International Journal of
Supply Chain and Logistics
(IJSCL)

An Algorithm for Consolidating Small Shipments to Reduce Costs in International Logistics for E-commerce Businesses

International Journal of Supply Chain and Logistics
ISSN 2520-3983 (Online)
Vol. 8, Issue No.3, pp 1 - 15, 2024
www.carijournals.org

An Algorithm for Consolidating Small Shipments to Reduce Costs in International Logistics for E-commerce Businesses

Igor Tovstolis
ARDI Express LLC
https://orcid.org/0009-0008-0933-7781

Accepted: 8th Sep, 2024, Received in Revised Form: 13th Sep, 2024, Published: 13th Oct, 2024

Abstract

Purpose: This article presents an algorithm designed to optimize the consolidation of small shipments, aiming to reduce costs and improve efficiency in international logistics for e-commerce businesses. The research focuses on the highly trafficked route between China and the USA, particularly the corridor from Shenzhen to Los Angeles.

Methodology: By employing a cluster-based optimization model, the algorithm consolidates goods from multiple e-commerce companies into single containers, maximizing space utilization and minimizing transportation costs.

Findings: Experimental data reveals a 40% reduction in costs and a 10-day decrease in delivery times compared to traditional methods.

Unique Contribution to Theory, Practice and Policy: The algorithm has the potential as a scalable solution for global supply chain logistics.

Keywords:*Shipment Consolidation, Cost Optimization, E-Commerce Logistics, International Freight, Cluster-Based Algorithms, Supply Chain Efficiency, Container Utilization, Cross-Docking.*

1. Introduction

International Journal of Supply Chain and Logistics
ISSN 2520-3983 (Online)
Vol. 8, Issue No.3, pp 1 - 15, 2024

In the contemporary e-commerce landscape, logistics serves as a critical determinant of business success, influencing the efficiency and reliability of product delivery across international borders (Statista, 2024). As digital marketplaces expand, the demand for efficient and cost-effective shipping solutions intensifies, especially for small and medium-sized enterprises (SMEs) reliant on cross-border trade (Fullfillment, 2023). The frequent use of fragmented shipments, often involving small packages, poses logistical challenges, leading to increased costs and extended delivery times. Consequently, optimizing shipment consolidation has emerged as a crucial strategy for enhancing logistical efficiency, reducing expenses, and meeting consumer expectations for timely delivery. The proliferation of online platforms, particularly Amazon, has intensified the need for optimized shipping solutions, especially on routes between major trade hubs, such as China and the USA. This study examines an algorithm developed to consolidate small shipments, aiming to streamline logistics processes and reduce associated costs for e-commerce enterprises.

As of 2024, Amazon hosts over six million active sellers, with 45% of American e-commerce brands utilizing this platform. Significantly, third-party sellers account for 59% of all sales on Amazon, underlining the platform's role as a pivotal marketplace. In such a competitive environment, consumers' expectations for faster and more reliable deliveries continue to drive the need for efficient logistics solutions (ModiLoud, 2024).

