managerial importance across the hierarchy.

Importance and perceived likelihood capture different dimensions of managerial priority. A highly weighted event may be perceived as uncommon, whereas a moderately weighted event may be encountered more regularly. Separately assessing perceived likelihood can therefore provide a contextual overlay to the AHP hierarchy. Likelihood was elicited for the preceding 12 months using common quantitative bands defined by the proportion of relevant shipments or operations affected. It is therefore interpreted as a standardized expert-rated ordinal likelihood measure rather than an objective incident rate. The study consequently examines whether this overlay changes the ranking and subjects the result to several robustness checks.

3. METHODOLOGY

3.1 Research design and risk identification

This study employed a sequential mixed-methods design comprising four stages: risk identification and classification; expert validation and source-event-consequence screening; group-level AHP prioritization combined with perceived-likelihood assessment; and multi-specification robustness analysis. This design provides a structured basis for prioritization when reliable firm-level incident and loss data

are unavailable.

Following ISO 31000 risk-identification principles, an initial set of factors was synthesized from road freight, logistics, customs, infrastructure, financial, environmental, and specialized-cargo studies [10, 12, 19-29, 32, 34-36]. Seven logistics professionals reviewed the relevance, wording, overlap, and categorization of the preliminary factors. Source-event-consequence screening excluded penalty-related additional costs and delayed customer payment as downstream financial consequences. The final hierarchy comprised seven categories and 25 risk sources and events, as shown in Table 1.

Table 1. Road freight risk sources/events and direct supporting evidence

Category	Code	Risk Factor	Supporting Source
Operational risk (RHD)	RHD1	Traffic collision or accident	[19]
	RHD2	Cargo damage or loss during transportation	[20]
	RHD3	Vehicle breakdown or technical failure	[19]
	RHD4	Cargo theft	[20, 34]
	RHD5	Driver or workforce shortage	[35]
	RHD6	Driver error or safety violation	[19]
	RHD7	Insufficient subcontractor capability	Expert interviews
Time and schedule risk (RTG)	RTG1	Ineffective transportation-time management	[10]
	RTG2	Congestion at ports, warehouses, or loading facilities	[21]
	RTG3	Ineffective alternative routing	[10]
Infrastructure risk (RHT)	RHT1	Inadequate physical infrastructure	[24]
	RHT2	Route blockage or disruption	[24]
	RHT3	Loading equipment failure at ports or warehouses	[22]
	RHT4	Insufficient digital infrastructure	Expert interviews
System and process operational risk (RVH)	RVH1	Documentation or customs procedure errors	[12]
	RVH2	Warehouse or cargo-handling process failure	[22]
	RVH3	Non-standardized delivery procedures among partners	[12]; expert interviews
	RVH4	Cybersecurity breach or system intrusion	[23]
	RVH5	Transportation or warehouse management system failure	[22]
Financial risk (RTC)	RTC1	Fuel-price volatility	[28]
Environmental risk (RMT)	RMT1	Natural hazards, including storms, floods, and landslides	[24, 36]
	RMT2	Long-term effects of climate change	[24, 36]
Specialized-cargo risk (RDT)	RDT1	Cold-chain failure	[20, 26]
	RDT2	Errors in hazardous-material handling	[25, 27]
	RDT3	Incidents involving oversized, overweight, or high-value cargo	[19]; expert interviews

Note: The financial-risk category contains the retained source factor RTC1 (fuel-price volatility); downstream financial consequences are not included in the AHP hierarchy.

3.2 Expert assessment and Analytic Hierarchy Process procedure

Twenty logistics professionals from 10 enterprises were purposively selected for the quantitative assessment, including seven participants who had previously validated the hierarchy. Participants had at least one year of direct experience in logistics coordination, documentation, cargo handling, road freight operations, or related managerial work in Ho Chi Minh City. The qualitative interviews and quantitative assessments were conducted from August to December 2025. Table 2 summarizes the panel characteristics.

