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The role of load consolidation and route optimization in supply chain resilience: a critical review.

The role of cargo consolidation and route optimization in supply chain resilience: a critical review

The role of load consolidation and route optimization in supply chain resilience: a critical review

Author: Murilo Domiciano dos Santos

- Bachelor's degree in Business Administration (Foreign Trade), São Francisco University (1998).
- MBA in Strategic Logistics, Torricelli Integrated Colleges (2009).

Summary:

Contemporary international trade has demanded innovative approaches to mitigate the vulnerability of global supply chains. Recent literature indicates that cargo consolidation and dynamic route optimization can act as defense mechanisms against disruptions and cost fluctuations. This article proposes a critical review of...

The effectiveness of these strategies in the context of freight forwarding is discussed . Based on a literature review between 2021 and 2025, this article explores how the adoption of analytical technologies favors logistics decision-making. It observes that, although theory points to significant benefits, practical implementation encounters organizational resistance, system integration costs, and information silos, which demands hybrid management approaches for effective success.

Keywords: International Logistics, Supply Chain Resilience, Cargo Consolidation, Route Optimization, Freight Forwarding.

Abstract:

Contemporary international trade has demanded innovative approaches to mitigate the vulnerability of global supply chains. Recent literature indicates that cargo consolidation and dynamic route optimization can act as defense mechanisms against disruptions and cost fluctuations. This article proposes a critical review of the effectiveness of these strategies in the context of freight forwarding. Through a literature analysis between 2021 and 2025, it discusses how the adoption of analytical technologies favors logistical decision-making. It is observed that, although the theory points to significant benefits, practical implementation encounters organizational resistance, system integration costs, and informational silos, requiring hybrid managerial approaches for effective success.

Keywords: International Logistics, Supply Chain Resilience, Cargo Consolidation, Route Optimization, Freight Forwarding.

Introduction

The dynamics of the global supply chain have gone through periods of significant change.

Volatility, highlighting the fragility of overly rigid logistic models. In

In recent decades, the relentless pursuit of efficiency has led organizations to adopt inventories.

minimal and highly stretched chains, which exposed them to external shocks. Studies suggest

that the occurrence of port strikes, tariff fluctuations and geopolitical crises requires a

A reconfiguration of logistical thinking, shifting the focus from mere cost efficiency to...

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Building structural resilience.

At the heart of this transition lies the role of the logistics intermediary, particularly that of
Freight forwarders , who orchestrate multimodal complexity. The literature
Current trends indicate that intelligent load consolidation and algorithmic route optimization are...
Key tools for mitigating market volatility. By grouping remittances
By breaking down logistics into smaller parts and redesigning transport flows in real time, logistics networks can, in
In theory, it offers greater traffic predictability and protection against abrupt fluctuations.
international shipping rates.

However, the adoption of these practices in Industry 4.0 is not without obstacles. This article
This aims to critically explore the intersection between multimodal logistics planning and resilience.
of supply chains. The work is structured to discuss the evolution of
freight forwarding, the impact of predictive technologies on route planning, feasibility
The economics of consolidation, the practical challenges of implementation, and finally, the importance of
Empowering the human factor to support these strategies.

1. The Evolution of Freight Forwarding and Resilience

Historically, freight forwarding has been understood as an activity
predominantly documentary and transactional, focused on the intermediation of physical spaces in
ships and aircraft. However, recent literature indicates that this role is becoming...
transforming profoundly. Christopher (2021) argues that the modern agent
evolved into a network solutions architect, taking on the responsibility of coordinating
Information flows are as critical as those of physical goods.
This metamorphosis is driven by the need for resilience. Dolgui and Ivanov (2021)
suggest that a dispatcher's ability to offer alternative routes and modes of transport
Secondary technologies act as an essential "buffer" *against* disruptions in the global supply chain.
The flexibility provided by qualified intermediaries tends to protect companies from
medium-sized companies that do not have sufficient volume to negotiate directly with the large ones.
global shipowners.
On the other hand, it is observed that the transition to a consultative service model requires
organizational maturity. Fosso Wamba et al. (2022) demonstrate that agents who
They base their decisions exclusively on the empirical experience of their operators.
Slower response times in the face of unforeseen tariff shocks. The study indicates that...

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Effective resilience depends on the integration of visibility systems that enable...
Proactive monitoring of cargo.
Furthermore, the literature points to a debate about the limits of this intermediation. While
Some authors advocate for complete digital disintermediation through platforms.
automated, Kache and Seuring (2021) consider that customs complexity
Cross-border trade still demands human intellectual capital. It is observed that automation...
The complete process runs up against local regulatory nuances, which justifies the agent's continued existence.
cargo management as a specialized consultant.
Thus, it is understood that contemporary freight forwarding oscillates between tradition.
relational and the need to adopt technologies. The ability of an intermediary to
Fostering the resilience of their customers' supply chains appears to depend closely on...
based on their ability to integrate decision algorithms with tacit knowledge about the
Peculiarities of global port infrastructures.