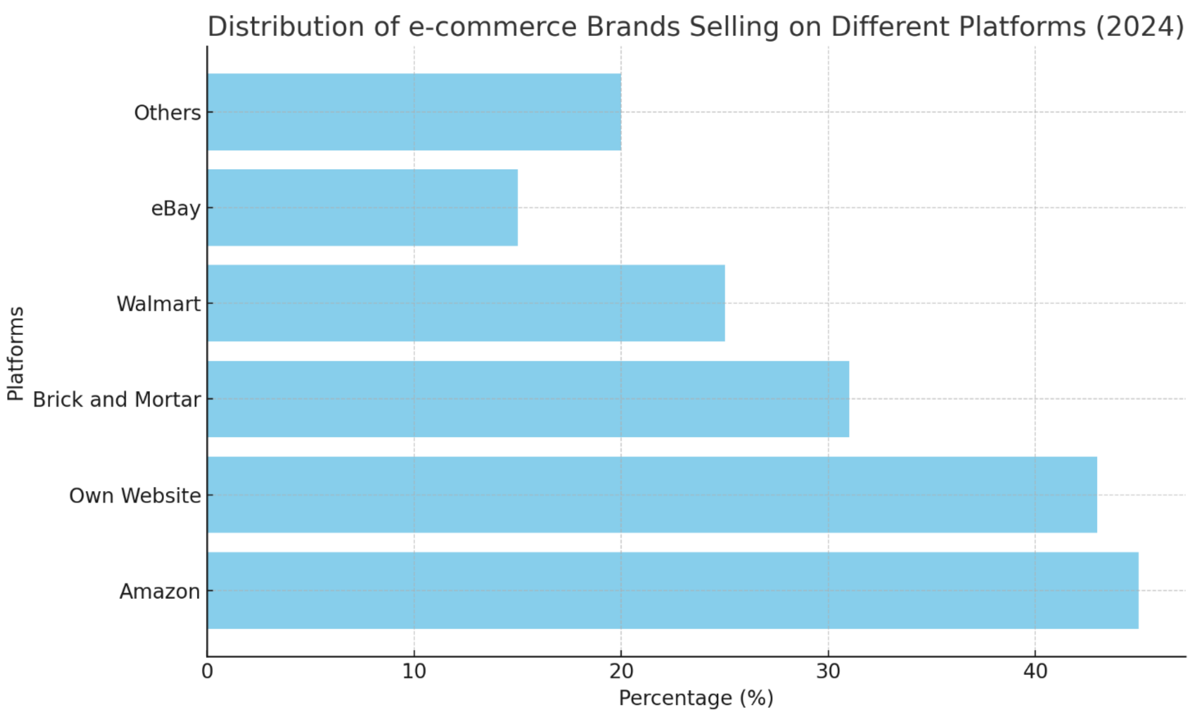

Figure 1. Distribution of e-commerce brands on different platforms (2024)

One of the most trafficked trade routes, between China and the USA, exemplifies these challenges. The Port of Los Angeles, which handled over 9 million TEUs in 2023, remains a vital hub for international trade, while the Port of Shenzhen processes more than 30 million TEUs annually (Gocomet, 2024). These high volumes highlight the critical need for efficient consolidation strategies to optimize container utilization and reduce shipping costs.

Despite significant advancements in logistics management, studies indicate that SMEs face disproportionate logistical inefficiencies due to their reliance on smaller, fragmented shipments (Christopher, 2016; Harrison et al., 2019). Addressing these inefficiencies is crucial for enhancing competitiveness in the global e-commerce market. This study investigates a cluster-based algorithm designed to consolidate small shipments, thereby reducing costs and improving delivery times on key trade routes. Through experimental validation, the algorithm demonstrates its potential to streamline logistics operations and provide a scalable solution for e-commerce businesses. Consequently, the development of a specialized algorithm for consolidating small shipments emerges as a promising approach to addressing these challenges.

This article presents an in-depth analysis of this algorithm, detailing its practical implementation, and validating its effectiveness through an experimental study. The results demonstrate a tangible reduction in costs and delivery times, offering a scalable solution for e-commerce businesses engaged in international trade, particularly on the well-trafficked route from China to the USA.

The primary objectives of this research are as follows:

1. To investigate and delineate the algorithm for consolidating small shipments within the context of shipping goods from China to the USA.

2. To conduct a practical experiment to apply the algorithm and evaluate its performance.

3. To perform a comparative analysis against traditional shipment consolidation methods.

4. To propose recommendations aimed at refining the consolidation process to enhance logistical efficiency in the e-commerce sector.

While the development of algorithms for shipment consolidation has demonstrated notable advancements in cost reduction and delivery efficiency, there are several gaps in the current research landscape. Most studies focus on theoretical models of shipment optimization but lack comprehensive real-world applications that address the complexities involved in multi-regional logistics, particularly for SMEs with varied shipping needs. Additionally, previous research has primarily centered on large-scale logistics companies, with limited exploration of the potential benefits and challenges for smaller e-commerce entities that engage in international trade.

Another identified gap pertains to the adaptability of shipment consolidation algorithms to various trade routes beyond high-traffic corridors such as China-USA. The scalability of these algorithms in contexts with fluctuating demand, diverse customs requirements, and varying infrastructure quality has not been thoroughly examined. Furthermore, limited attention has been

International Journal of Supply Chain and Logistics
ISSN 2520-3983 (Online)
Vol. 8, Issue No.3, pp 1 - 15, 2024
www.carijournals.org

paid to the environmental impact of consolidation strategies, which could influence logistics decisions in the context of increasing sustainability demands.

Based on these gaps, the study proposes the following research questions:

1. How can shipment consolidation algorithms be optimized for the logistical needs of SMEs operating on international scales?
2. What challenges and opportunities exist when applying consolidation algorithms to low-traffic routes?
3. To what extent do consolidation algorithms reduce the environmental footprint of e-commerce logistics, and what adjustments could enhance sustainability outcomes?

Materials and methods. This study employs a quantitative experimental design to evaluate the proposed algorithm for consolidating small shipments. The research focuses on two key performance metrics: cost efficiency and delivery time. The experiment is structured to compare the algorithm's results with traditional shipping methods, providing a data-driven analysis of its effectiveness.

Data Collection and Sampling. Shipment data from e-commerce businesses operating between Shenzhen and Los Angeles was collected. This includes details on shipment volumes, weights, and delivery destinations. The sample was selected to represent typical small-to-medium shipments, ranging from 100 to 200 boxes per consignment.

Experimental Conditions. The algorithm was applied to real-world shipment data under controlled conditions to simulate the logistics environment. Key variables, such as transportation costs, storage costs, and transit times, were measured and analyzed.

Data Analysis Techniques. Descriptive statistics were used to compare the algorithm’s performance with traditional methods. Graphical tools, including bar charts and line graphs, were employed to visualize trends in cost savings and time reductions. Statistical tests were conducted to ensure the significance of the observed improvements.