Table 2. Available profile of the Ho Chi Minh City expert panel

Characteristic	Category	n	%
Study participation	Qualitative validation and quantitative assessment	7	35
Study participation	Quantitative assessment only	13	65
Experience	1–2 years	4	20
Experience	More than 2–5 years	8	40
Experience	More than 5–10 years	7	35
Experience	More than 10 years	1	5
Organizational role	Managerial or supervisory	6	30
Organizational role	Operational or professional	14	70
Organizational coverage	Distinct enterprises represented	10	-

The panel included six managerial or supervisory participants and 14 operational or professional participants, with experience ranging from one year to more than ten years. All experts were located in Ho Chi Minh City, and their judgments are interpreted within this urban logistics context. The experts were assigned equal influence during aggregation, and personal and organizational identities are omitted for confidentiality.

The questionnaire comprised two components. First, experts evaluated the general relative managerial importance of the seven categories and the factors within each category using Saaty's nine-point pairwise-comparison scale [11]. These comparisons captured overall managerial importance for prioritizing intervention rather than separate measures of severity, financial impact, controllability, urgency, or disruption potential. The revised hierarchy contained 25 risk sources and events after source-event-consequence screening. Because RTC1 was the only retained factor in the financial-risk category, no within-category pairwise comparison was required for RTC; its local weight was fixed at 1. Second, experts rated the perceived likelihood of encountering each factor during the preceding 12 months using five ordered bands based on the proportion of relevant shipments or operations affected: 0% to <5% (1), 5% to <10% (2), 10% to <20% (3), 20% to <40% (4), and ≥40% (5).

For each pairwise comparison, the majority direction and modal intensity of the 20 responses were used to form a representative reciprocal group matrix. Local weights were obtained by column normalization and row averaging, and global weights were calculated as the product of category and

local weights. Consistency was assessed for the seven group matrices and for each expert's category-level matrix and five within-category matrices containing at least three factors. The maximum CR across these matrices was used as the individual-level consistency measure. The two-factor RMT matrix is inherently consistent, while a within-category CR is not applicable to the single-factor RTC category.

$$w_{ij}^{G} = w_i^{C} \times w_{ij}^{L}$$

where, w_i^C denotes the category weight and w_{ij}^L denotes the factor's local weight within that category.

Judgment consistency was evaluated using:

$$CI = \frac{\lambda_{\max} - n}{n-1}, CR = \frac{CI}{RI}$$

where, $\lambda_{\max}$ is the maximum eigenvalue, *n* is the matrix order, and RI is the corresponding random consistency index. Aggregated and individual matrices with CR ≤ 0.10 were considered acceptable [11].

3.3 Perceived-likelihood integration and sensitivity analysis

Perceived likelihood was assessed separately from the AHP comparisons for the preceding 12 months. Experts selected one of five ordered bands defined by the estimated proportion of relevant shipments or operations affected: 0% to <5% (1), 5% to <10% (2), 10% to <20% (3), 20% to <40% (4), and ≥40% (5). These common anchors improved comparability across respondents while retaining an ordinal expert-judgment format. To make the lower endpoint equal to zero, the primary normalized score was calculated as follows:

$$L_i = \{[(\Sigma_j x_{ij})/N] - 1\}/4$$

where, L_i is the zero-based perceived-likelihood score for factor *i*, x_{ij} is expert j's ordinal 12-month rating, and N = 20. The transformation maps a mean rating of 1 to 0 and a mean rating of 5 to 1. Although the categories use quantitative percentage anchors, L_i remains an expert-rated ordinal likelihood score and is not interpreted as an observed annual probability or incident rate.

The RPI was calculated by multiplying the global AHP weight of each risk factor by its normalized perceived-likelihood score:

$$RPI_i = GW_i \times L_i$$

where, GW_i is the global AHP importance weight, and L_i is the zero-based perceived-likelihood score. Higher RPI values indicate greater relative priority for managerial intervention. The RPI is not an absolute probability of loss, an expected-loss measure, or a conventional probability-impact score; it is a multiplicative screening index combining relative managerial importance with expert-rated 12-month perceived likelihood.

