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OPERATIONAL RESILIENCE IN U.S. AND INTERNATIONAL CARGO LOGISTICS (2026): RISK-ADJUSTED ROUTING, DIGITAL INTEROPERABILITY, AND MULTIMODAL CAPACITY UNDER VOLATILE DEMAND

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ABSTRACT

Freight operators face a persistent decision problem: a route that appears economical at dispatch may become expensive after congestion, a missed connection, additional handling, or cargo damage. The problem is particularly visible when a domestic road movement must be compared with a cross-border movement involving several carriers and transport modes. This article develops a decision-oriented framework for evaluating these alternatives without equating low nominal freight rates with operational efficiency. Drawing on the practical context of specialist forwarding and a comparison with the U.S. domestic carrier environment, the study identifies four managerial levers: documentary readiness, capacity matching, risk-aware routing, and cargo-specific control. A directed multimodal network model is formulated with monetary costs, expected delay, scenario-based downside risk, compatibility restrictions, and transfer feasibility. The contribution is a transparent decision procedure that separates assumptions, operational data requirements, and testable performance metrics. No firm-specific savings are presented as measured results, because shipment-level observations are not included in the available study material. The framework can be evaluated through a prospective pilot or historical dispatch records.

Keywords: Freight Forwarding; Multimodal Transport; Operational Resilience; Conditional Value-At-Risk; Capacity Allocation; Customs Readiness; Logistics Decision Support.

1 INTRODUCTION

The operational value of a freight route cannot be established solely from a carrier quotation. Transport managers ultimately purchase a combination of movement, delivery reliability, cargo integrity, documentation, and the ability to respond when a plan fails. A seemingly inexpensive corridor may impose substantial costs if it produces missed cut-offs, vehicle idling, additional warehousing, or unsuccessful delivery attempts. These costs are often recorded by different departments and therefore are not visible at the moment of route selection.

The 2026 U.S. market illustrates why static assumptions about demand are inadequate. The Bureau of Transportation Statistics reported that the Freight Transportation Services Index for July 2026 was 2.0% below its July 2025 level [1]. This aggregate measure does not predict the volume of an individual forwarder or corridor. It does, however, justify examining routing decisions under changing demand rather than assuming stable capacity utilization. U.S. road operators also plan within hours-of-service recording requirements administered by the Federal Motor Carrier Safety Administration [2]. In cross-border forwarding, the organizational challenge often shifts toward coordination among carriers, terminals, and documentation intermediaries.

This study asks two questions. First, what operational capabilities allow a forwarder to preserve delivery performance when transport prices and border or terminal delays vary? Second, how can these capabilities be expressed in a reproducible routing model rather than in a general recommendation to use more digital tools? The paper addresses these questions by developing a conceptual operational framework and an optimization formulation. It does not claim an experimentally validated software implementation.

2 RESEARCH APPROACH AND SCOPE

The paper is a practice-informed conceptual study. Its starting point is the forwarding activity described for Helion Ukraine / Helion International, including contracted capacity, specialized cargo, customs coordination, and door-to-airport movements. This context is used to identify managerial decisions; it is not treated as a verified dataset or a representative statistical sample. Statements in the original working draft concerning annual tonnage, geographic coverage, percentage savings, and claim rates require documentary support before they can be used as empirical findings.

The analysis proceeds in three stages: identifying recurring cost and reliability decisions; translating them into a network optimization problem; and specifying how the proposed policy could be assessed in a dispatch pilot. The U.S. versus international comparison is institutional and operational, not a claim that every U.S. company is asset-heavy or that every European forwarder is asset-light. Each market contains multiple business models, and the relevant comparison depends on the shipment and contractual responsibility.

3 WHERE THE TWO OPERATING MODELS DIFFER

A road carrier owning tractors and trailers controls vehicle availability and can standardize maintenance, dispatch, and driver supervision. These advantages become less valuable when demand falls below the utilization required to cover fixed expenses. An asset-light forwarder can change providers and modes more readily, but it must monitor subcontractor reliability and manage the risk of information being lost between organizations. Neither structure is inherently superior: ownership substitutes asset exposure for some degree of operational control, while outsourcing substitutes procurement flexibility for coordination exposure.