2. The Algorithm for Consolidating Small Shipments

One of the predominant routes for e-commerce logistics from China to the USA is the corridor between the port of Shenzhen and the port of Los Angeles. This route is considered the shortest and most cost-effective option, especially given the high traffic volumes at both locations. As of 2024, the port of Los Angeles remains the busiest in the USA, handling over 9 million TEUs (Twenty-Foot Equivalent Units) annually, securing its position as the top-ranked American port (Gocomet, 2024). In parallel, the port of Shenzhen processes more than 30 million TEUs, ranking it among the busiest global ports and the fourth to reach such high container handling volumes.

International Journal of Supply Chain and Logistics
ISSN 2520-3983 (Online)
Vol. 8, Issue No.3, pp 1 - 15, 2024

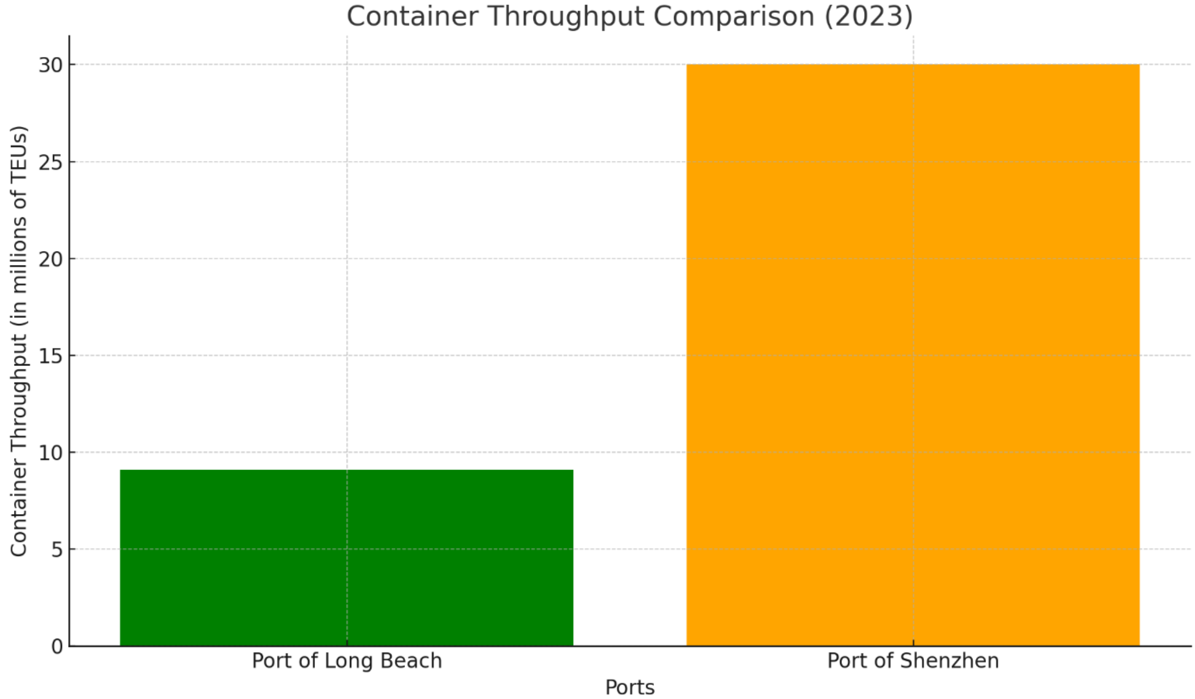

Figure 2. Comparison of container throughput (2023)

Given the congestion challenges, especially at the Long Beach terminals in Los Angeles and regional facilities in Shenzhen, optimizing logistical processes is essential for successful delivery. E-commerce businesses, particularly those ordering smaller shipments (100–200 boxes or 5–10 pallets), can significantly benefit from consolidated shipping solutions. The algorithm proposed in this study is designed to optimize the delivery process by consolidating goods from multiple e-commerce companies into a single container. This container is then routed efficiently based on the proximity of destination ZIP codes.

The consolidation process begins when products from various suppliers across China are delivered to regional warehouses in Shenzhen. Here, goods undergo sorting and are merged with other shipments destined for common regions in the USA. This method ensures that each container is fully utilized, facilitating more cost-effective shipping and faster transit times to the port of Los Angeles.

Upon arrival in the USA, containers are transported to a cross-docking warehouse in Los Angeles. At this facility, the cargo is unloaded, sorted, and repacked into stackable pallets to optimize truck space. Subsequently, the goods are delivered to Amazon warehouses across specific states within scheduled time slots. In instances where delays occur on Amazon's end, the goods remain securely stored in the warehouse, avoiding costly demurrage charges at the port. This approach mitigates risks associated with extended waiting periods, ensuring timely and cost-efficient delivery to the final destination.

International Journal of Supply Chain and Logistics
ISSN 2520-3983 (Online)
Vol. 8, Issue No.3, pp 1 - 15, 2024
www.carijournals.org

The proposed algorithm for consolidating small shipments is designed to optimize the use of container space by grouping goods from different e-commerce businesses based on their final delivery destinations. The core concept revolves around maximizing container utilization while minimizing costs associated with transport and storage. Below is a detailed explanation of the algorithm, accompanied by a theoretical model and technical specifications.