Robustness analysis comprised four components. First, a one-at-a-time test increased and decreased each of the seven category weights by 10%, with the remaining weights proportionally rescaled to sum to one. This produced 14 category-weight scenarios while holding local weights and likelihood scores constant:

$$w_c^{(s)} = (1+\delta)w_c$$

The weights of the remaining categories were proportionally adjusted to preserve their relative structure and ensure that the complete weight vector summed to one:

$$w_i^{(s)} = w_i\left(\frac{1-w_c^{(s)}}{1-w_c}\right), i \neq c$$

where, w_c and w_i are the baseline category weights, while $w_c^{(s)}$ and $w_i^{(s)}$ are their corresponding weights under scenario s. Scenario-specific global weights were then obtained by multiplying each adjusted category weight by the unchanged local weight of the corresponding risk factor:

$$GW_{ij}^{(s)} = w_i^{(s)} \times LW_{ij}$$

The RPI was subsequently recalculated for every scenario as:

$$RPI_i^{(s)} = GW_i^{(s)} \times L_i$$

Second, the zero-based likelihood transformation was compared with the alternative *x*/5 rule. Third, a diagnostic equal-weight additive score combined min-max-scaled global importance with zero-based likelihood, testing whether conclusions depended on multiplication. Fourth, a 20,000-iteration Monte Carlo analysis varied all category and local weights simultaneously using independent U(0.90, 1.10) multipliers, renormalized weights at the category and within-category levels, and bootstrapped 20 likelihood ratings for each factor from its observed five-level response distribution. A fixed seed of 45364 ensured reproducibility. Robustness was summarized using Spearman rank correlations, maximum rank movement, top-five and top-ten inclusion rates, and changes in the leading set.

4. RESULTS AND DISCUSSION

4.1 Consistency assessment and category-level priorities

Table 3 presents the consistency results for the category-level group matrix and the within-category group matrices. All applicable group-level CR values were below 0.10 [11]. The two-factor RMT matrix was inherently consistent, while a within-category consistency test was not applicable to the single-factor RTC category.

Table 4 reports the maximum individual CR for each expert, calculated across the category-level matrix and the five within-category matrices containing at least three factors.

The CR values for the six nontrivial aggregated matrices ranged from 0.0565 to 0.0942. The category-level matrix produced the highest CR (0.0942), followed by the operational-risk matrix (0.0922). Individual maximum CR values ranged from 0.0092 to 0.0937 (Table 4); all 20 questionnaires satisfied the CR <= 0.10 criterion and were retained. At category level, financial risk received the highest weight (w = 0.3395), followed by system and process operational risk (w = 0.2670) and specialized-cargo risk (w = 0.1668). Together, these categories represented 77.34% of total relative managerial importance. The complete category-level priorities are reported in Table 5.

Table 3. Consistency of the aggregated pairwise comparison matrices

Risk Matrix	n	λmax	Consistency Index (CI)	Random Index (RI)	Consistency Ratio (CR)	Result
Category-level risk matrix	7	7.7458	0.1243	1.32	0.0942	Acceptable
RHD	7	7.7300	0.1217	1.32	0.0922	Acceptable
RTG	3	3.0655	0.0328	0.58	0.0565	Acceptable
RHT	4	4.2386	0.0795	0.90	0.0884	Acceptable
RVH	5	5.3985	0.0996	1.12	0.0890	Acceptable
RTC (single retained factor)	1	-	-	-	-	Not applicable
RMT	2	2.0000	0.0000	0.00	-	Fully consistent
RDT	3	3.0958	0.0479	0.58	0.0826	Acceptable

Table 4. Maximum individual consistency ratio (CR) by expert

Expert	Maximum CR
1	0.0747
2	0.0937
3	0.0826
4	0.0683
5	0.0469
6	0.0719
7	0.0455
8	0.0924
9	0.0482
10	0.0937
11	0.0922
12	0.0533
13	0.0826
14	0.0513
15	0.0466
16	0.0922
17	0.0124
18	0.0110
19	0.0092
20	0.0123

Note: Maximum CR is the largest value among the category-level and five within-category matrices with n >= 3 for each expert. The acceptance threshold is CR <= 0.10. The two-factor RMT matrix is inherently consistent, and a within-category CR is not applicable to RTC.