2. Route Optimization in the Era of Logistics Digitalization

Route optimization has traditionally been approached through modeling.
Static mathematics, aiming for the lowest cost or the shortest distance traveled. However, the
The evolution of algorithms in Industry 4.0 has introduced dynamic and predictive routing. Studies
Ivanov's (2024) work on "Digital Twins" *illustrates* how networks
Logistics operations can be simulated in real time, allowing managers to visualize the impact.
of storms or port congestion before making decisions of
redirection.
This predictive capability fundamentally alters logistics planning. Dubey et al.
(2023) observed that organizations that use routing algorithms powered by
Big data exhibits greater tolerance for variations in the capacity of
transporters. The results suggest that artificial intelligence applied to logistics allows
the rapid reconfiguration of multimodal traffic, transferring cargo from maritime transport to the
Air or road transport offers agility that minimizes stock shortages.
In contrast, some researchers warn against excessive reliance on these technologies.
Waller and Fawcett (2022) emphasize that optimization algorithms assume premises of
rationality and continuity of data that often do not hold up in reality.
The chaotic nature of international trade. When the quality of the data entered into the system is low,

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Route optimization can lead to unforeseen costs and extended transit times.
Furthermore, the implementation of complex routing systems *(Transport Management)*
Systems (TMS) require significant capital investments. For medium-sized organizations
Size, licensing costs, and the cost of integrating these *software programs* with legacy systems (ERP).
This may jeopardize the return on investment in the short term. Gunasekaran et al. (2022)
They recommend that companies adopt modular and cloud-based solutions to overcome these.
financial barriers and maintaining the economic viability of the project.
It can be stated that digitized route optimization contributes to the fluidity of commerce.
But it is not a panacea. Evidence from the literature indicates that the best results...
These occur when the algorithmic suggestion is critically validated by logistics experts.
ensuring that non-quantifiable variables, such as the relationship with the authorities, are not taken into account.
local customs regulations should be taken into account when planning the route.

3. Cargo Consolidation and its Economic Implications

The strategy of consolidating cargo *(Less than Container Load* - LCL) represents a
A vital tactical lever for shippers with less-than-truckload (LTL) volumes. From the point of view
Economically, the literature demonstrates that grouping multiple remittances into a single one...
Containers significantly reduce the unit cost of freight. Recent studies indicate that
This practice also mitigates exchange rate volatility and fluctuations in surcharges.
fuel, providing greater budgetary stability to importers (Christopher, 2021).
In addition to cost reduction, consolidation has been studied from a sustainability perspective.
environmental. Fosso Wamba et al. (2022) show that optimizing volumetric capacity
The use of containers reduces the carbon footprint per unit of cargo transported. It is observed that...
Rigorous consolidation practices contribute to the decarbonization of the supply chain.
supplies, aligning companies with contemporary ESG compliance requirements.
(Environmental, Social, and Governance).
However, consolidation introduces both temporary and operational risks. The need to wait
Filling the container space completely in the origin warehouses can extend the time.
transit time (lead time), which, according to Kache and Seuring (2021), can negatively affect the
Inventory velocity in time-sensitive supply chains, such as those for products.
perishable or high-tech. The literature suggests that a cautious balance must be struck.
between economies of scale and the opportunity cost of inventory in transit.

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To mitigate these delays, logistics intermediaries have adopted consolidation strategies.
"hub-and-spoke" and advanced *cross-docking* programs . Dubey et al. (2023) report that
Logistics operations that precisely synchronize the arrival of less-than-truckload (LTL) shipments at
Consolidating warehouses tend to reduce waiting times to marginal levels. This synchronization,
However, it requires acute systemic visibility and transparent sharing of
Information is shared between all suppliers involved.
It can be concluded that cargo consolidation is a powerful tool for competitiveness.
middle-market. However, evidence suggests that its success depends on orchestration.
refined temporal. Practice requires logistics managers to continually consider the *trade-*
There is a disconnect between the immediate reduction in freight costs and the potential impacts on service levels.
agreed with the end customer.

4. Challenges, Limitations, and the Reality of Implementation

Despite the theoretical appeal of predictive routing and intelligent consolidation strategies,
Its implementation in daily organizational life runs into severe structural limitations. One
One of the main obstacles identified in the literature is data fragmentation. Kache and
Seuring (2021) points out that "information silos" within companies themselves prevent the
Logistics systems access sales and inventory data in real time, compromising the
effectiveness of any optimization model.
Additionally, there is a lack of standardization of information across the different links in the global supply chain.
(transporters, customs, warehouses) acts as a limiting factor. Ivanov (2024) describes that
the incompatibility between the application programming interfaces (APIs) of the providers of
The service results in visibility gaps. When the freight forwarder loses track of
A shipment during multimodal transfer, all the algorithmic network intelligence is
invalid.