Table 1. Comparative Decision-Making Characteristics of Asset-Owning Road Carriers and Contract-Based Multimodal Freight Forwarders

Decision dimension	Asset-owning road carrier	Contract-based multimodal forwarder
Capacity	Fleet and driver allocation; utilization risk	Carrier selection; contracted capacity and availability risk
Information	Vehicle position, duty status, maintenance	Cross-carrier milestones, document status, handoffs
Main disruption	Equipment failure, congestion, hours-of-service constraints	Border/terminal delay, missed modal connection, inconsistent documentation
Management trade-off	More direct control with fixed capital commitments	More flexibility with greater coordination demands

The distinction matters because a routing algorithm cannot repair a missing transport document or a contract that assigns no responsibility for temperature excursions. Optimization must therefore be linked to documentary, contractual, and cargo-specific controls.

4 FOUR OPERATIONAL INTERVENTIONS

4.1 Document readiness before physical arrival

Customs declarations, shipment descriptions, permits, consignee details, and cargo restrictions should be checked before pickup wherever the applicable procedure allows. The managerial mechanism is straightforward: documentation errors discovered before dispatch are usually less disruptive than errors discovered at a terminal after loading. Yet electronic documents are not universally accepted in every jurisdiction or movement. A practical implementation should record whether a document is prepared, verified, submitted, accepted, or awaiting intervention. These are different states, and a digital dashboard should not classify them all as completed clearance.

4.2 Capacity matching and empty-distance control

Backhaul matching and shipment consolidation may improve utilization, but consolidation is not costless. Combining consignments can add sorting time, handling risk, or intermediate stops. The relevant threshold is whether savings in line-haul capacity exceed the expected costs of extra handling and service deterioration. A forwarder should therefore monitor loaded distance, empty repositioning distance, revenue contribution by movement, and missed delivery commitments together, rather than optimizing the empty-mile percentage in isolation.

4.3 Risk-adjusted mode selection

The cheapest route at the time of quotation may not minimize expected final cost. Consider two alternatives: a road-only service with a low booked rate but uncertain crossing time, and a road–air service with a higher rate but a more predictable delivery window. The second option becomes economically defensible when the contractual consequence of late arrival exceeds the premium for air transport. The appropriate choice depends on cargo value, deadlines, handling exposure, and the cost of disruption, not on an unconditional preference for faster modes.

4.4 Cargo protection and traceability

Specialized shipments—including temperature-sensitive goods, artworks, live animals, and other regulated or fragile cargo—require compatible equipment and documented custody transfers. Monitoring devices may reveal an excursion, but alerts only have value when someone has authority and time to intervene. A defensible resilience program specifies alert thresholds, ownership of the response, escalation contacts, and the evidence retained after delivery. Claims that packaging or telemetry reduces losses to near zero cannot be sustained without audited claims histories.

5 RISK-ADJUSTED MULTIMODAL ROUTING MODEL

5.1 Network, choices, and observations

Let $G = (V, E)$ be a directed network. Each feasible edge $e \in E$ identifies an origin node, a destination node, and one transport mode $m \in \{road, rail, air, sea\}$. Mode transfer is represented by dedicated handling edges; this prevents an algorithm from changing modes at a location where no physical transfer is possible. Let $x_e \in \{0,1\}$ indicate selection of edge e for one shipment. An eligibility parameter $a_e \in \{0,1\}$ captures legal, equipment, and cargo compatibility. Edge monetary cost c_e includes the applicable carrier tariff, terminal charge, road toll, and other movement-specific fees. Fuel is either embedded in the carrier tariff or added separately, never both.

For each scenario s with probability p_s, let t_{es} denote travel plus expected operational and queue time on edge e. Delays must be estimated from shipment records or appropriately sourced corridor information, not assumed to follow a Gamma distribution without goodness-of-fit testing. Let $\ell_s(x)$ be the monetary late-delivery loss in scenario s. This distinguishes the consequences of a delayed arrival from the delay itself.

5.2 Objective function

The proposed decision criterion combines planned transport spending, the expected value of delay-related losses, and tail exposure:

$$\text{Minimize } Z(x, \eta, u) = \Sigma_e c_e x_e + \Sigma_s p_s \ell_s(x) + \lambda[\eta + (1/(1-\alpha))\Sigma_s p_s u_s].$$

Subject to $u_s \geq \ell_s(x) - \eta$ and $u_s \geq 0$ for each scenario s. The bracketed term is the standard scenario representation of conditional value-at-risk (CVaR) at confidence level α; η is an auxiliary loss threshold and $\lambda \geq 0$ expresses the decision-maker's additional concern for severe losses [3]. Costs and losses are expressed in the same currency. This avoids combining hours, probabilities, and money through unexplained weights. Where service time itself has an economic

cost independent of lateness, that valuation can be explicitly added to c_e or to scenario loss, but should not be counted twice.