Table 5. Analytic Hierarchy Process (AHP) priorities of road freight transportation risk categories

Rank	Code	Priority Weight	Share (%)	Cumulative Share (%)
1	RTC	0.3395	33.95	33.95
2	RVH	0.2670	26.70	60.65
3	RDT	0.1668	16.68	77.34
4	RTG	0.1021	10.21	87.54
5	RHD	0.0620	6.20	93.75
6	RMT	0.0383	3.83	97.58
7	RHT	0.0242	2.42	100.00
	Total	1.0000	100.00	

Financial risks were assigned approximately 1.27 times the weight of system and process operational risks and more than twice the weight of specialized-cargo risks. The second tier consisted of time and schedule risks (w = 0.1021) and operational risks (w = 0.0620). Environmental risks (w = 0.0383) and infrastructure risks (w = 0.0242) received the lowest category-level priorities. These weights indicate the relative importance assigned to each category within the AHP hierarchy; they do not independently represent the probability of occurrence or the absolute severity of the underlying risk factors. The category weights were subsequently combined with the local priorities of the individual factors to obtain global AHP weights.

4.2 Local and global priorities of individual risk factors

Local weights were estimated for the factors within each category. Because RTC1 was the only retained financial-risk factor, its local weight was fixed at 1.0000 and its global weight equalled the financial-category weight. Table 6 presents the local and global weights and ranks for 25 risk sources and events. The global weights sum to 1.0000.

The leading local factor in each category was cargo theft (RHD4; LW = 0.3937), congestion at ports, warehouses, or loading facilities (RTG2; LW = 0.6434), loading-equipment failure (RHT3; LW = 0.6326), documentation and customs-procedure errors (RVH1; LW = 0.4892), fuel-price volatility (RTC1; LW = 1.0000), natural hazards (RMT1; LW = 0.8333), and incidents involving oversized, overweight, or high-value cargo (RDT3; LW = 0.7071).

After category weights were incorporated, fuel-price volatility became the leading AHP factor (GW = 0.3395), followed by documentation and customs-procedure errors (GW = 0.1306) and incidents involving oversized, overweight, or high-value cargo (GW = 0.1180). Congestion at ports, warehouses, or loading facilities ranked fourth (GW = 0.0657), and warehouse or cargo-handling process failure ranked fifth (GW = 0.0647).

Table 6. Local and global Analytic Hierarchy Process (AHP) priorities of 25 risk sources/events

Category	Code	Local Weight	Global Weight	Global Rank
RTC	RTC1	1.0000	0.3395	1
RVH	RVH1	0.4892	0.1306	2
RDT	RDT3	0.7071	0.1180	3
RTG	RTG2	0.6434	0.0657	4
RVH	RVH2	0.2423	0.0647	5
RVH	RVH5	0.1637	0.0437	6
RDT	RDT2	0.2014	0.0336	7
RMT	RMT1	0.8333	0.0320	8
RTG	RTG1	0.2828	0.0289	9
RHD	RHD4	0.3937	0.0244	10
RVH	RVH3	0.0650	0.0173	11
RHD	RHD2	0.2471	0.0153	12
RHT	RHT3	0.6326	0.0153	13
RDT	RDT1	0.0915	0.0153	14
RVH	RVH4	0.0399	0.0107	15
RHD	RHD1	0.1497	0.0093	16
RTG	RTG3	0.0738	0.0075	17
RMT	RMT2	0.1667	0.0064	18
RHT	RHT2	0.2237	0.0054	19
RHD	RHD3	0.0859	0.0053	20
RHD	RHD6	0.0676	0.0042	21
RHT	RHT1	0.0962	0.0023	22
RHD	RHD5	0.0314	0.0019	23
RHD	RHD7	0.0246	0.0015	24
RHT	RHT4	0.0475	0.0011	25

Note: Global weights use unrounded values.

The global weights represent relative managerial importance within the source/event hierarchy. Section 4.3 examines the extent to which perceived likelihood modifies this AHP profile.

4.3 Perceived likelihood and integrated prioritization

The highest zero-based perceived-likelihood score was recorded for documentation and customs-procedure errors (RVH1; L = 0.7875), followed by congestion at ports, warehouses, or loading facilities (RTG2; L = 0.7250), transportation or warehouse management system failure (RVH5; L = 0.6750), and errors in hazardous-material handling (RDT2; L = 0.6625). Traffic collision or accident (RHD1; L = 0.2500), insufficient subcontractor capability (RHD7; L = 0.2750), and ineffective alternative routing and route blockage or disruption (both L = 0.3125) received the lowest perceived-likelihood scores. Table 7 presents the zero-based likelihood scores and integrated RPI values for the 25 retained risk sources and events.