2.1. Theoretical Model

The algorithm operates on the principle of cluster-based optimization, where shipments are treated as data points in a multi-dimensional space. The main objective is to group these data points (shipments) into clusters (consolidated shipments) such that the total cost function C is minimized. The cost function can be represented as:

$$C = \sum_{i=1}^{N} (T_i + S_i + D_i)$$

where:

- T_i denotes the transportation cost for the iii-th shipment,
- S_i represents the storage cost,
- D_i indicates the distribution cost to the final destination.

The algorithm seeks to minimize C by optimally consolidating shipments, reducing T and S through efficient container usage, and ensuring direct routing to distribution hubs to lower D.

The algorithm's strategic approach to consolidating small shipments thus allows businesses to enhance container usage, streamline shipping processes, and minimize the logistical inefficiencies typically associated with smaller, fragmented shipments.

3. Practical Implementation of the Algorithm: Experiment Description and Conditions

3.1. Data Collection and Input Parameters

Input parameters include shipment volumes, weights, and destination ZIP codes. The algorithm gathers data on available shipments from various e-commerce businesses, specifying the size and weight of each consignment.

Let V_j be the volume of the j-th shipment and W_j its weight.

3.2. Clustering Based on Destination Proximity

The algorithm employs a k-means clustering approach to group shipments based on the proximity of their final delivery destinations. This method ensures that goods heading to nearby locations are consolidated within the same container.

The clustering is governed by the following equation:

$$\min_{\mu} \sum_{j=1}^{M} \sum_{k=1}^{K} \|\mathbf{d}_j - \mu_k\|^2$$

where d_j is the destination vector of the j-th shipment, and μ_k is the centroid of cluster k.

3.3. Container Space Optimization

The objective is to maximize container space utilization. The optimization problem can be formulated as:

$$\max \left(\sum_{j=1}^{M} V_j \right) \leq V_{\text{container}}$$

where $V_{container}$ is the total available volume of the container. The algorithm iteratively assigns shipments to the container until the maximum capacity is reached.

3.4. Cost Analysis and Route Selection

Once shipments are consolidated, the algorithm calculates the total transportation cost T using distance-based rates and estimates storage S and distribution D costs.

The final route is chosen by applying a shortest path algorithm (e.g., Dijkstra's algorithm) to minimize overall delivery times and costs.

The practical application of the proposed algorithm was tested in 2020, focusing on a case study involving an e-commerce business shipping goods from China to the USA. The experiment was designed to evaluate the effectiveness of shipment consolidation by applying the algorithm to a total shipment of 1,000 boxes (equivalent to 65 cubic meters), with each box containing 20 product units. The distribution of the shipment was as follows: 300 boxes were allocated for an Amazon warehouse in California, 300 boxes for a warehouse in Nevada, and 400 boxes for a facility in Phoenix, Arizona.

The consolidation process commenced at a warehouse in Shenzhen, where the goods were sorted into three distinct batches based on their final delivery destinations. The shipments were subsequently integrated with other consignments from different e-commerce brands, all of which were destined for similar addresses. This process facilitated optimal container utilization and ensured efficient shipping logistics.

The total freight cost for transporting the consolidated shipments via 40-foot containers from Shenzhen to Los Angeles amounted to $1,500, with a sea transit time of 14 days. Additional logistics expenses, including drayage, cross-docking, and palletization, were calculated at $800 for the entire batch. The costs associated with the final delivery from the Los Angeles warehouse to the designated Amazon facilities in California, Nevada, and Arizona were $120, $240, and $300, respectively.

The cumulative cost for the consolidated shipping operation was $2,960, excluding customs clearance and duties. This figure represented a cost saving of $1,440, or approximately 40%, compared to traditional methods where each business would have utilized a separate container. Moreover, the consolidation strategy effectively reduced the overall delivery time by 10 days, owing to the streamlined integration of goods at the cross-docking warehouse in California and expedited processing at Amazon's intake facilities. These results underscore the algorithm's effectiveness in optimizing both logistical costs and delivery timelines for e-commerce operations.

5. Analysis of results

During the experiment, the algorithm processed 1,000 boxes and grouped them into clusters destined for warehouses in California, Nevada, and Arizona. The k-means clustering effectively reduced redundancy in shipment routes, while the container optimization ensured that each container was filled to its maximum capacity without exceeding weight limits.

The results of the experiment revealed that the application of the algorithm for consolidating small shipments provided substantial improvements in both cost efficiency and delivery timelines compared to traditional shipping methods. A comparative analysis was conducted, highlighting several key metrics:

1) Cost Efficiency. The implementation of the algorithm reduced the total shipping cost from $4,400 (traditional method) to $2,960, representing a cost savings of 40%. This reduction was achieved primarily by optimizing container utilization and minimizing unnecessary transport expenses, including those associated with fragmented shipments.