5.3 Feasibility constraints

Flow conservation applies at each node v: Σ_e outgoing from v x_e − Σ_e incoming to v x_e = 1 at the origin, −1 at the destination, and 0 otherwise. Cargo compatibility imposes $x_e \le a_e$. If a contractual deadline is strict, it must be treated explicitly: for example, $P(T(x) \le T_{max}) \ge 1-\varepsilon$, or its sample-based scenario equivalent. A planning model should not reject a valid route on expected time alone while silently ignoring the probability of extreme delayCapacity restrictions can be imposed with $qx_e \le K_e$ where q is the shipment quantity and K_e the available capacity, provided the units are consistent. Separate transfer edges are used to incorporate both handling time and transfer charges. More detailed applications should include departure schedules, connection cut-offs, driver-hour limits, customs availability, and multimodal carrier service calendars. These extensions transform the problem into a resource-constrained path or time-expanded network problem, rather than a conventional shortest-path calculation

5.4 Feasible solution method and dynamic replanning

A simple shortest-path method such as Dijkstra or A* is suitable when edge weights are fixed, additive, and no path-level time or risk constraints exist. The full formulation above contains scenario-dependent loss and potentially non-additive feasibility conditions. It therefore requires an appropriate mixed-integer optimization model, label-setting algorithm for resource-constrained paths, or a restricted candidate-route approach followed by scenario evaluation. Calling an ordinary A* result the global optimum of the full stochastic model would be inaccurate.

The operational sequence is: (1) validate shipment requirements and documents; (2) generate physically and legally feasible routes; (3) acquire time, tariff, and capacity observations; (4) evaluate routes across delay and disruption scenarios; (5) choose a route under the stated risk preference and deadline rule; (6) monitor milestones during execution; and (7) re-optimize the remaining journey when an observed event materially changes feasibility or expected loss. Any reroute must preserve completed movements and existing commitments.

6 PROPOSED VALIDATION DESIGN

A future evaluation should use anonymized shipment-level data: route and mode, quoted and final cost, cargo classification, planned and actual milestone times, transfer counts, customs holds, empty kilometers where applicable, damage or claim events, and reasons for rebooking. To reduce confounding, shipments should be grouped by lane, cargo class, service level, and season before comparisons are made. The baseline could be historical dispatcher choice or least-quoted-price selection. Performance measures would include total realized cost per shipment, on-time delivery rate, upper-tail delay, claim frequency, and transfer-related exceptions.

A prospective pilot should predefine when the model is permitted to override a dispatcher and when professional judgment controls. Reported outcomes should include instances where the model recommends a higher-cost route and whether the eventual service benefit justifies that choice. The study should distinguish predictive accuracy (did estimated delays correspond to actual delays?) from decision quality (did selecting routes from those predictions improve outcomes?). Without these observations, the proposed framework remains a methodological contribution rather than a measured demonstration of annual financial savings.

7 DISCUSSION

Three implications follow. First, resilience is not synonymous with redundancy: spare routes and additional carriers are beneficial only when they can be activated within operational and contractual deadlines. Second, interoperability is an organizational problem as much as a software problem. A shared milestone vocabulary and documented exception ownership may have greater practical value than adding another isolated dashboard. Third, an asset-light forwarder should not treat outsourcing as elimination of risk. It reallocates direct equipment obligations while increasing dependence on verified partners, timely data, and effective handoffs.

The primary limitation is the absence of original shipment-level observations and independent verification of company-scale claims in the source draft. In addition, the model simplifies dependencies among weather, congestion, terminal closures, and capacity. These events may be correlated, particularly when many operators divert to the same alternative corridor. Future work should compare independent-delay assumptions with correlated scenarios, test the stability of risk preferences, and evaluate whether re-optimization actually improves delivered outcomes after switching costs.

8 CONCLUSION

Operational resilience in freight forwarding can be understood as disciplined control of information, feasible transport options, and the consequences of delay. The article contributes a practical four-part management framework and a risk-adjusted route selection model that separates transport charges from service-loss exposure. Its central proposition is testable: better documentation, capacity matching, and scenario-aware routing should improve outcomes when evaluated against comparable dispatch decisions. Whether they do so, and by how much, must be established with operational records rather than projected percentages. This distinction between a plausible managerial mechanism and demonstrated savings is essential for credible logistics research.

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

Disclosure of conflict of interest

The authors disclose that Vitalii Semenets is the founder and owner of Helion Ukraine and Helion International, whose professional activities provide context for this study. No company-specific financial or operational performance results are presented as independently verified empirical findings. Apart from this disclosed professional affiliation, the authors declare no conflicts of interest regarding this manuscript.

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