Table 7. Zero-based perceived likelihood and risk-priority ranking

RPI Rank	Code	Global Weight	Perceived-Likelihood Score	RPI
1	RTC1	0.3395	0.5375	0.1825
2	RVH1	0.1306	0.7875	0.1028
3	RDT3	0.1180	0.6125	0.0723
4	RTG2	0.0657	0.7250	0.0476
5	RVH2	0.0647	0.6000	0.0388
6	RVH5	0.0437	0.6750	0.0295
7	RDT2	0.0336	0.6625	0.0223
8	RHD4	0.0244	0.6250	0.0153
9	RMT1	0.0320	0.4750	0.0152
10	RTG1	0.0289	0.4000	0.0115
11	RHT3	0.0153	0.6125	0.0094
12	RHD2	0.0153	0.6000	0.0092
13	RVH3	0.0173	0.4625	0.0080
14	RDT1	0.0153	0.4500	0.0069
15	RVH4	0.0107	0.4000	0.0043
16	RMT2	0.0064	0.5625	0.0036
17	RTG3	0.0075	0.3125	0.0024
18	RHD1	0.0093	0.2500	0.0023
19	RHD3	0.0053	0.4000	0.0021
20	RHT2	0.0054	0.3125	0.0017
21	RHD6	0.0042	0.3625	0.0015
22	RHT1	0.0023	0.3750	0.0009
23	RHD5	0.0019	0.3375	0.0007
24	RHT4	0.0011	0.4125	0.0005
25	RHD7	0.0015	0.2750	0.0004

Note: Risk Priority Index (RPI). L = (mean ordinal rating - 1)/4. RPI = global AHP importance weight × L. Values use unrounded weights.

Fuel-price volatility recorded the highest integrated priority (RPI = 0.1825), followed by documentation and customs-procedure errors (RPI = 0.1028) and incidents involving oversized, overweight, or high-value cargo (RPI = 0.0723). Congestion at ports, warehouses, or loading facilities ranked fourth (RPI = 0.0476), and warehouse or cargo-handling process failure ranked fifth (RPI = 0.0388). The same five factors occupied the leading positions in the AHP-only and multiplicative RPI rankings.

The AHP-only and RPI rankings were very highly correlated (Spearman's rho = 0.9904). Thus, perceived likelihood supplied only limited independent ranking information and should be understood as a contextual refinement rather than a second dominant component. The high association indicates that the integration provides incremental rather than transformative ranking information. Perceived likelihood nevertheless affected relative distances and several lower positions. For example, RVH5 combined a moderate global weight with a relatively high likelihood score and ranked sixth in the multiplicative RPI.

4.4 Sensitivity and ranking-stability analysis

The 14 one-at-a-time category-weight scenarios retained the same top-five set and order. Spearman correlations with the baseline ranged from 0.9973 to 1.0000, and the largest movement was two positions. The alternative x/5 likelihood normalization also preserved the baseline top-five set and produced rho = 0.9973 relative to the zero-based ranking. Accordingly, removing the 0.20 lower bound changed score magnitudes more than the leading order.

Overall, the robustness checks identify a stable core rather than complete invariance. The first four priorities persisted across normalization, category-weight, and joint-uncertainty checks. The identity of the fifth factor depended on the aggregation rule, and the very high correlation between AHP and RPI confirms that AHP importance remains the principal driver of the final ranking.

The equal-weight additive diagnostic preserved the first four factors but replaced RVH2 with RVH5 in fifth position; its correlation with the baseline multiplicative ranking was lower (rho = 0.9364). In 20,000 joint simulations, RTC1, RVH1, and RDT3 appeared in the top five in 100% of iterations, RTG2 in 99.9%, and RVH2 in 92.2%. The mean rank correlation was 0.9946, the fifth percentile was 0.9897, the minimum was 0.9802, and the 95th percentile of maximum rank movement was three positions. These results indicate a stable core of four priorities, while the fifth position is somewhat aggregation-sensitive. Table 8 summarizes the results of the alternative normalization, aggregation, category-weight, and joint-uncertainty analyses.