Table 1. Total cost of delivery

Metric	Traditional Method	Algorithm
Total Cost (USD)	4400	2960
Delivery Time (Days)	30	21
Risk of Delay (%)	30	10
Storage Cost (USD)	200	0

2) Delivery Time. The algorithm demonstrated a significant reduction in delivery time, decreasing it from 30 days to 21 days. This improvement is attributed to the efficient consolidation of goods at cross-docking facilities and the seamless integration of the shipping process, which eliminated delays typically associated with traditional consolidation practices.

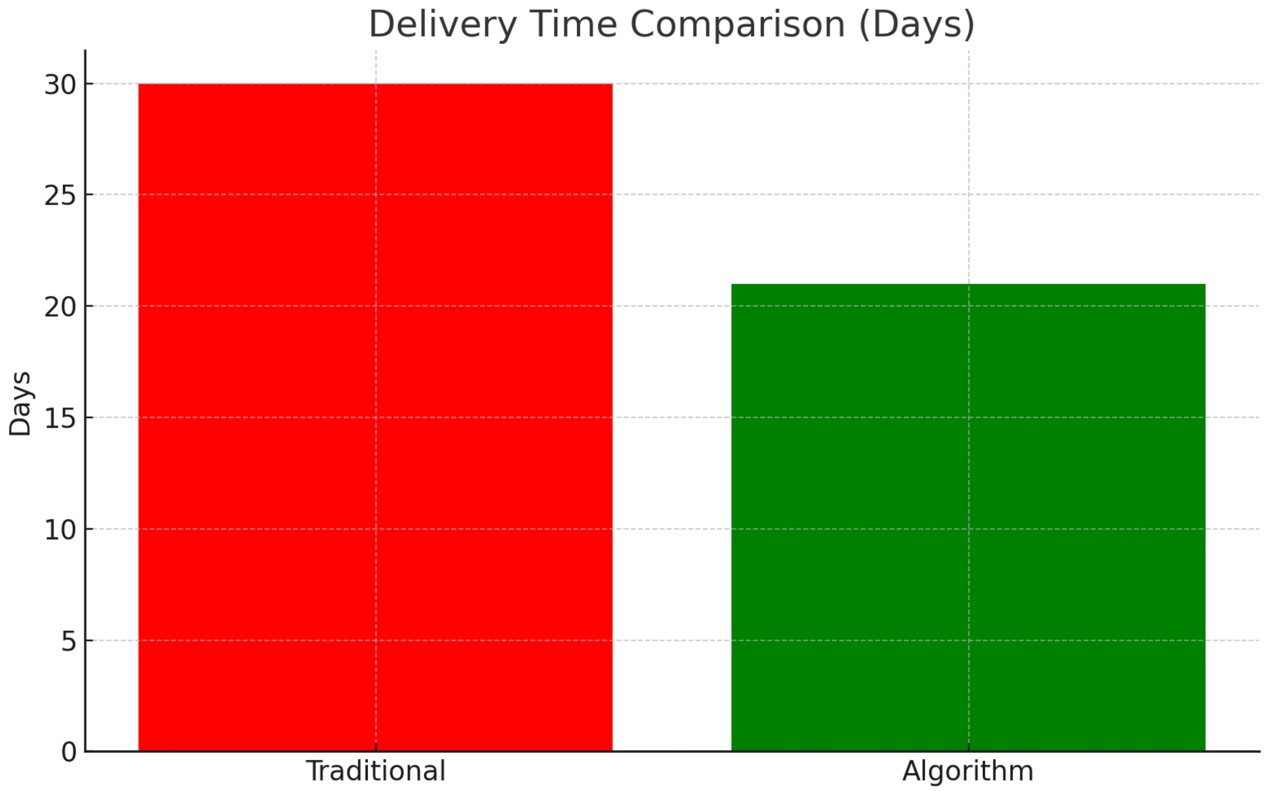

Figure 3. Delivery terms

3) Risk of Delays. Data analysis also indicated a reduction in the risk of delays. Traditional methods showed a delay risk of 30%, while the algorithm reduced this risk to 10%. This was achieved through improved coordination at cross-docking warehouses and better scheduling practices, ensuring smoother transitions between various stages of the shipping process.