The literature also highlights the chronic presence of "algorithmic aversion" in operations.
logistics. Waller and Fawcett (2022) observed that transportation planners with decades of
Experience tends to ignore the recommendations generated by optimization systems.
believing that their personal heuristics are more accurate in the face of customs complexity.
This cultural resistance hinders the adoption and scaling up of control technologies.
The hidden costs of integration constitute another significant barrier. Although solutions
Although *Software as a Service* (SaaS) -based technologies have made TMS tools more affordable,

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The cost of process reengineering and clean data auditing can be prohibitive for companies.
medium-sized companies. Gunasekaran et al. (2022) demonstrate that many projects of
Logistics digitization fails not because of software deficiencies , but because of underfunding.
Legacy data transition steps.
From this analysis, it becomes evident that logistics technology does not operate in a vacuum.
Studies suggest that organizations that fail to manage behavioral change...
Their teams, and those that don't invest in the integrity of their databases, rarely manage to extract...
The value promised by technological literature. Mitigating these flaws requires a
Realistic recognition of corporate limitations before implementation begins.

5. Analytical Skills and Valuing the Human Factor

Recognizing the barriers to technological implementation culminates in the understanding that
The human factor remains central to logistical resilience. The transition from one model
A shift from empirical decision-making to a data - driven culture requires a
intentional process of executive empowerment. Authors such as Choi et al. (2022) emphasize the
The importance of "human-in-the-loop," arguing that critical human supervision is
Essential for correcting biases in predictive models.
For data integration and route optimization to work, logistics managers
They need data literacy . The literature indicates that professionals
capable of correctly interpreting confidence intervals and analyzing trends in *dashboards.*
Understanding the limitations of an algorithm leads to much greater success in its practical application.
Multimodal solutions are more important than those that only operate the platform mechanically.
Corporate programs focused on internal skills development, such as workshops.
Continuous simulation and training tend to reduce the aforementioned technological aversion.
previously. Dubey et al. (2023) suggest that the involvement of line operators
The focus on customizing the optimization system rules creates a sense of belonging.
(ownership), increasing systemic adherence rates and reducing adaptation time.
operational.
Valuing human capital also contributes to reducing chronic dependence on
expensive external consulting. By institutionalizing knowledge within the company itself, the
Foreign trade departments gain autonomy to conduct experiments in
Small-scale load consolidation, validating hypotheses before restructuring.

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on a large scale. This method of empirical learning has been identified as more sustainable.
for lean organizations.
In summary, the evidence suggests that the best logistics system is not necessarily the most efficient.
automated, but one in which there is a clear synergy between the analytical tool and the
managerial discernment. Targeted training, therefore, should be understood not as
It's not an accessory cost, but it acts as the structural pillar that enables true innovation in the supply chain.
contemporary supply chain.

Conclusion

This review sought to critically analyze the role of cargo consolidation strategies and
Predictive route optimization plays a role in building the resilience of global supply chains.
Based on the literature reviewed, it is observed that the logistics and freight forwarding sector
It is in a period of severe transition, in which the reliance on empirical methods
This has given way to an imperative for analytical intelligence and structured digitization.
The synthesis of the studies suggests that load consolidation *(LCL)* remains a mechanism.
economically effective for reducing unit costs and mitigating exchange rate fluctuations.
However, it has been found that its success depends on a systemic orchestration that avoids the
Excessive transit time. The introduction of routing algorithms addresses this issue.
in synergy with these operations, providing greater predictability to multimodal flows and
allowing for the early identification of port and road bottlenecks.
As a theoretical contribution, the article highlights that the concept of logistic resilience is not...
It is limited by the physical robustness of transport assets, but mainly depends on agility.
Informational. The debate demonstrates that the operational flexibility offered by intermediaries
Skilled professionals complement the accuracy of *Business Analytics systems,* suggesting a
a theoretical approach in which technology and empirical customs knowledge must be
studied in a unified, and not mutually exclusive, manner.
In terms of practical contribution, the discussion alerts managers to the real difficulties.
in technological implementation. The literature indicates that investing in sophisticated technologies is pointless.
optimization systems if corporate databases remain fragmented and the
The team expressed aversion to algorithms. The text reinforces the importance of implementation.
phased implementation and continuous validation of results by experienced professionals.
Among the limitations of this study, it is noteworthy that the literature is frequently based on...

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macroeconomic contexts of largely mature markets, whose conclusions may vary.
when applied to port infrastructure in emerging economies, where bottlenecks
Bureaucratic factors overcome algorithmic shortcomings. Furthermore, cost analyses of
The timing opportunities for cargo consolidation can vary enormously depending on...
perishability or the added value of the transported product.
Finally, with regard to a future research agenda, the development of
empirical investigations focused on the behavior of the logistics operator in the face of intelligence.
artificial. Studies that quantitatively measure how training programs mitigate the
Resistance to TMS systems, as well as investigations into the use of *Blockchain* technology.
Eliminating information silos in *cross-docking* will be of great value to the
Advances in the science of logistics operations management.

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