The findings indicate that perceived road freight priorities among the participating Ho Chi Minh City logistics professionals are shaped primarily by operating-cost exposure, documentation and customs processes, specialized-cargo incidents, congestion, and cargo-handling processes. Fuel-price volatility, documentation and customs-procedure errors, incidents involving oversized, overweight, or high-value cargo, congestion at ports and loading facilities, and warehouse or cargo-handling process failure formed the leading five.

This multidimensional structure is consistent with the broader supply-chain risk literature, which identifies operational, financial, infrastructural, regulatory, and external disruptions as interconnected sources of enterprise exposure [1, 2, 4, 16]. Recent road freight research similarly shows that transport risks arise from interactions among operational processes, information systems, infrastructure conditions, governance arrangements, and external disruptions rather than from isolated events [3]. The high priority assigned to documentation errors is consistent with evidence that inaccurate declarations and regulatory non-compliance can delay customs clearance and generate storage charges and penalties [12]. Similarly, the prominence of congestion and fuel-price volatility accords with evidence that infrastructure constraints, transport disruptions, and cost uncertainty materially affect freight operations and supply-chain performance [2, 37, 38].

Table 8. Extended normalization, aggregation, weight, and likelihood robustness checks

Analysis	Specification	Top-Five Order	Spearman's Rho
Baseline	Zero-based likelihood; multiplicative	RTC1-RVH1-RDT3-RTG2-RVH2	1.0000
RHD-	Category weight changed 10%; renormalized	RTC1-RVH1-RDT3-RTG2-RVH2	0.9993
RHD+	Category weight changed 10%; renormalized	RTC1-RVH1-RDT3-RTG2-RVH2	0.9973
RTG-	Category weight changed 10%; renormalized	RTC1-RVH1-RDT3-RTG2-RVH2	0.9979
RTG+	Category weight changed 10%; renormalized	RTC1-RVH1-RDT3-RTG2-RVH2	1.0000
RHT-	Category weight changed 10%; renormalized	RTC1-RVH1-RDT3-RTG2-RVH2	0.9986
RHT+	Category weight changed 10%; renormalized	RTC1-RVH1-RDT3-RTG2-RVH2	1.0000
RVH-	Category weight changed 10%; renormalized	RTC1-RVH1-RDT3-RTG2-RVH2	0.9993
RVH+	Category weight changed 10%; renormalized	RTC1-RVH1-RDT3-RTG2-RVH2	1.0000
RTC-	Category weight changed 10%; renormalized	RTC1-RVH1-RDT3-RTG2-RVH2	1.0000
RTC+	Category weight changed 10%; renormalized	RTC1-RVH1-RDT3-RTG2-RVH2	0.9993
RMT-	Category weight changed 10%; renormalized	RTC1-RVH1-RDT3-RTG2-RVH2	1.0000
RMT+	Category weight changed 10%; renormalized	RTC1-RVH1-RDT3-RTG2-RVH2	0.9993
RDT-	Category weight changed 10%; renormalized	RTC1-RVH1-RDT3-RTG2-RVH2	1.0000
RDT+	Category weight changed 10%; renormalized	RTC1-RVH1-RDT3-RTG2-RVH2	1.0000
Alternative normalization	x/5 likelihood	RTC1-RVH1-RDT3-RTG2-RVH2	0.9973
Alternative aggregation	Equal-weight additive	RTC1-RVH1-RDT3-RTG2-RVH5	0.9364
Joint uncertainty	20,000 simulations; weights and likelihood	RTC1-RVH1-RDT3-RTG2-RVH2*	Mean 0.9946; P5 0.9897

Note: Correlations compare each specification with the zero-based multiplicative baseline. *Monte Carlo top-five inclusion: RTC1 100.0%, RVH1 100.0%, RDT3 100.0%, RTG2 99.9%, and RVH2 92.2%; RVH5 entered the top five in 3.4% of simulations.