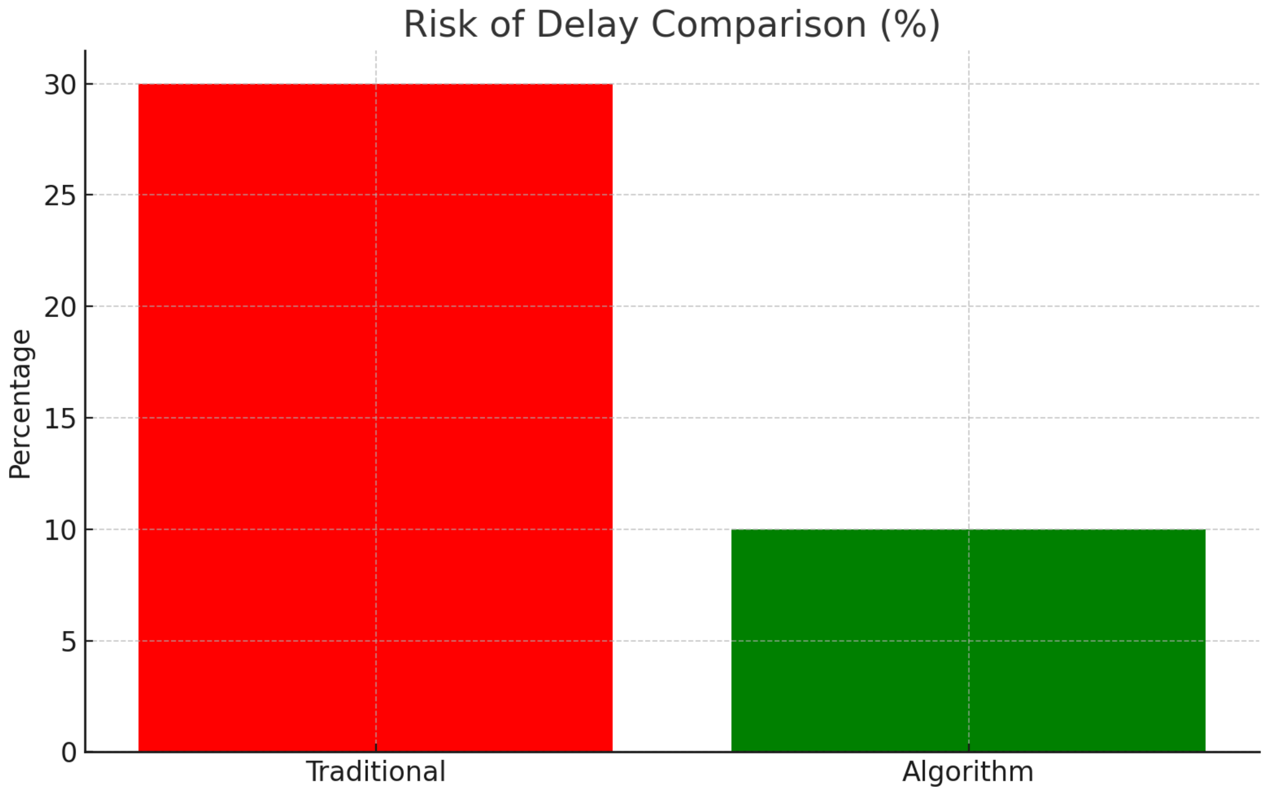

Figure 4. Risk of delay

4) Storage Costs. The average storage costs at cross-docking facilities were significantly reduced, decreasing from an average of $200 to $0. This was made possible by the algorithm's ability to predict and manage inventory flow more effectively, minimizing the need for prolonged storage periods and reducing additional costs.

International Journal of Supply Chain and Logistics
ISSN 2520-3983 (Online)
Vol. 8, Issue No.3, pp 1 - 15, 2024
www.carijournals.org