The prominence of documentation and customs-procedure errors reflects the enterprise-level perspective adopted here. The global AHP weights captured general relative managerial importance, whereas the second assessment captured perceived likelihood during the preceding 12 months. Their very high rank correlation shows that multiplication made only modest changes to the priority structure. The framework should therefore be viewed as a transparent screening device for data-constrained firms, not as a substitute for incident-rate, severity, recovery-time, or expected-loss analysis.

The priority structure indicates that road freight vulnerability in this setting is not limited to physical hazards. Documentation errors may cause delays and financial consequences, while congestion and fuel-price volatility affect journey times and operating costs. Operational safety should therefore be coordinated with compliance control, cost monitoring, cargo-handling assurance, and transport planning.

The study contributes a locally reviewed hierarchy of 25 risk sources and events for the participating Ho Chi Minh City setting, a source-event-consequence distinction that reduces double-counting, and a multi-specification assessment of ranking robustness. The results support a stable core of four leading priorities, while the fifth position and some lower ranks vary across aggregation assumptions.

5. CONCLUSION AND IMPLICATIONS

This study applied a hierarchy of seven categories and 25 risk sources and events to prioritize enterprise-level road freight risks in Ho Chi Minh City. Fuel-price volatility, documentation and customs-procedure errors, specialized-cargo incidents, congestion, and warehouse or cargo-handling process failure formed the leading five. Robustness analysis identified a stable core of four priorities, while the high AHP-RPI correlation and aggregation-sensitive fifth position indicate that perceived likelihood refines rather than independently determines the ranking.

The evidence is context-specific to the participating logistics professionals and enterprises in Ho Chi Minh City and may inform similar data-constrained urban logistics settings. Firms can use the results as an initial screening guide while adapting controls to their size, cargo segment, routes, and verified incident history.

The priority structure supports differentiated treatment. The leading sources and events warrant early preventive controls, while medium-priority factors require contingency procedures, training, inspection, and partner coordination. Lower-ranked events should still be monitored when their potential consequences are severe. Because the index does not measure severity directly, rank alone should not be used to remove minimum safety, insurance, or continuity controls.

At enterprise level, fuel-price volatility can be addressed through fuel-consumption monitoring, route planning, preventive maintenance, and transparent adjustment clauses. Documentation and customs-procedure errors require standardized cargo- and route-specific checklists, dual verification, clear compliance responsibility, and systematic recording of errors and their downstream costs. Larger firms can progressively integrate transport, warehouse, customer, and customs information, while smaller carriers can begin with lower-cost process controls.

Specialized cargo should not be managed as an extension of routine transportation. Oversized, overweight, and high-value shipments require route surveys, vehicle and equipment inspections, cargo-securing standards, contingency plans, enhanced tracking, appropriate insurance, and explicit allocation of responsibilities among contractual parties. Where firms lack specialized assets or technical expertise, verified subcontractor networks and shared operating protocols may offer a more feasible solution than maintaining costly in-house capacity. Congestion and fuel-price volatility likewise require collective responses. Carriers should combine route optimization, preventive maintenance, driver training, fuel-consumption monitoring, and transparent fuel-adjustment clauses with information sharing on terminal capacity, waiting times, appointment schedules, and alternative routes.

Public agencies, terminals, associations, and platform providers can support interoperable documentation, clearer regulatory guidance, coordinated appointment systems, and accessible digital solutions. The RPI should guide sequencing rather than justify the neglect of lower-ranked risks. Accidents, cybersecurity failures, infrastructure disruptions, and environmental events may be perceived as less likely yet

have severe consequences that are not directly measurable; therefore, minimum monitoring, insurance, emergency procedures, and continuity arrangements remain necessary.

Several limitations qualify the findings. First, the purposive panel was located in Ho Chi Minh City, four participants had one to two years of experience, and firm-size and cargo-segment data were unavailable; consequently, the findings are context-specific. Second, the group aggregation used majority direction and modal intensity. Third, the likelihood ratings represent subjective perceptions rather than directly observed firm-level frequencies. Fourth, the high AHP-RPI correlation indicates limited incremental ranking information from likelihood, and the additive diagnostic altered the fifth position. Finally, the hierarchy does not model all causal interdependencies. Future studies should use objective incident records and examine interdependencies through complementary methods.

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