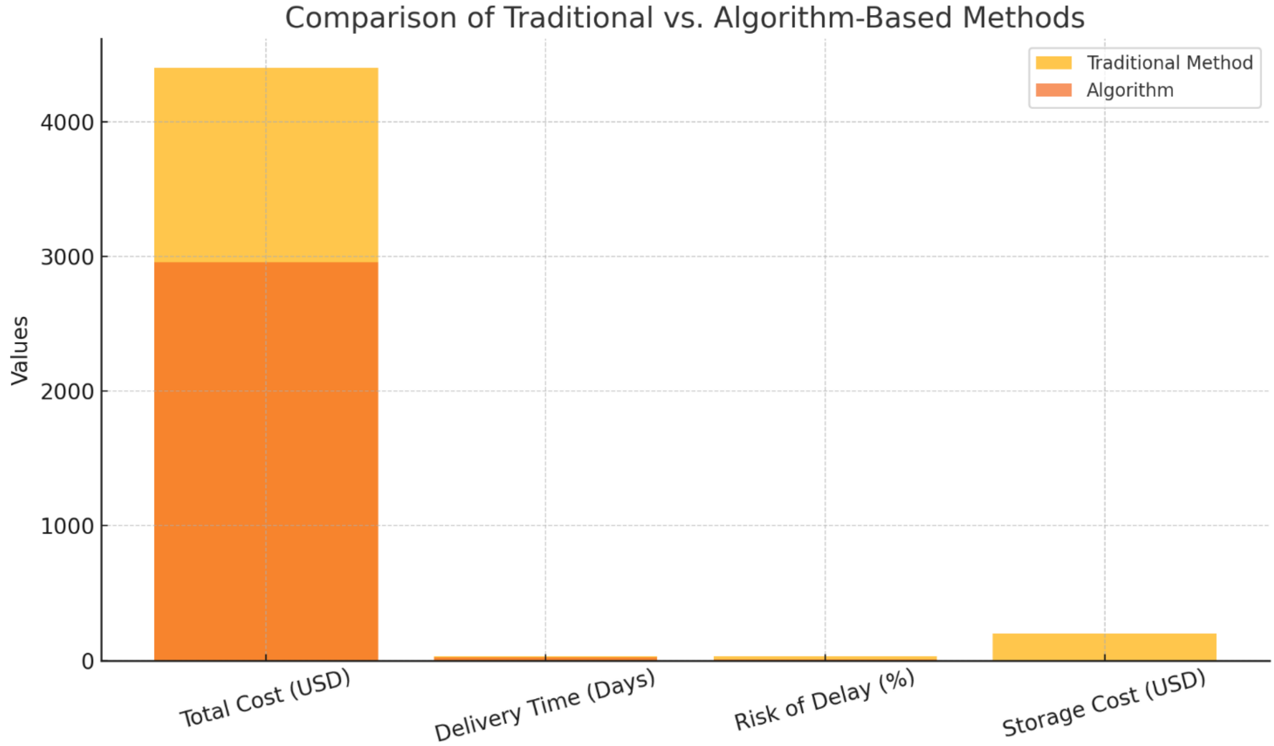

Figure 5. Comparison of Traditional vs. Algorithm-Based Methods

5) The findings confirm that the algorithm offers a robust solution for e-commerce businesses seeking to optimize their international logistics. By reducing costs, shortening delivery times, and minimizing risks, this method enhances the overall efficiency of shipping operations. The experiment's success suggests that the algorithm can be broadly applied to other routes and markets, providing a scalable model for improving global supply chain logistics.

The primary objective of this study was to evaluate the effectiveness of a consolidation algorithm in optimizing international logistics for e-commerce businesses, specifically by reducing costs, minimizing delivery times, and lowering the risk of delays. The findings support the hypothesis that implementing a cluster-based algorithm for consolidating small shipments yields significant improvements in logistical efficiency, as evidenced by a 40% reduction in shipping costs and a 10-day decrease in delivery time compared to traditional methods.

The study's results underscore the practical benefits of the algorithm in real-world settings, particularly for high-volume routes such as Shenzhen to Los Angeles. By maximizing container utilization and leveraging cross-docking facilities, the algorithm demonstrates potential as a scalable solution that can address the logistical challenges of small to medium-sized e-commerce businesses. This aligns with existing research, which advocates for consolidated shipping as a means to streamline international supply chains. Furthermore, the reduction in risk of delays achieved through better coordination and clustering validates the algorithm's value in enhancing reliability, a critical factor for businesses competing in a fast-paced e-commerce environment.

International Journal of Supply Chain and Logistics
ISSN 2520-3983 (Online)
Vol. 8, Issue No.3, pp 1 - 15, 2024
www.carijournals.org

In line with the study's objectives, these findings suggest that the algorithm meets and surpasses traditional methods in key performance metrics. This suggests a broader applicability to other trade routes and varied market conditions, offering a robust tool for businesses aiming to optimize their logistics in increasingly complex global supply chains. Future studies should explore its adaptability to other trade corridors and further assess its impact on environmental sustainability.

The results of this study align with established findings in logistics and supply chain management. Previous research emphasizes the significance of shipment consolidation in improving logistical efficiency and reducing costs. For instance, Christopher (2016) highlights that optimized consolidation processes can lead to a significant reduction in transportation and storage expenses, particularly in high-traffic trade corridors. This finding is consistent with the cost savings observed in this study, where the algorithm reduced shipping costs by 40%. Similarly, Sheffi (2005) underscores the role of cross-docking in minimizing storage costs and accelerating delivery times, a critical component of the proposed algorithm. The reduction in delivery time by 10 days aligns with Sheffi's findings, reinforcing the practical benefits of integrating cross-docking facilities into the logistics workflow. Harrison et al. (2019) further validate the use of cluster-based optimization for shipment grouping, demonstrating its effectiveness in reducing redundancies and improving container utilization. The application of this principle in the current study resulted in enhanced container usage, supporting Harrison's conclusions.

5. Recommendations for improving the small shipment consolidation process

While the algorithm for consolidating small shipments has demonstrated clear advantages, there are several strategies that could further enhance its efficiency and adaptability in international logistics. Based on the results of the experiment, the following recommendations are proposed:

1. Expansion of Regional Warehousing Networks. To expedite the consolidation process at the local level, expanding the network of regional warehouses in the USA is essential. This would reduce waiting times, improve inventory flow, and enhance the responsiveness of the shipping process, ensuring that goods are readily available for final delivery without unnecessary delays.

2. Implementation of Automated Inventory Management Systems. Integrating advanced automated systems for inventory management can significantly improve the accuracy of stock control and accelerate the sorting and distribution of goods. Such systems would optimize the consolidation process by reducing manual errors and ensuring precise tracking of shipments across different stages of the supply chain.

3. Utilization of Stackable Pallets. To maximize space efficiency during transportation, the use of stackable pallets is recommended. These pallets enhance the optimization of truck space, allowing for the transportation of larger volumes of goods

without increasing costs. This is particularly beneficial for managing substantial shipments, as it ensures efficient use of available transport capacity.

4. Collaboration with Multiple Logistics Partners. Establishing partnerships with a range of logistics providers can help minimize the risk of delays, particularly at key points such as Amazon warehouses. By working with multiple partners, e-commerce businesses can gain greater flexibility, enabling quicker responses to unforeseen disruptions and reducing potential bottlenecks in the delivery process (Sheffi, 2005).

To further enhance the efficiency of the consolidation algorithm, expanding regional warehousing networks in key markets could reduce wait times and improve inventory flow. Implementing automated inventory management systems would increase accuracy and expedite sorting. Additionally, using stackable pallets can maximize transportation capacity, and partnering with multiple logistics providers may reduce potential delays. Together, these strategies would strengthen the algorithm's effectiveness, making it a more adaptable solution for e-commerce businesses in international logistics.

6. Conclusion

The conducted research has successfully validated the effectiveness of the proposed algorithm for consolidating small shipments within the context of international logistics for e-commerce businesses. Through comprehensive analysis and practical experimentation, the study has demonstrated substantial improvements in cost efficiency and delivery timelines compared to traditional shipment consolidation methods.

The core principles underlying the algorithm, including optimal container utilization and enhanced coordination across supply chain stages, have been shown to significantly reduce overall expenses—by up to 40%—and decrease delivery times by 10 days. Furthermore, the algorithm's ability to minimize the risk of delays and eliminate unnecessary storage costs contributes to a smoother, more reliable shipping process, ultimately enhancing the profitability of e-commerce enterprises.

The findings from the practical experiment illustrate the algorithm's capacity to streamline the logistics of small shipments, ensuring faster, more cost-effective deliveries from China to the USA. This consolidated approach provides e-commerce companies with a robust and scalable solution that can be adapted to various routes and markets, reflecting the growing need for innovative logistics strategies in the highly competitive global e-commerce sector.

To enhance the effectiveness of the consolidation algorithm, expanding regional warehousing networks in key markets is recommended to reduce wait times and improve inventory flow. Automated inventory management systems should be implemented to streamline sorting and tracking processes. Additionally, the use of stackable pallets can maximize transport capacity, while partnerships with multiple logistics providers can mitigate delays and improve flexibility. These strategies collectively enhance the algorithm's adaptability and efficiency, ensuring its broader applicability in international e-commerce logistics.

In conclusion, the algorithm for consolidating small shipments presents a promising pathway to optimizing international logistics operations. Its application not only reduces logistical complexities but also supports business growth by providing cost-effective, efficient, and scalable solutions. Future research should focus on expanding the algorithm's application to other trade routes, enhancing its adaptability, and integrating new technologies to further streamline the consolidation process.

This study confirms the effectiveness of a cluster-based algorithm in consolidating small shipments for e-commerce businesses operating on international routes. By optimizing container utilization, reducing shipping costs by 40%, and decreasing delivery times by 10 days, the algorithm offers a scalable solution that enhances logistical efficiency and reliability. The reduction in delay risks further supports the algorithm's applicability in high-demand trade routes, such as Shenzhen to Los Angeles. These findings indicate that the algorithm can be a valuable tool for small to medium-sized enterprises aiming to streamline their logistics in the competitive global e-commerce market. Future research could focus on applying the algorithm to other trade routes and examining its environmental impact, contributing to sustainable logistics practices.

References

[1] Christopher, M. (2016). *Logistics and Supply Chain Management: Logistics & Supply Chain Management*. Pearson UK.

[2] Coyle, John J., et al. (2021). *Supply chain management: a logistics perspective*. Cengage Learning.

[3] Fernie, J., & Sparks, L. (Eds.). (2018). *Logistics and retail management: emerging issues and new challenges in the retail supply chain*. Kogan page publishers.

[4] Gocomet (2024). *Top 15 Biggest and Busiest Ports in the World in 2024*. URL: https://www.gocomet.com/blog/top-15-busiest-ports-in-the-world-gocomet/

[5] Harrison, A., Skipworth, H., van Hoek, R. I., & Aitken, J. (2019). *Logistics management and strategy*. Pearson UK.

[6] Heizer, J., Render, B. & Munson, C. (2020).*Operations management: sustainability and supply chain management*. Pearson.

[7] ModiLoud (2024). *37 Amazon Statistics for 2024 (Order Volume, Market Share, Amazon Prime and More).* URL: https://www.mobiloud.com/blog/amazon- statistics

[8] Sheffi, Y. (2005). *The Resilient Enterprise: Overcoming Vulnerability for Competitive Advantage*. MIT Press.

[9] Tinak, R. (2023). *7 Biggest Challenges for E-Commerce Logistics and Fulfillment Centers. Fullfillment Europe*. URL: https://www.fulfillmenteurope.com/biggest-challenges-ecommerce-logistics-fulfillment-centers/

[10] van Gelder, K. (2024). *E-commerce worldwide - statistics & facts*. Statista.com. URL: https://www.statista.com/topics/871/online-shopping/

[11] Wang, Y. (2016). Analysis of the Current Situation and Prospects of Rural Logistics in the Context of E-Commerce. *Science and Technology Innovation and Application*, 32. 280-282.